Short-term Effects of Mechanical Shrub Treatment and Livestock Grazing Exclusion on Vegetation in a Native Wyoming Big Sagebrush Community, East-Central Idaho

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INTRODUCTION

An estimated 75% of the seemingly vast sagebrush steppe of the American west has been lost or substantially changed as a result of conversion to agriculture or other development, fire and subsequent dominance by non-native annual grasses, and historical overgrazing by livestock (Noss et al. 1995, Hann et al. 1997, West 2000). The remaining 25% may harbor mostly native species but the herbaceous species are much less productive and diverse than thought to be the pristine condition (West 2000). Revitalization of this native but depauperate portion of the sagebrush steppe ecosystem may be more readily and quickly achieved than attempting to restore the 75% of sagebrush steppe that has been substantially altered or lost. And restoration of these depauperate native communities may provide rapid boosts to many faltering greater sage-grouse (*Centrocercus urophasianus*) populations (and other sagebrush obligate species) that have experienced widespread and substantial declines in recent decades (Paige and Ritter1999, Connelly et al. 2000, Sands et al. 2000).

Sagebrush steppe is adapted to natural disturbances such as fire and drought, and disturbance can be induced by managers to achieve desired conditions. Current management practices that can introduce controlled disturbance into sagebrush ecosystems include fire, livestock grazing, mechanical treatments, and herbicides. Yet, there is uncertainty in the outcomes of disturbances, and the consequences can be negative (Eddleman and Doescher 2000). Recovery of sagebrush after fire can take many decades (Bunting et al. 1987). Exotic annuals, e.g. cheatgrass (*Bromus tectorum*), can invade following disturbances and permanently change fire frequencies and community dynamics (Pyke 2000). Fire, livestock trampling, and crushing by vehicles can destroy biotic soil crusts depending on fire temperatures, fire frequencies, extent of trampling, etc. (Belnap 2000). Therefore, caution in introducing disturbance as management is warranted and rangeland restoration designed as experiments can inform management in an adaptive approach. Mechanical shrub crushing is an appealing alternative to prescribed fire that is intended to restore the herbaceous component of sagebrush steppe while retaining young-age sagebrush that can rapidly return to prominence in the community.

In the upper Pahsimeroi Valley of east-central Idaho, thousands of hectares of a Wyoming big sagebrush (*Artemisia tridentata wyomingensis*)/bluebunch wheatgrass (*Pseudoroegneria spicata*) community were in an apparently depauperate late seral stage as of 2003 (State III *sensu* West 2000). Sagebrush typically was not dense and fire had not been a significant factor in the Pahsimeroi Valley for at least a half century or more (W. Diage, former Bureau of Land Management Challis Field Office ecologist, personal communication), likely because of inadequate fine fuels removed by livestock grazing. Bluebunch wheatgrass had low cover ($\bar{x}$ cover = 1-2%) and low vigor with most plants growing under protective shrub canopies. Bluebunch wheatgrass, a principal forage for livestock and wildlife and important for nesting cover, is expected to contribute about 40% of the biomass to the community (Natural Resources Conservation Service 2002). Sandberg's bluegrass (*Poa secunda*) was the most prevalent grass ($\bar{x}$ cover = 14%) although generally occurring as widely separated individual plants. Sandberg's bluegrass provides little forage or cover, and dries early in the growing season so that what little forage there is lasts only for a short duration.

My presumption was that > 100 years of livestock grazing (cattle and sheep) combined with low annual precipitation and competition from sagebrush and Sandberg's bluegrass had restricted bluebunch wheatgrass to protected sites within the canopy of shrubs. Stand succession appeared stagnant (Yeo 1998). West et al. (1984) and West (2000) reported that this condition can continue for decades even with the reduction or removal of livestock grazing. This suggested that significant disturbance might be necessary to change the current condition. Disturbances may liberate resources for establishment of new species or allow expansion of suppressed species (e.g., bluebunch wheatgrass).

This project assessed the use of mechanical crushing of shrubs as an alternative to prescribed fire to stimulate restoration of cover and vigor of bluebunch wheatgrass and other native herbs. The project design addressed several questions about community responses to range restoration treatments:

- Does bluebunch wheatgrass (and other herbs) respond positively to mechanical brush crushing?
- Does mechanical brush crushing retain sufficient sagebrush seedlings to allow rapid recovery of sagebrush and create diverse age classes of sagebrush?
- How does the plant community respond to the removal of livestock grazing?

This report describes the vegetation response to mechanical crushing for the first 4 growing seasons following treatment.

METHODS

Project Area

The project area was located in the Pahsimeroi Valley of east-central Idaho within the Bureau of Land Management (BLM) Challis Field Office Upper Pahsimeroi grazing allotment. A large stand of Wyoming big sagebrush/bluebunch wheatgrass vegetation type, extending well beyond the boundaries of the allotment, occurs across a broad, flat valley (elevation range within the project area = 2010 – 2075 m). Soils are deep ($\geq$ 152 cm), gravelly loams, and estimated to receive 205 – 308 mm of annual precipitation (Natural Resources Conservation Service 2002). There can be scattered areas of hardpan at 25 – 50 cm of depth where the dominant shrub switches from Wyoming big sagebrush to low sagebrush (*A. arbuscula*). For years prior to initiation of this project, Wyoming big sagebrush, Sandberg's bluegrass, and Hood's phlox (*Phlox hoodii*) were the most abundant plant species. Non-native plants including cheatgrass, although present, were not prevalent in the project area.

Cattle were grazed within the allotment in a 5-pasture deferred rotation grazing system. The project occurred within 1 pasture of the allotment – the West Flat pasture. Stocking rates and the timing of cattle grazing varied over the years of the project with the lowest rates during 2005 (**Table 1**). During 2003 and 2005, cattle entered the West Flat pasture in early July about the same time that sampling was conducted so that grazing had little impact on measures of cover in those years. In 2007, cattle entered the pasture in mid June resulting in about 2 weeks of grazing prior to vegetation sampling.

Table 1. Cattle numbers, period of use, and stocking rates (AUMs – animal unit months) in the West Flat pasture of the Upper Pahsimeroi Allotment, 2003 – 2007.

Year	Cattle Numbers	Period of Use	AUMs
2003	350	7/1 – 8/1	368
	550	8/1 – 8/14	253
2004	350	7/1 – 8/1	368
	550	8/2 – 8/14	235
2005	250	7/1 – 8/1	263
	550	8/2 – 8/14	235
2006	349	7/6 – 8/21	539
2007	531	6/13 – 7/2	349
	381	7/3 – 7/7	63
	356	7/8 – 7/12	59
	196	7/13 – 8/2	135
	531	8/3 – 8/3	17

Weather

An automated weather station was placed in the center of the project area in early April 2003. The station recorded ambient temperature (C), rainfall (mm), solar radiation (watts/m^2), wind speed (kph), wind direction (degrees), relative humidity (%), soil temperature (C) at 25 cm rooting depth, and soil moisture (centibars) at two rooting depths: 25 cm and 75 cm. Additionally, evapotranspiration was calculated. Measurements were taken every minute and integrated on an hourly basis with data saved to a data logger.

Weather data were recorded from April 2003 through July 2007. Unfortunately, 14 months had gaps in the monthly record. These gaps resulted from inability to download data during winter months and problems with maintaining power to the data logger. The nearest National Weather Service station is located in the Pahsimeroi Valley at May, Idaho, about 35 km northeast of the project area. The elevation at the May station is 1560 m while elevation at the project weather station is 2042 m. Precipitation and temperature data collected at May, Idaho were compared with data from the project weather station. Monthly precipitation at May was significantly correlated with precipitation at the project weather station ($r = 0.84$, $p < 0.0001$, n = 37 months). Likewise, average monthly temperatures were highly correlated between the two weather stations ($r = 0.99$, $p < 0.0001$, n = 37 months). Therefore, I used the May weather record to depict weather patterns for the project area.

Treatments

I conducted an *a priori* power analysis to determine the number of treatment replications needed to achieve a power = 0.80 at $\alpha = 0.05$ with paired comparisons. Restoration of a vigorous understory of bluebunch wheatgrass was the principal objective of the project so I used data on cover of bluebunch wheatgrass collected during June 2002 as part of a sagebrush avian research project. I compared average bluebunch wheatgrass cover collected from within the restoration project area (cover = 1.8% ± 2.2%) to the average value of bluebunch wheatgrass cover from 13 other stands of Wyoming big sagebrush/bluebunch wheatgrass vegetation within the Challis

Field Office area (cover = 13.4% ± 5.3%). I calculated the standard deviation of the differences between treatments (based on the sample variances and an assumption of high correlation of response [$r = 0.80$]) as 4.61. This produced a sample size estimation of 4 replications/treatment. I varied the standard deviation of the differences up to 6% to allow for a greater range of variances, which resulted in 5 treatment replications as sufficient.

The experimental units were located within the project area using a systematic random sampling design with two restrictions: all sites were > 0.4 km from water troughs to avoid areas of excessive livestock use, and plots didn't straddle established roads including two-tracks. This approach provided random placement of each unit with good dispersion of units throughout the project area.

Three treatments were employed on 15 experimental units: (1) mechanical brush crushing augmented by seeding with native grasses using a rangeland drill ("seeded"), (2) mechanical brush crushing with natural seeding by resident plants ("no seed"), and (3) no treatment ("control"). In late fall 2003, ten of these sites were treated with mechanical brush crushing (using two passes on each site with a Lawson aerator **– Cover Figure**) in 2 parallel 30-m wide strips (with a 30 m strip in between **–** see **Figure 1**). Each experimental site was 4 ha with half (2 ha) fenced to exclude livestock (yet permit access by wildlife, "fenced" plot), and the other half left open to livestock grazing ("open" plot). Within treated sites, there were areas where the treatment occurred and adjacent areas where no treatment occurred. I included these adjacent untreated areas as separate treatments to evaluate whether areas adjacent to treated areas might also show increased herbaceous cover as a result of increased seed sources in the treated areas (**Figure 2**).

Experimental units were sampled in early July 2003 prior to treatment and fencing. Ten of the 15 sites were treated with a Lawson aerator in fall 2003. Bluebunch wheatgrass and Indian ricegrass (*Oryzopsis hymenoides*) were seeded on 5 of the treated units using a rangeland drill immediately after mechanical crushing with the Lawson aerator. The seed mix was 90% bluebunch wheatgrass (Goldar variety) and 10% Indian ricegrass (NezPar variety) at a rate of about 11-13 kg/ha (10 – 12 lb/ac). Fencing of the grazing exclosures was completed in spring of 2004. Subsequent sampling occurred in early July of 2005 and 2007.

Vegetation Cover

Vegetation cover and ground cover were estimated within each 2-ha experimental unit on 10 randomly-located, permanent transects (15 interception points/transect). Transects were perpendicular to the long central axis of each unit with 6 transects (n = 90 interception points) positioned within the 2 30-m wide treatment strips (**Figure 1**). Each point was considered independent with ~ 2-m distance (3 strides) between points so the transects served to provide good dispersion of points throughout the unit while allowing greater sampling efficiency. The positioning and length of the transects provided a ≥ 15 m buffer where no sampling occurred between the unit boundary fences and sample points to avoid the potential impacts from cattle trailing along fence lines.

Point interceptions along each transect were used to estimate canopy cover of vegetation, and cover of bare ground (defined as land surface not covered by vegetation, rock, and litter; Society of Range Management 1999), and litter. Visible biological crusts (cryptogams – lichens and mosses including vagrant lichens) and standing dead vegetation were included in cover estimations (Pellant et al. 2000). Litter was defined as persistent and non-persistent organic matter that is in contact with the soil surface (Pellant et al. 2000). Standing dead vegetation was defined as aboveground dead plant material produced before the current growing season not in contact with the soil surface (Pellant et al. 2000). Canopy cover was defined as "the percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants" (Society of Range Management 1999). Small openings within the canopy (≤ 5 cm diameter) were included as canopy cover (Pellant et al. 2000).

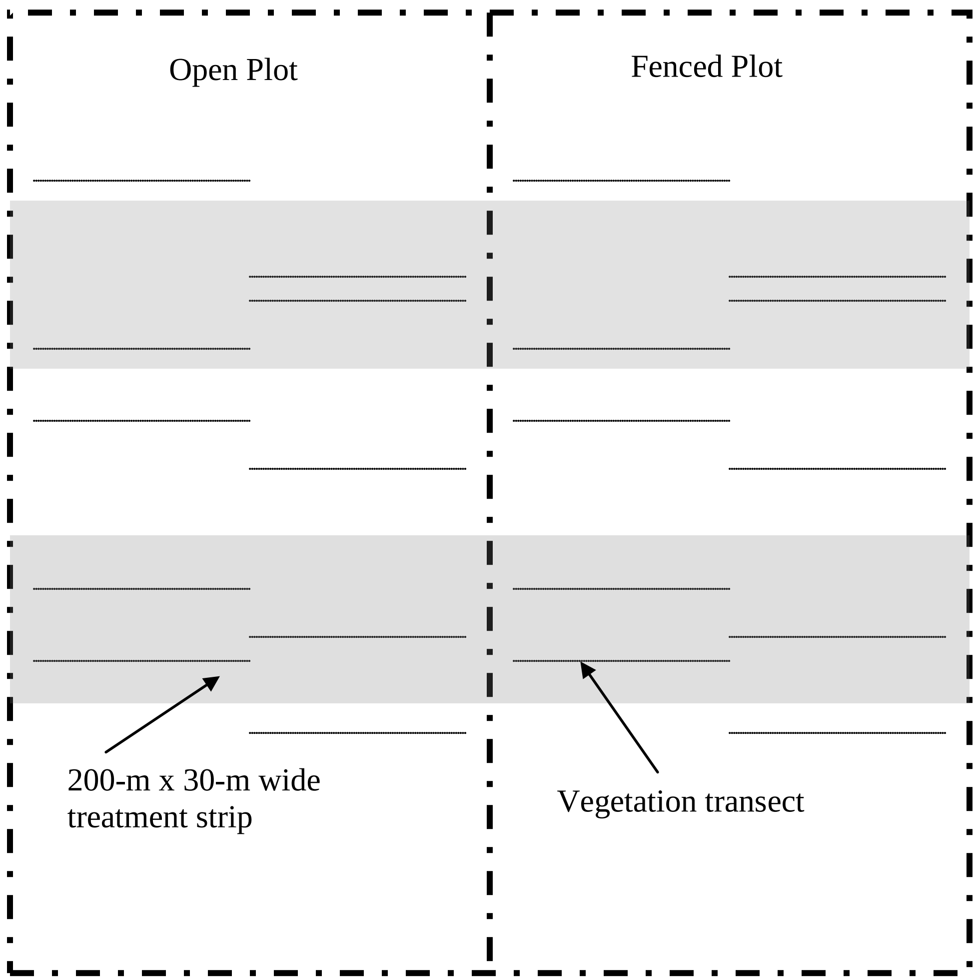


Figure 1. Transect distribution within both the fenced and open sides of the 4-ha experimental unit. Shaded strips are areas treated with the Lawson aerator in fall 2003. One half of the unit was fenced to exclude livestock, the other half left open to livestock grazing (although the open side was fenced with temporary electric fencing to exclude livestock for 1 year after treatment to allow seeding establishment).

Experimental Unit	Grazing	Mechanical Crushing
Control	**Fenced**	**Untreated**
	Open	
No Seed	**Fenced**	**Treated**
		Untreated
	Open	**Treated**
		Untreated
Seeded	**Fenced**	**Treated**
		Untreated
	Open	**Treated**
		Untreated

Figure 2. Experimental treatments with each treatment combination replicated at 5 sites.

Data Analyses

The Pearson correlation index was used to compare May weather station data to the project weather station records. Within each sample year, cover estimates were obtained from 4,500 points summed across all experimental units. Estimates for controls equaled 150 points/unit, estimates for treated sites equaled 90 points/unit, and estimates for untreated units equaled 60 points/unit. Comparisons among treatments are presented graphically. Fenced and open sites are treated separately because of the impacts of livestock grazing on annual cover values in 2007. I tested for differences among treatments across years using repeated measures analysis of variance (ANOVA) or its nonparametric equivalent, the Friedman test on ranks. A 1-

way ANOVA tested for differences between treatments in a particular year. Estimates were deemed significantly different at α = 0.05

RESULTS

Weather

Climate diagrams (Walter et al. 1975) are useful for depicting average climatic conditions for a site and the pattern of mesic and xeric periods throughout the course of a year. Annual climate diagrams for the May weather station from 2001 through summer 2007 describe changes in the availability of water for plant growth (**Figure 3**). The years 2004 and 2005 had robust peaks of rainfall during the spring, and 2005 and 2006 had comparatively short arid periods indicating that plant growth conditions were more favorable than in the previous period 2001 – 2003. A long and severe arid period also was evident in 2007 with very limited rainfall prior to summer.

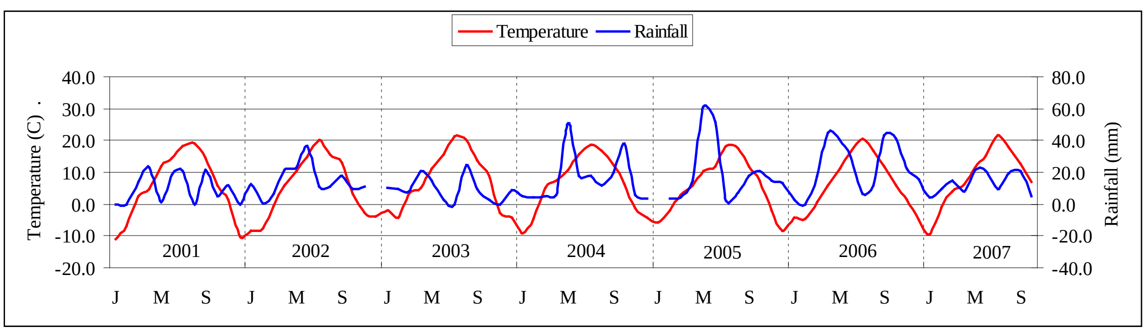


Figure 3. Continuous climate diagram of data from May, Idaho, using the methods of Walter et al. (1975). Within each year, those intervals when the temperature exceeds rainfall indicate arid periods. The horizontal extent of the arid period identifies the time when evaporative loss exceeds water recharge, and the vertical extent of the arid period signifies the severity of the relative drought period. Months depicted on the x-axis are: J = January, M = May, S = September.

Vegetation and Ground Cover Responses

Wyoming Big Sagebrush

Prior to mechanical treatment, canopy cover of live Wyoming big sagebrush averaged 19% across all 15 sites although there was large variation among sites (range = 7 – 32% cover). Within fenced areas that were treated, average canopy cover was reduced from 20-22% in 2003 to 6-8% in 2005, but then increased to 10-13% in 2007 ($P < 0.001$; **Figure 4a**). On treated sites open to livestock grazing, changes in Wyoming big sagebrush canopy cover values showed similar patterns (**Figure 4b**). On both fenced and open areas not treated, including control sites, average canopy cover remained similar among years although there was some variation among sites ($P = 0.83$; range = 19 – 21% cover; **Figures 4 a & b**). For example, average big sagebrush cover on open seeded, untreated sites increased from 13% in 2003 to 21% in 2007, and average cover increased from 16% and 17% in 2003 and 2005, respectively, to 22% in 2007 on open control sites ($P = 0.006$).

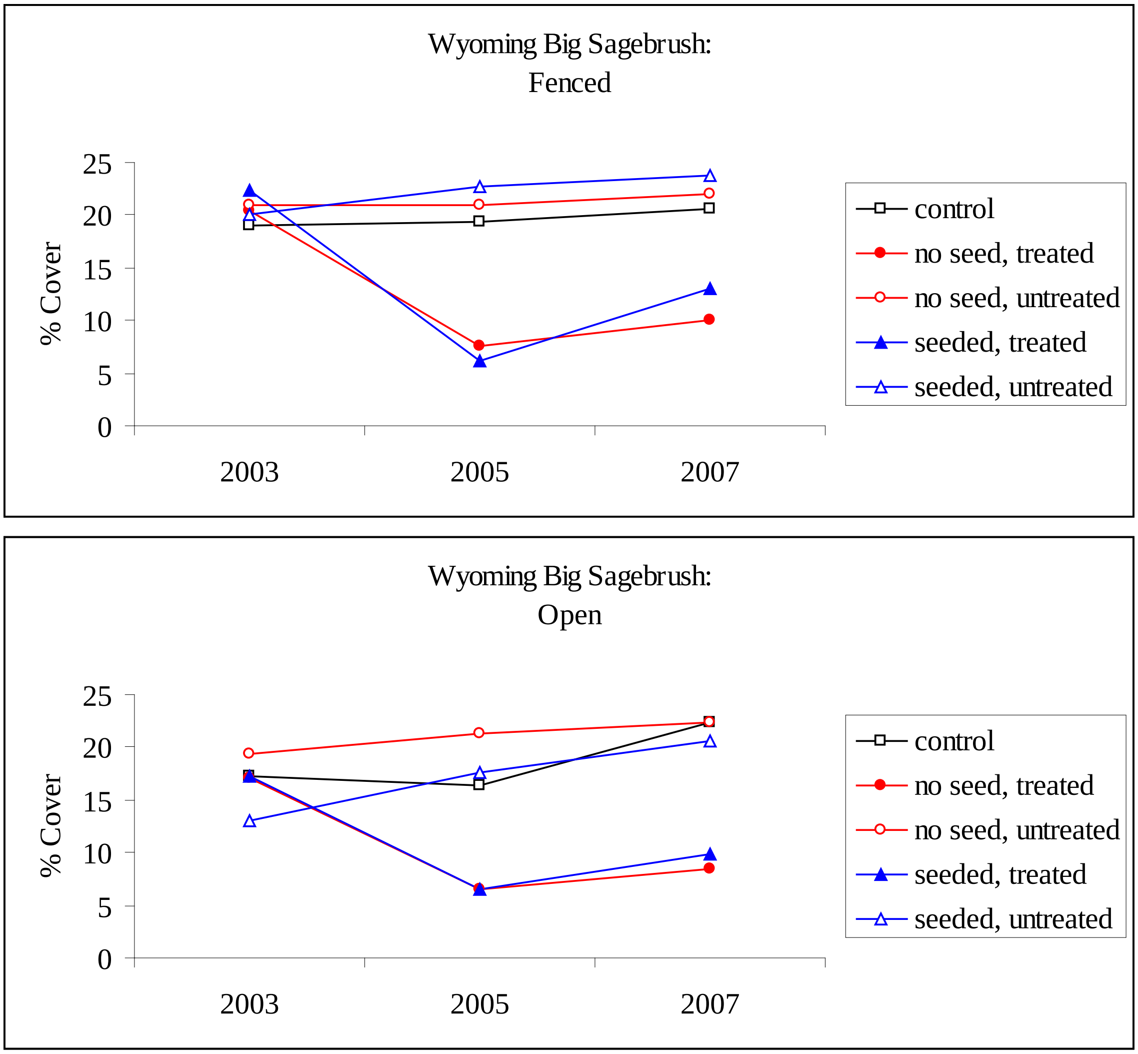


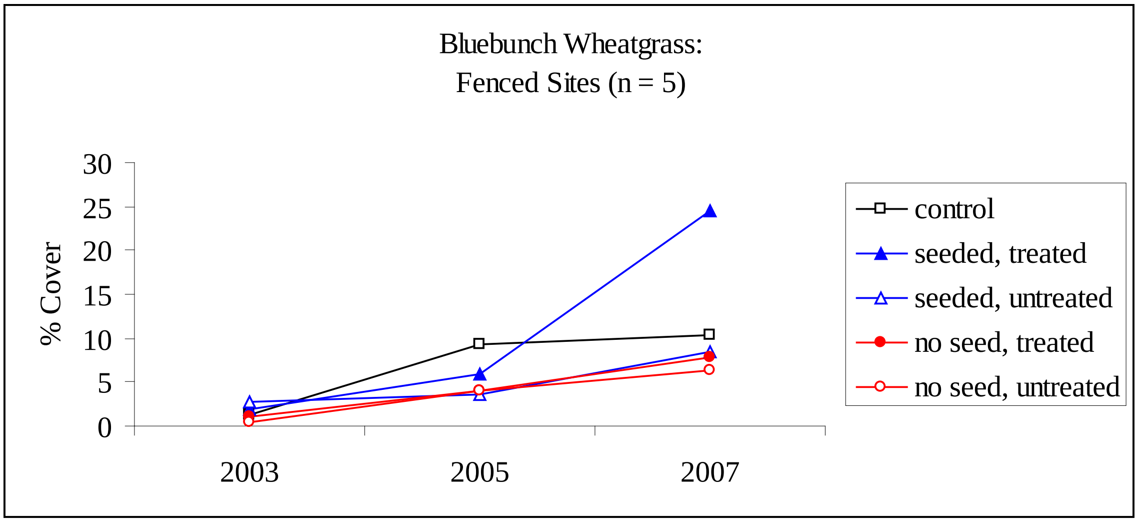
Figure 4a & b. Changes in average cover of Wyoming big sagebrush comparing among 5 treatment types (n = 5 replicates/treatment type) between 2003 and 2007 on sites fenced from livestock grazing (a) and open to livestock grazing (b).

Other shrubs were encountered on transects but these species occurred sporadically across the area at low cover values. Shrubs included saltsage (*Atriplex nuttallii*), rabbitbrushes (*Chrysothamnus* spp.), low sagebrush, winterfat (*Eurotia lanata*), and prickly phlox (*Leptodactylon pungens*).

Bluebunch Wheatgrass

In July 2003, prior to the construction of the fenced enclosures and treatment with the pasture aerator, bluebunch wheatgrass cover within the experimental units averaged 1.3% (range = 0 – 6%) with about 1/3 of the sites showing 0% cover. The most pronounced response to the experimental treatments by bluebunch wheatgrass was on fenced seeded and treated sites (bluebunch wheatgrass comprised 90% of the seed mix), increasing from 2% cover in 2003 (range = 0-4%) to an average of 24% cover in 2007 (range = 13-34%) ($P = 0.002$; **Figure 5a**). Average cover values on other fenced treatments indicated modest but not statistically significant increases in cover between 2003 and 2007 (1-3% in 2003 to 6-8% in 2007). Average cover of bluebunch wheatgrass within fenced control units also apparently increased from 1% in 2003 (range = 0-3%) to 10% in 2007 (range = 0-21%) ($P = 0.08$), although again not statistically significant.

Sites open to livestock showed a similar pattern of increasing cover of bluebunch wheatgrass from 2003 to 2007 although the average cover values were lower than in fenced sites (**Figure 5b**). Seeded, treated sites had the highest average bluebunch wheatgrass cover in 2007 ($\bar{x} = 10\%$), although with large variability among the 5 sites (range = 1-23%; $P = 0.07$). Control sites, both fenced and open, had the highest average cover values in 2005 ($\bar{x} = 8$-9%).



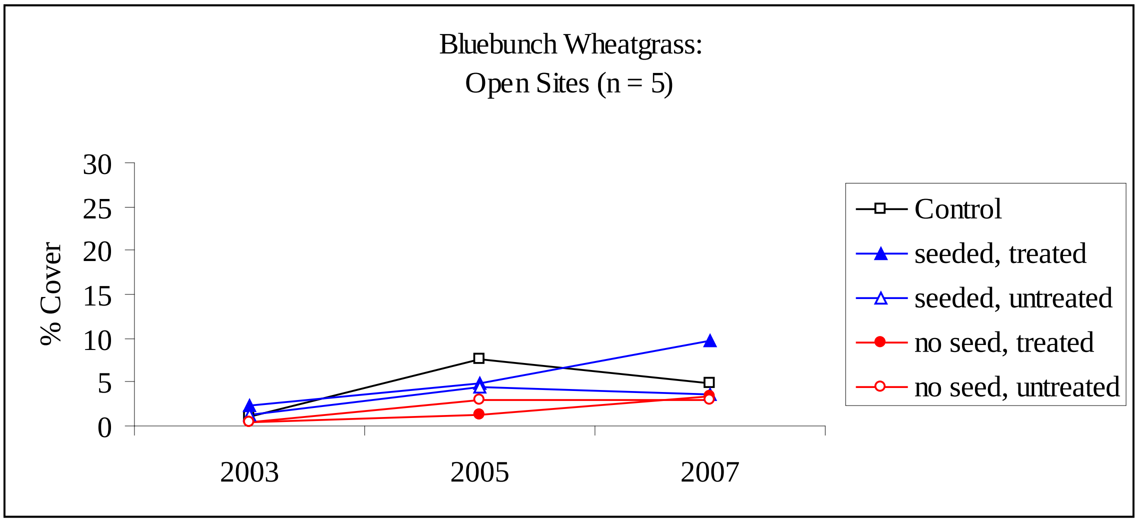


Figure 5a & b. Changes in average cover of bluebunch wheatgrass comparing among 5 treatment types (n = 5 replicates/treatment type) between 2003 and 2007 on sites fenced from livestock grazing (a) and open to livestock grazing (b).

Indian Ricegrass

Indian ricegrass comprised 10% of the seed mix. However, Indian ricegrass was rarely encountered on any sites in any of the 3 years. On just seeded, treated sites this also was true – Indian ricegrass was encountered only at 1 point in 2007.

Sandberg's Bluegrass

Bluegrass cover in fenced sites was similar between 2003 and 2005 for all treatments, and increased for all treatments in 2007 (**Figure 6a**). Bluegrass in open sites had similar patterns to fenced sites and similar values, particularly in 2007 (**Figure 6b**). Average cover of Sandberg's bluegrass in 2003 for both fenced and open sites was 14% ± 2%. Cover increased to 23% ± 2% in 2007. There were no apparent differences among treatment types or impacts from crushing on bluegrass.

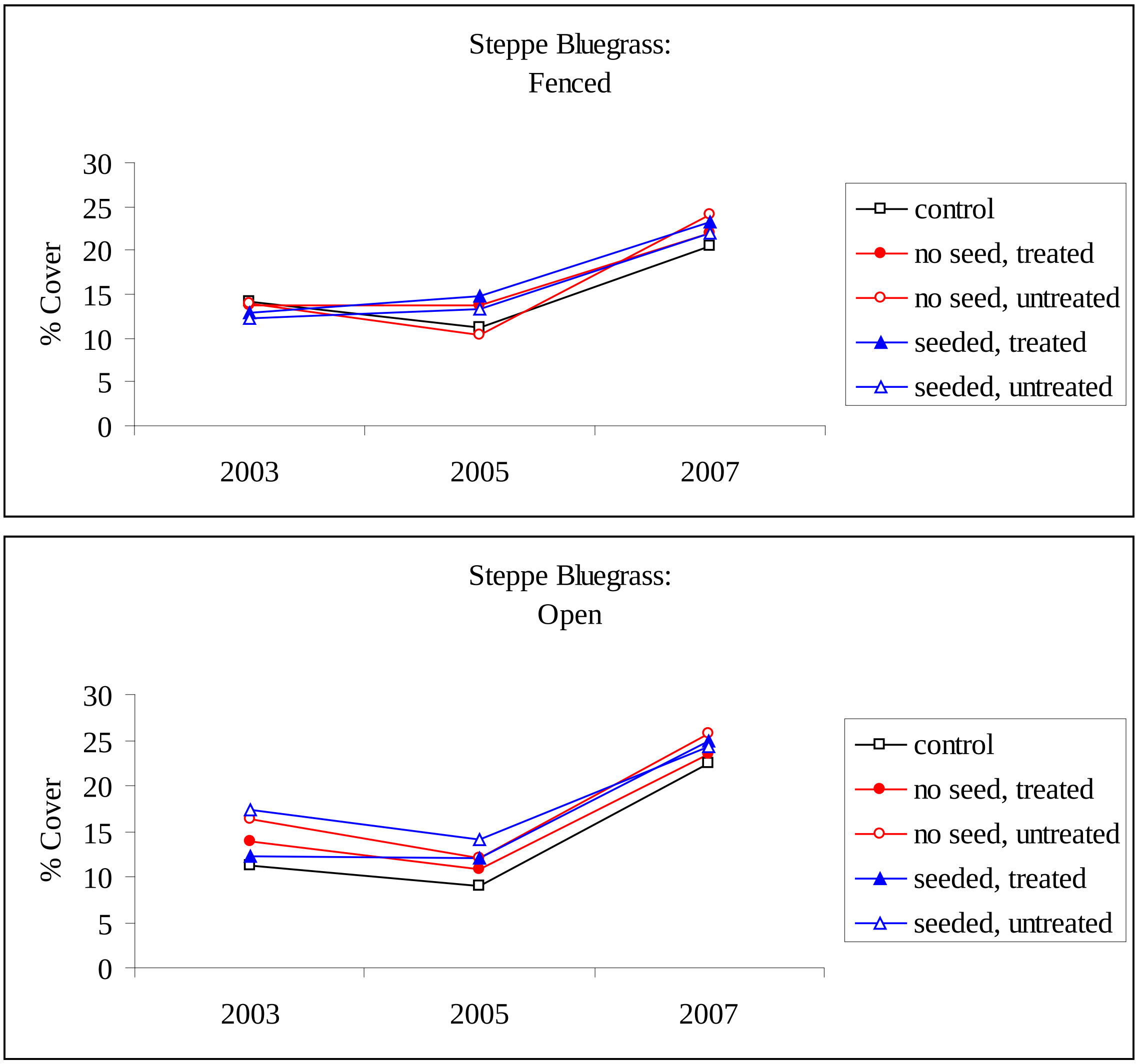


Figure 6a & b. Changes in average cover of Sandberg's bluegrass comparing among 5 treatment types (n = 5 replicates/treatment type) between 2003 and 2007 on sites fenced from livestock grazing (a) and open to livestock grazing (b).

Bottlebrush Squirreltail

Bottlebrush squirreltail (*Sitanion hystrix*) on fenced treated sites, both seeded and no seed, responded differently than untreated sites and controls. On treated sites, squirreltail increased 4-fold in cover from pre-treatment in 2003 to 2005, and remained at that cover level in 2007 (**Figure 7a**). This was not true of untreated sites or controls. Controls and untreated sites increased about 2-fold between 2003 and 2005 and remained at these levels, about half the cover of treated sites, in 2007.

On open sites, the same pattern and similar cover values of bottlebrush squirreltail occurred as on fenced sites although the average cover values in 2005 were about 5% higher than on fenced sites (**Figure 7b**). Cover values on treated areas declined slightly in 2007.

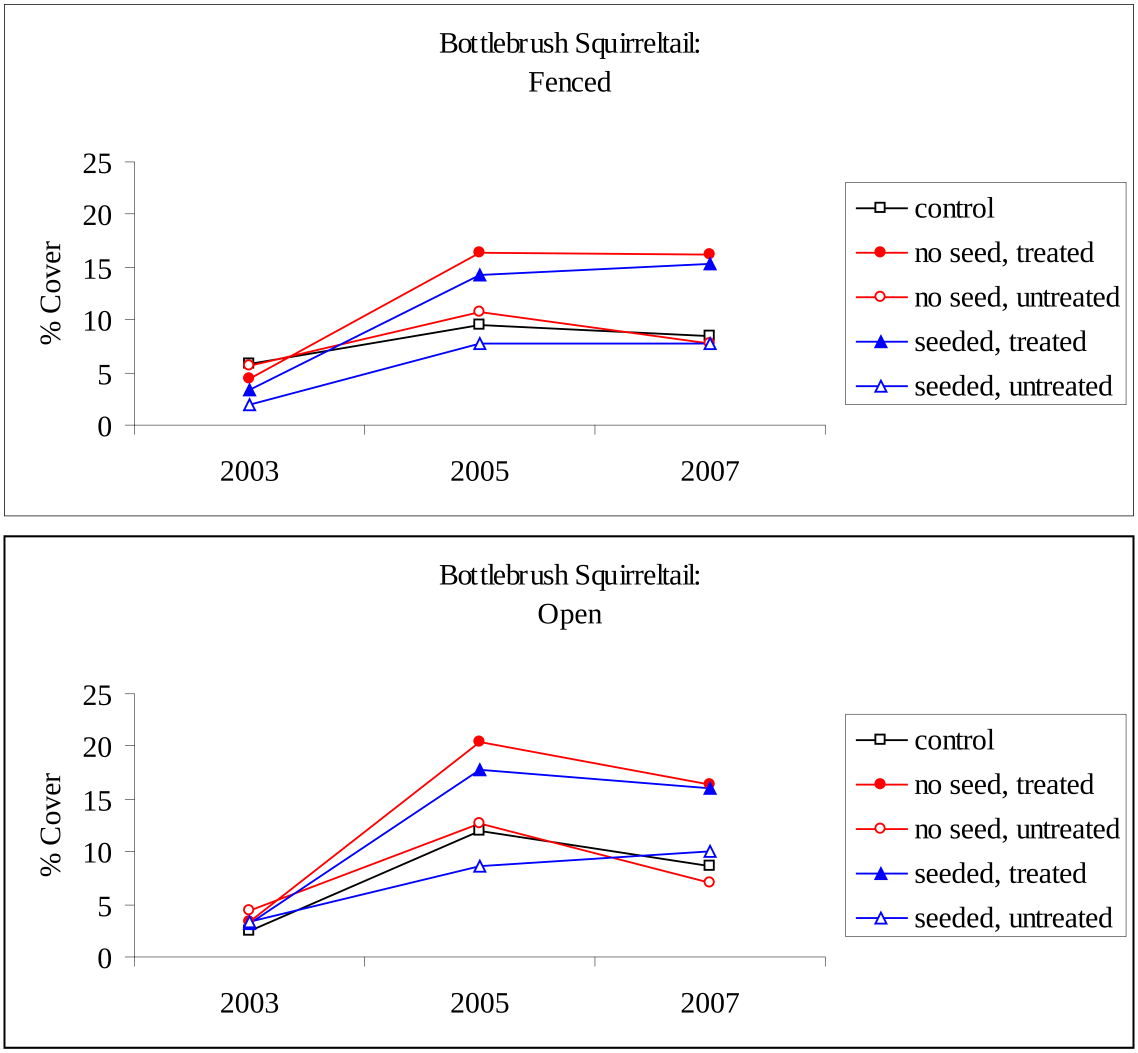
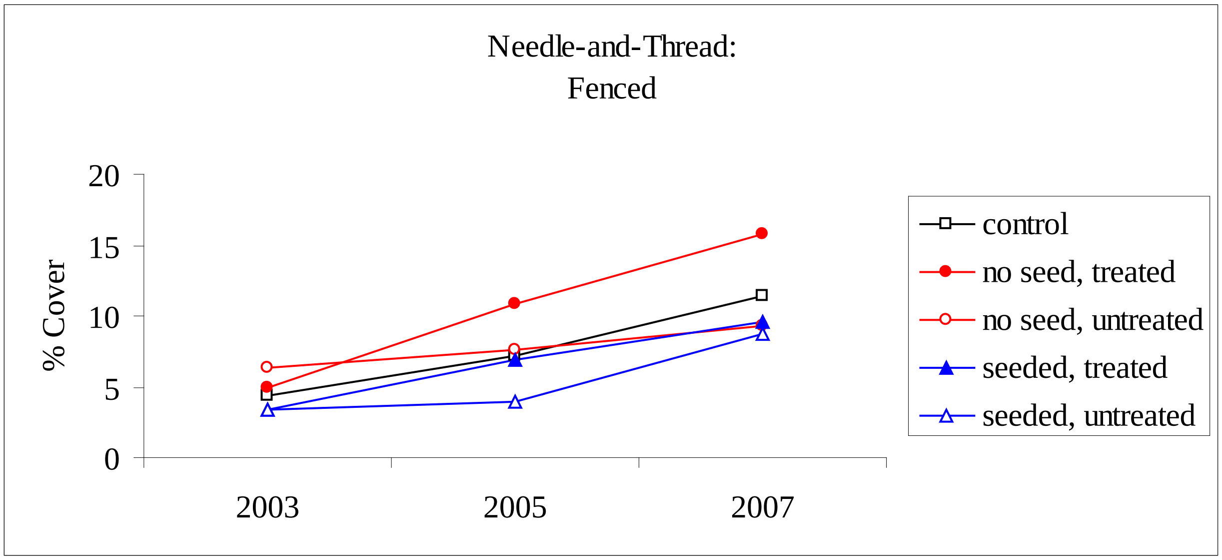


Figure 7a & b. Changes in average cover of bottlebrush squirreltail comparing among 5 treatment types (n = 5 replicates/treatment type) between 2003 and 2007 on sites fenced from livestock grazing (a) and open to livestock grazing (b).

Needle-and-Thread

Within fenced areas, needle-and-thread (*Stipa comata*) averaged 3-6% cover in 2003 (**Figure 8a**). Cover generally increased between 2003 and 2007 on all fenced sites. Increases in cover were most pronounced on no seed, treated sites which increased 3-fold between 2003 and 2007 (from 5% in 2003 to 16% average cover in 2007).

Open sites showed a slightly different pattern of cover responses (**Figure 8b**): treated, no seed sites had the highest average cover values in 2005 (similar to fenced sites) but declined to values similar to other open sites in 2007, although variation among units was high (range = 0-23%). Treated and untreated seeded sites had similar values in all 3 sample years, gradually increasing by 2007.



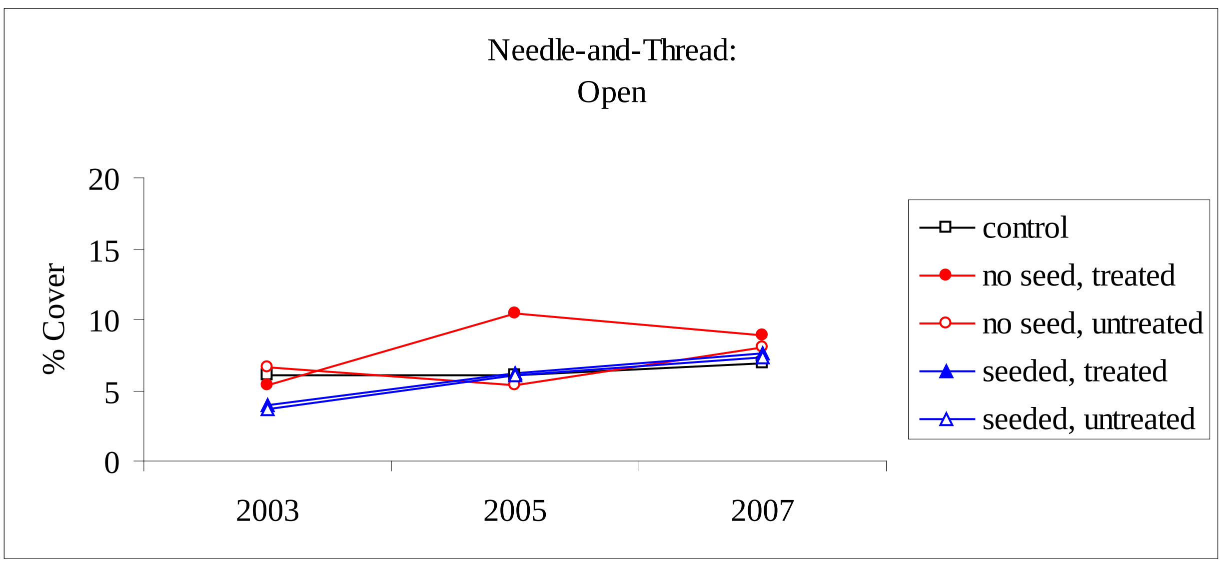


Figure 8a & b. Changes in average cover of needle-and-thread comparing among 5 treatment types (n = 5 replicates/treatment type) between 2003 and 2007 on sites fenced from livestock grazing (a) and open to livestock grazing (b).

Other grass species were encountered at low cover during the course of the project. Western wheatgrass (*Agropyron smithii*) was recorded sporadically in 2003, with higher cover values at a few sites in 2005 (10 – 19% cover), and rarely in 2007. Western wheatgrass was most prevalent on seeded, treated areas suggesting the possibility that the seed mix may have been adulterated. Swallen's ricegrass (*Oryzopsis swallenii*) also was encountered rarely on a few sites.

Cheatgrass

Cheatgrass was sparsely scattered within the pasture and was only measured as 1 "hit" on one open seeded site within a treated area. Cheatgrass did not invade disturbed areas with the highest cover of bare soil.

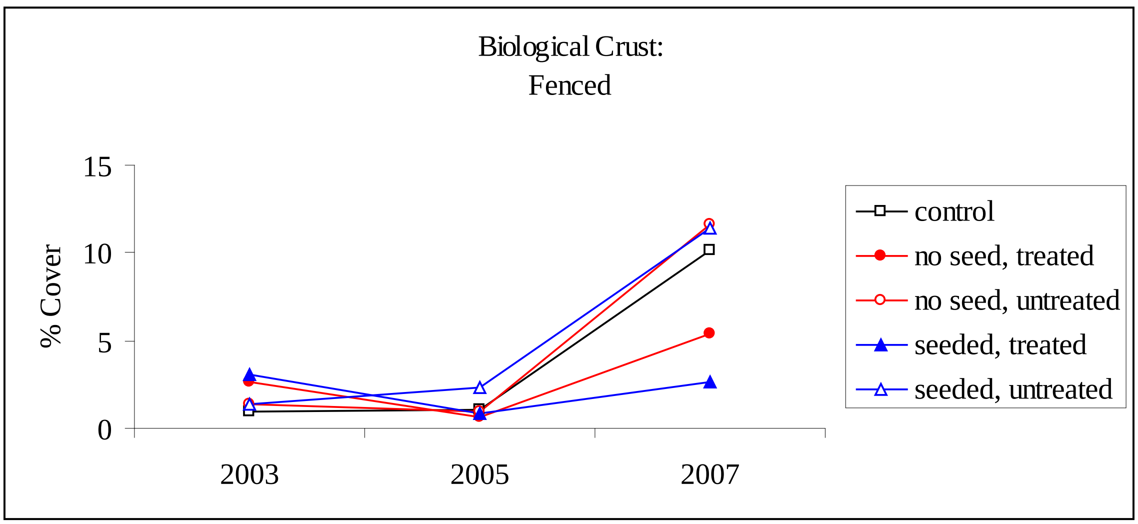
Forbs

About 20 species of forbs were encountered on the experimental units during 2003-07. Hood's phlox (*Phlox hoodii*) and stemless goldenweed (*Haplopappus acaulis*) were the most commonly observed forbs on most sites although lava aster (*Aster scopulorum*) was occasionally locally prevalent at one or more sites. Overall, though, forbs provided little cover (1-7% in 2003). Sampling occurred in early July which means that early flowering forbs (May – June) would have desiccated by the time sampling occurred. Also, 2007 was exceedingly hot and dry likely causing even less representation of forbs.

There was no indication that any treatments reduced or increased forb cover within the 4 year post-treatment time span. A couple sites showed declines in stemless goldenweed between 2005 and 2007 consistent with much drier conditions in 2007 than in 2005.

Ground Cover

Mechanical crushing repressed biological soil crusts such that untreated areas and controls showed increases in cover between 2003 and 2007 that were 2-fold greater than treated areas (**Figure 9 a & b**). Sites open to cattle grazing showed increased cover of crusts although cover values in 2007 were half those on fenced sites. Bare soil cover did not increase in 2005 after the treatments, and declined substantially within fenced sites by 2007 (**Figure 10a**). Bare soil cover remained unchanged on open control sites and on open untreated, seeded sites but declined on other treatments (**Figure 10b**). Litter cover remained similar among treatments on fenced and open sites except for open, treated areas (**Figure 11 a & b**). Litter in 2007 on open, treated sites averaged 10% greater cover than on other treatments. Cover of surface rock declined substantially on all treatments by 2007.



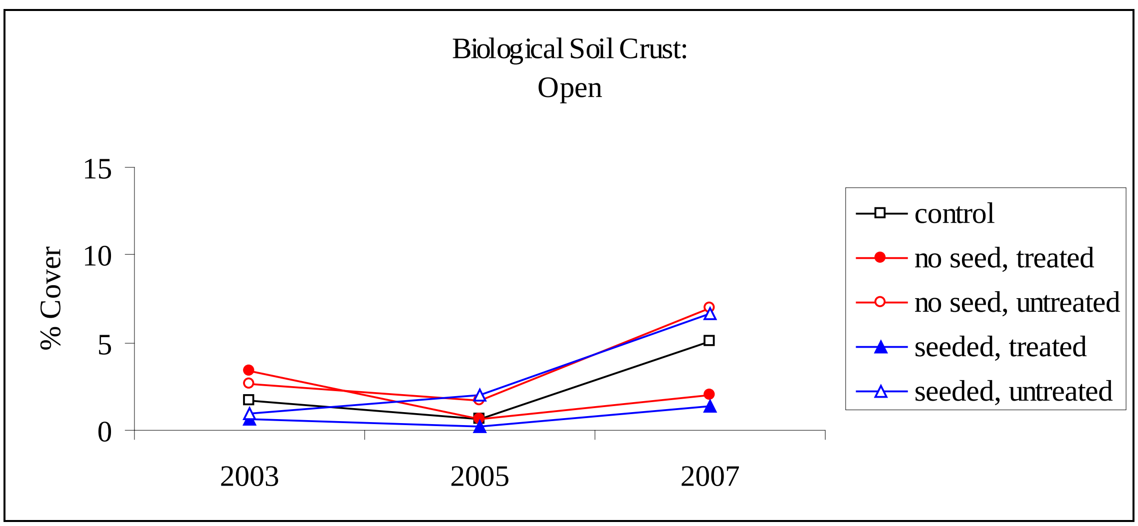


Figure 9a & b. Changes in average cover of biological soil crust comparing among 5 treatment types (n = 5 replicates/treatment type) between 2003 and 2007 on sites fenced from livestock grazing (a) and open to livestock grazing (b).

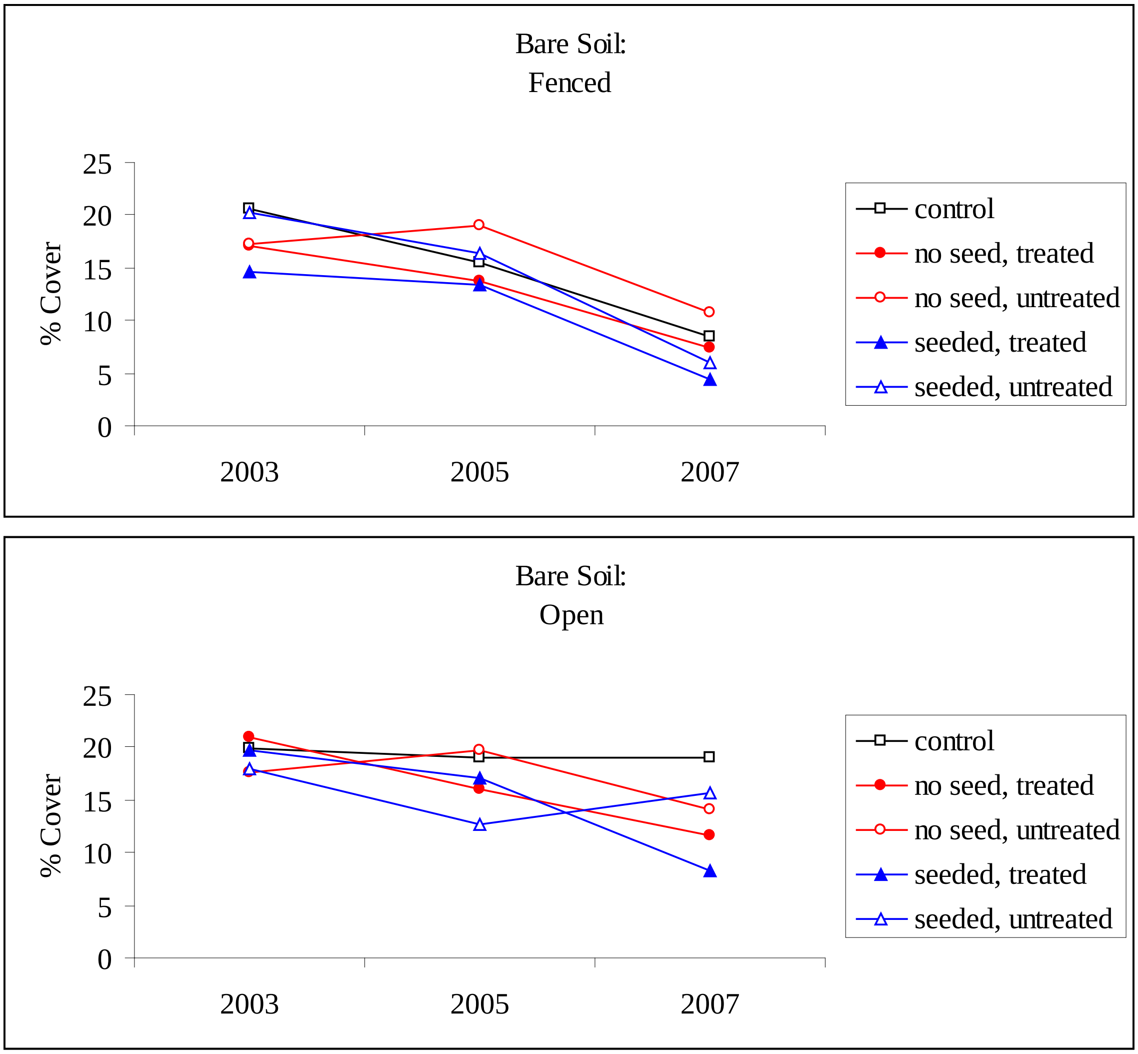


Figure 10a & b. Changes in average cover of bare soil comparing among 5 treatment types (n = 5 replicates/treatment type) between 2003 and 2007 on sites fenced from livestock grazing (a) and open to livestock grazing (b).

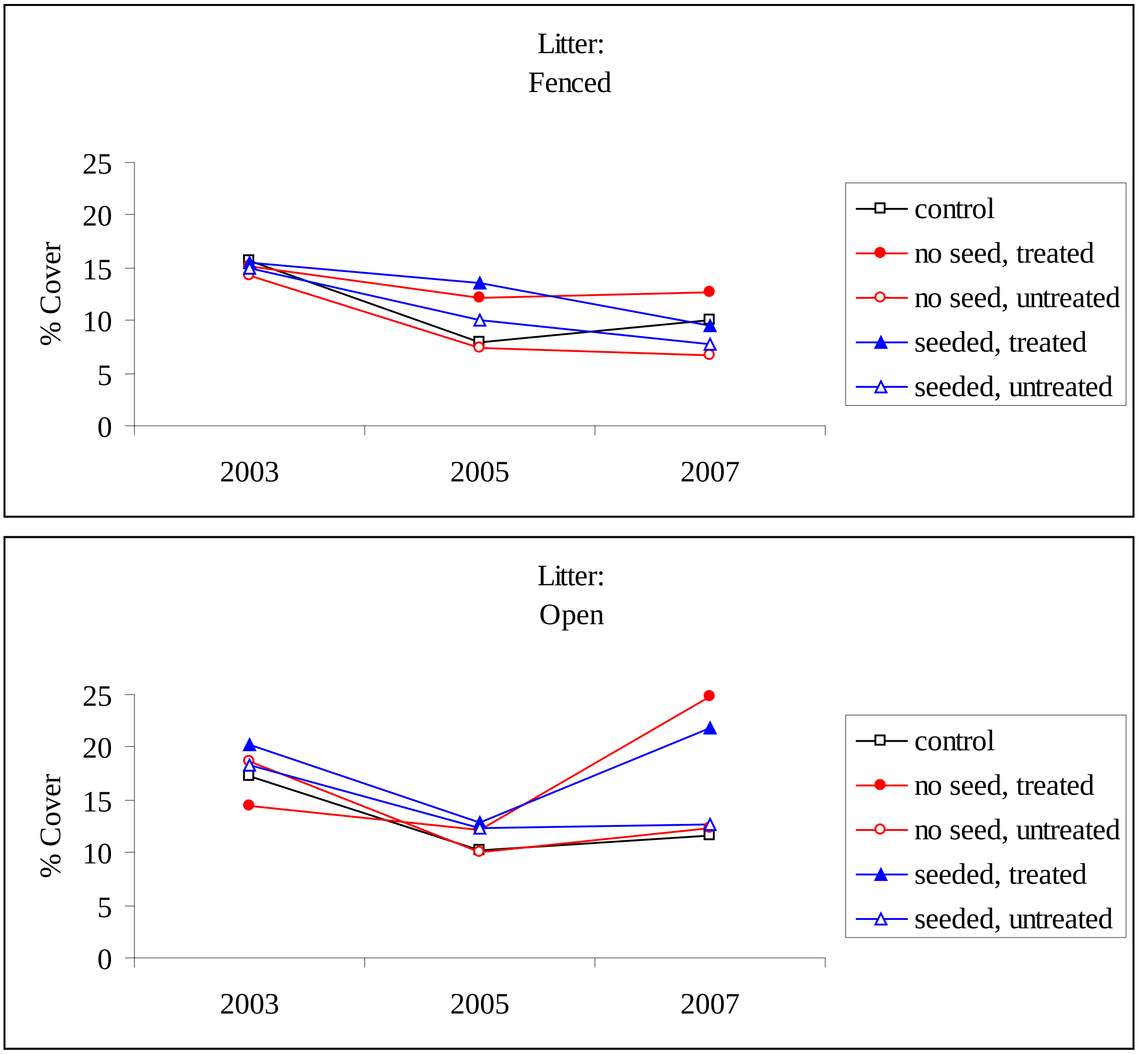


Figure 11a & b. Changes in average cover of litter comparing among 5 treatment types (n = 5 replicates/treatment type) between 2003 and 2007 on sites fenced from livestock grazing (a) and open to livestock grazing (b).

DISCUSSION

The primary objective of this restoration project was to determine if shrub crushing was a useful approach for revitalizing and restoring bluebunch wheatgrass and forbs to the understory of a depauperate stand of Wyoming big sagebrush. Two concerns were whether crushing would retain Wyoming big sagebrush in sufficient abundance to recover much more rapidly than from prescribed burning, and whether soil disturbance from the crushing would result in invasion of noxious weeds, principally cheatgrass. On the second concern, cheatgrass remained rare across the project area despite the extensive soil disturbance resulting from the crushing, and did not invade treated, no seed sites (the areas most susceptible to invasion). Cheatgrass was uncommon prior to the project and, although widespread in the area, rarely exists in dense stands. In areas where cheatgrass does overwhelm communities after disturbance, such as the Snake River Plain, invasion of sites after crushing should still be an important management concern.

Wyoming big sagebrush response to crushing was as anticipated. Cover was reduced about 3-fold by crushing yet within 4 growing seasons post-treatment sagebrush cover was increasing. Favorable weather in 2004 – 2006 likely contributed to the positive response. Anderson and Inouye (2001) documented a 3-year lag period between favorable precipitation and increased growth for Wyoming big sagebrush on the Idaho National Laboratory. If cover trends continue, I expect that within a few years (say within 7-10 years post-treatment) Wyoming big sagebrush on treated areas may be within the range of cover values (15-25%) recommended for greater sage-grouse habitat (Connelly et al. 2000). This clearly is much faster recovery than from prescribed burning. Bunting et al. (1987) reported that Wyoming big sagebrush can take 40 – 80 years to recover after burning. Summers (2005) reported that crushing Wyoming big sagebrush using a Lawson aerator in northern Utah reduced sagebrush canopy cover from 20% to 5%. Yet, two years post treatment, sagebrush leader lengths and seed stalk lengths were greater on treated sites than untreated sites indicating increased sagebrush vigor in response to crushing (Summers 2005).

In sagebrush steppe, even though arid, there can be substantial variation among species in response to environmental variation. Because water availability is highly variable in time, the response of vegetation to disturbance can take a long time in an arid environment (Anderson and

Inouye 2001). There can be 2-5 year lags between changes in precipitation and vegetation responses in Wyoming big sagebrush communities (Anderson and Inouye 2001). Cover of grasses commonly doesn't track precipitation (Anderson and Inouye 2001, Passey et al. 1982, West et al. 1979). Vegetation response to protection from grazing can also take decades (Valone et al. 2001, Yeo 2005).

I hypothesized that cover of bluebunch wheatgrass on treated areas, both on seeded and no-seed treatments, would increase as a result of reduced competition from sagebrush. Bluebunch wheatgrass cover on seeded, treated sites substantially increased in cover after an initial lag. Bluebunch wheatgrass seed germinates fairly uniformly and mature stands can develop in 2-3 years following seeding (Monsen et al. 2004). On no seed, treated sites and untreated sites (including controls) cover increases were slight and more likely a response to improved growing conditions from weather. Bluebunch wheatgrass can be restored with protection from disturbance (livestock grazing) if residual plants remain (Anderson and Inouye 2001). Bluebunch wheatgrass was sparse across the project area and so seed from existing plants also would be sparse. On the INL, recovery in the abundance of grasses was not correlated with rainfall; rather cover of grasses reflected the changing availability of seed as depleted populations increased in size resulting in exponential increases in grass cover (Anderson and Holte 1981). As populations of bluebunch wheatgrass increase on the project area, I also expect that on sites protected from livestock grazing bluebunch wheatgrass will increase in cover. That did happen to a limited extent –within fenced sites cover increased from about 0-3% cover in 2003 to about 8-10% cover in 2007. Clearly there was a lag period of growth response on all treatments after improved growing conditions in 2004-2006, even on the seeded sites, with little response evident until 2007. Low availability of plants for seeding apparently reduced new seedlings although all treatments suggest a trend of increasing bluebunch wheatgrass cover between 2003 and 2007. There was large variation in cover among sites. This suggests that as bluebunch wheatgrass increases across the project area, the rate of cover increase may be exponential as the availability of seed increases yet the distribution of newly formed stands may be patchy. Areas open to livestock grazing may not recover as rapidly or to the same levels but continuation of monitoring on the experimental units would provide the opportunity for examining specifically the impact of grazing management on restoration goals.

Indian ricegrass comprised 10% of the seed mix yet there was no evidence of any response to seeding, treatments, or exclusion of livestock grazing. Indian ricegrass has a complex dormancy which slows establishment of seeded stands and can produce erratic stand development (Monsen et al. 2004). Indian ricegrass doesn't do well with competition. However, the apparent complete absence of development from seed suggests that seeded areas did not germinate, nor did reduction of sagebrush improve the existing very sparse stands of Indian ricegrass within the time studied. One possible explanation for the apparent lack of germination is that seed may have not been covered to the appropriate soil depth during the drilling operation. Indian ricegrass should be drilled to a depth of two to four inches in coarse sandy soils or one to three inches in silt loam or sandy loam soils (Lambert 2005). Also, the scarcity of seed in the seed mix may have contributed to the lack of establishment initially.

The presence or absence of livestock grazing had no discernible impact on Sandberg's bluegrass. Nor did the treatments have an impact. Sandberg's bluegrass is highly resistant to grazing and trampling (Monsen et al. 2004). Bluegrass matures and sets seed in late spring or early summer. By the time cattle entered the pasture in July, bluegrass was senescent. The substantial cover increases on all treatments between 2005 and 2007 likely was due to the favorable growing conditions during 2005 and 2006.

Both bottlebrush squirreltail and needle-and-thread apparently responded positively to the reduced competition from big sagebrush as a result of the treatments along with favorable growing season precipitation. The treatments had greater cover of squirreltail in both fenced and open sites. And the improvement in cover was greater on sites open to livestock suggesting that livestock grazing may enhance growth. Squirreltail is a short-lived, early successional species that is very competitive (Jones 1998, Monsen et al. 2004). Squirreltail germinates readily, has rapid reproduction and maturity, and has excellent seed dispersal (Jones 1998). Establishment of squirreltail may facilitate the establishment of the longer-lived, slower establishing bluebunch wheatgrass (Jones 1998).

Growth of needle-and-thread took off in 2005 with favorable precipitation and continued into 2007 with increased cover. It increased most substantially on treated, no seed sites suggesting that reduced competition from big sagebrush enhanced its growth. Grazing in 2007 reduced cover from 2005 levels on open sites. Needle-and-thread is one of the first species to disappear with overgrazing and one of the first to respond and reoccupy native communities with rest from grazing (Monsen et al. 2004). But cover increased on both open and fenced sites so that it will be interesting to monitor this species in the future to see whether cover values continue to increase.

That biotic soil crusts responded with substantial increases in cover on treated sites by 2007 after slight declines in 2005 is encouraging. Treated sites, of course, had lower cover values than untreated sites but all showed increases in 2007, particularly so in fenced units. This positive response probably is due to increased rainfall and decreased arid periods during 2005 and 2006. Mechanical crushing occurred in late fall 2003 after a recent snowfall. Soils were moist and cold. Although the tractor and aerator may have caused some mortality of biotic soil crusts, the timing and soil conditions likely minimized damage (Belnap 2000). The treatments obviously repressed crusts compared to untreated areas. The 2007 cover estimates are encouraging particularly on areas protected from cattle.

Overall, live vegetation cover increased between 2003 and 2005 on both open and fenced sites, although fenced sites had higher cover values than open sites in 2007. Increased vegetation resulted in reduced cover of bare ground from around 20% in 2003 to about 10% on fenced sites. Litter cover increased on open, treated sites (both seeded and no seed) likely due to the increased cover of grasses on these sites combined with livestock grazing to produce more litter. Fenced sites showed some decline in litter cover for all treatments supporting the contention that cattle were an agent for creating more litter cover on those sites that had greater grass growth. Increased vegetation cover was inversely related to reduced cover of rock and gravel as would be expected given that rock and gravel were not recorded when there was an overstory of vegetation.

CONCLUSION

Within the short period of the project, Wyoming big sagebrush appears to be only briefly impacted by shrub crushing, and seeding of bluebunch wheatgrass resulted in substantial increases in cover within 4 growing seasons. The reduction in competition from sagebrush apparently resulted in substantial increases in squirreltail (particularly in areas open to livestock grazing) and needle-and-thread (more so in areas protected from livestock grazing). The cover of bare soils resulting from treatment quickly fell below pretreatment levels with increased vegetative cover. Even biological crusts suffered little impact and improved cover with favorable weather. Summers (2005) recommended use of the Lawson aerator for release of the understory herb layer in Wyoming big sagebrush steppe communities for smaller project areas on generally rock-free ground. Dahlgren (2005), however, considered shrub treatment in mountain big sagebrush (*A. tridentata vaseyana*) using the Lawson aerator as ineffective for improving herbaceous vegetation. Both these studies spanned only 2 years post-treatment so these conclusions may not reflect community responses for longer periods. There was not a response by forbs to treatments or protection from cattle grazing within 4 growing seasons post-treatment. That may occur over time with improved native grass cover.

In 2007, cattle grazing in the project area commenced a couple weeks earlier than in previous years confounding comparisons between fenced and open sites. I recommend that subsequent sampling should occur in late May/early June prior to cattle entering the project area so that fenced and open sites can be compared for grass and forb cover, diversity, and height. Low herb cover and low shrub cover are showing positive responses to treatments compared to controls and untreated areas in a very dry year (2007). Fenced units should be maintained so that sagebrush responses can be assessed over longer time periods, e.g. 10 -20 years. I recommend that the next samples be obtained in 2013 which would be 10 years post-treatment.

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