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Vegetation response of a Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis) community to 6 mechanical treatments in Rich County, Utah

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VEGETATION RESPONSE OF A WYOMING BIG SAGEBRUSH (*ARTEMISIA TRIDENTATA* SSP. *WYOMINGENSIS*) COMMUNITY TO SIX MECHANICAL TREATMENTS IN RICH COUNTY, UTAH

by

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ABSTRACT

VEGETATION RESPONSE OF A WYOMING BIG SAGEBRUSH (*ARTEMISIA TRIDENTATA* SSP. *WYOMINGENSIS*) COMMUNITY TO SIX MECHANICAL TREATMENTS IN RICH COUNTY, UTAH

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Master of Science

In recent years, the importance of sagebrush to shrub-steppe ecosystems and associated plant and animal species has been recognized. The historical removal of herbaceous species by excessive and uncontrolled livestock grazing on many of our sagebrush ecosystems has resulted in a stagnant state where dense, competitive stands of sagebrush prevent herbaceous species from recovering. Most early research on sagebrush control was directed toward eradication to increase herbaceous forage for livestock production, rather than sagebrush thinning to improve shrub vigor and understory production for wildlife habitat and community diversity. Mechanical treatments have the ability to retain shrub and herbaceous components, while improving diversity within degraded sagebrush communities. This study evaluated the effects of 6 mechanical treatments and revegetation of a Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) community in northern Utah that were treated in the fall of 2001 and spring of 2002 (aerator only). Disking and imprinting killed 98% of the sagebrush and significantly ($p < 0.05$) lowered cover and density of sagebrush more than any other treatment. Disking and imprinting was the only mechanical treatment to reduce cover and density of residual understory species, but also to successfully establish seeded grasses. One-way Ely chaining, 1-way and 2-way pipe harrowing, and aerating in the fall and spring reduced sagebrush cover from greater than 20% to less than 5% and reduced density by about half. Two years after mechanical treatment surviving sagebrush had greater leader and seed stalk growth than untreated sagebrush. Choice of a mechanical treatment to increase and diversify the perennial herbaceous component and retain the shrub component of sagebrush communities depends on the amount of residual herbaceous species, as well as economics. Chaining is potentially most economical for diversifying communities with a residual herbaceous perennial component. It is uncertain whether successful revegetation from disking and imprinting was a result of significant reduction in sagebrush, residual perennial herbaceous species, or both. Response of sagebrush communities with a very limited perennial herbaceous understory needs to be tested to determine how much and what kind of mechanical reduction in sagebrush is needed for successful revegetation.

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INTRODUCTION

Big sagebrush (*Artemisia tridentata* Nutt.) is a dominant species on 60 million ha of rangeland in western North America (Beetle 1960). The intermountain sagebrush steppe ecosystem covers 44.8 million ha, and of this total, 1.1 million ha are found in northern Utah (West 1983b). The Great Basin-Colorado Plateau sagebrush semi-desert ecosystems occupy 17.9 million ha (West 1983a). In pristine conditions, the intermountain sagebrush steppe is usually typified by a co-dominance of sagebrush and bunchgrasses (West 1983b).

Sagebrush rangelands in western North America were altered by the introduction of domestic livestock during the last half of the nineteenth century. After 25 years of expansive livestock production, the native bunchgrass component of sagebrush-grassland ranges was greatly reduced (Young et al. 1979). Stewart (1941) and Hull and Hull (1974) wrote of the abundance of grasses prior to the introduction of livestock. Big sagebrush and other shrubs increased in density as grasses were reduced (Young et al. 1979, Stevens and Monson 2004b). About 25% of the sagebrush steppe has become stagnant due to dense, competitive stands of excess sagebrush, which prevents the recovery of perennial herbaceous species even when grazing is reduced or removed (West 2000, Bork et al. 1998).

Rehabilitation of degraded sagebrush lands started in the 1930s and increased after World War II. Degraded sagebrush stands were plowed and seeded to introduced grasses such as the drought tolerant crested wheatgrass (*Agropyron cristatum* [L.] Gaertner) (Young et al. 1979). Following the discovery of 2, 4-D (2, 4-

dichlorophenoxyacetic acid), herbicidal sagebrush control became widely practiced (Young et al. 1979, Evans et al. 1979). Mechanical and burning treatments were also used for sagebrush control (Evans et al. 1979).

The majority of early research on sagebrush control was directed toward eradication to increase herbaceous forage for livestock production, while little work focused on sagebrush thinning to improve wildlife habitat and plant diversity (Urness 1979). In recent years, the importance of sagebrush to the ecosystem has been recognized. Sagebrush communities provide habitat and forage for many wildlife species (West 2000, Sands et al. 2000, Wisdom et al. 2003). Sagebrush restoration efforts are becoming more common. Stevens and Monson (2004b) recommend that the shrub overstory need not be removed, but reduced to lessen competition with understory species. This will facilitate seeding and establishing grasses and forbs that have been depleted. Impacts of properly designed mechanical treatments may be less severe than those of fire or chemical methods. Advantages of mechanical treatments include the ability to retain shrub and herbaceous components while controlling the size and shape of the treatment (Urness 1979). Fairchild (1990) noted that restoring understory species diversity while maintaining sagebrush as a dominant species should be a management goal for depleted sagebrush stands, in order to improve wildlife habitat.

The purpose of this study was to determine the effects of 6 mechanical treatments on a Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* (Beetle & Young) Welsh) community in northern Utah by determining the response of shrubs, the residual understory species, and seeded herbaceous species.

METHODS

Study Site

The study site is located in Rich County (UTM 12T 4577041 N, 487535 E), in northern Utah on private land owned by Deseret Land & Livestock and public lands managed by the Bureau of Land Management. The study site is found at an elevation of 2,000 m and located about 2.5 km south of Neponset Reservoir. The study plots are on soils from the Lariat series and classified as coarse-loamy, mixed frigid Xerollic Calciorthids. The typical pedon is Lariat fine sandy loam, moderately deep, well drained, and derived from sandstone. Average annual precipitation is about 23 to 30 cm (USDA 1981).

This area is characterized by rolling hills covered by Wyoming big sagebrush. Western wheatgrass (*Elymus smithii* [Rydb.] Gould), Sandberg bluegrass (*Poa secunda* Presl), longleaf phlox (*Phlox longifolia* Nutt.), carpet phlox (*Phlox hoodii* Richards), and puberulent rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *viscidiflorus* Hook.) are all common species. The area is utilized by pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), and sage grouse (*Centrocercus urophasianus*) during different periods of the year. Domestic livestock also graze the area as part of Deseret Land & Livestock's short duration, high intensity grazing system. However, cattle grazing was excluded from the study site for the duration of this experiment. Plant names follow Welsh et al. (1993).

Experimental Design

In October 2001 and April 2002, 6 mechanical treatments were used to manipulate Wyoming big sagebrush at the study site. These treatments were: 1) disk plow followed by a land imprinter, 2) 1-way chaining using an Ely chain, 3) 1-way pipe harrow, 4) 2-way pipe harrow, 5) meadow aerator (fall), and 6) meadow aerator (spring). Undisturbed control areas without mechanical manipulation were also used for comparison purposes. The experiment was a randomized complete block with 3 blocks. Each treatment plot in each block was a 1.1 ha strip (61 m by 183 m) surrounded by a 15 m buffer of untreated sagebrush. Blocks were separated by 40 m strips to allow adequate space for equipment to move from plot to plot.

Revegetation

Each plot was seeded with a mixture of native and introduced grasses, forbs, and four-wing saltbush (*Atriplex canescens* [Pursh] Nutt.) (Table 1). The same seed mix and seeding rate (18.3 kg/ha PLS) was used on each plot. Seed was applied using a broadcast seeder mounted on the back of a tractor. The seeding took place prior to the treatments with the exception of the disk plow and land imprinter. Seed on the disk treatment was applied using a seed box on the imprinter, which dropped seed directly in front of the imprinter after the soil had been disked. The other treatments were seeded with the broadcaster before treatments except the 2-way pipe harrow treatment, which was seeded after the first pass and before the second pass of the harrow.

Vegetation Sampling

Pre-treatment vegetation sampling was conducted during the summer of 2001 and post-treatment sampling was completed in the summers of 2002 and 2003. Each treatment was sampled using a permanently marked 150 m transect divided into 5, 30 m baseline transects which are marked by 6 half-high fence posts that were pounded into the ground. One 30 m cross transect was placed perpendicular to each baseline transect at a random number along the baseline transect. Twenty evenly spaced 0.25 m^2 quadrats were read on the same side of each 30 m cross transect. Aerial cover and density values were estimated for all species occurring within each quadrat. Cover values were also determined for total vegetation, litter, rock, pavement, cryptogams, and bare ground within each quadrat.

Cover was estimated using a slightly modified Daubenmire (1959) cover class method (Bailey and Poulton 1968). The 7 cover classes used were: 1) .01-1%, 2) 1.1-5%, 3) 5.1-25%, 4) 25.1-50%, 5) 50.1-75%, 6) 75.1-95%, 7) 95.1-100%.

Cover of shrubs was measured using the line intercept method for all of the cross transects (Bonham 1989). Shrub density was measured using 5, 0.004 ha strips (1.34 m wide by 30 m long) centered over the length of each 30 m cross transect. All shrubs rooted within each strip were counted and placed into 1 of 5 age classes: seedling, young, mature, decadent, or dead (USDI, BLM 1996). Shrubs were also classified by amount of use and given a vigor class as used in the modified Cole browse method (Cole 1963). Every 3 m along each cross transect height and maximum crown width of the nearest mature shrub was measured. Up to 50 individuals of each shrub species could be measured to get an average height and crown width.

Estimates of annual leader growth, seed stalk length, and the number of seed stalks/shrub were measured for selected shrubs along the baseline transect. Shrubs were measured at each of the 6 posts of the baseline transect. The nearest mature shrub to the post in each of the 4 quarters around the post were selected. This yielded a sample of 24 shrubs per plot.

Leader lengths of 5 randomly selected leaders per shrub were measured to the nearest 0.5 cm. Leader length was measured from the beginning of the current year's leader growth to the end of the outermost leaf extending past the end of the stem. A total of 120 leader measurements were taken per plot to obtain mean leader length.

The seed stalks of each sampled plant were counted to determine the average number of stalks per plant. From the same plant, 5 seed stalks were randomly selected and measured to determine mean seed stalk length. If there were only 5 or less then each seed stalk was measured (Fairchild 1990).

Horizontal obscurity was measured to determine the effect of each treatment on a habitat characteristic that has been considered to be the greatest influence on sage grouse predation (Gregg 1991, Gregg et al. 1994, and DeLong et al. 1995). Horizontal obscurity was measured at 4 of the baseline posts to compare pre-treatment and post-treatment differences. This is quantified using a 1 m^2 cover board divided into 36 equal squares. Horizontal obscurity measurements were then taken from a height of 25-35 cm (sage grouse height) at 2.5, 5, and 10 m from the cover board in 4 directions. A square within the grid was considered obscured if any vegetation or object was within its perimeter. The total number of squares was recorded for each distance (Baxter 2003, Bunnell et al. 2004).

Species richness (S) was designated as the number of species sampled in each treatment. Species diversity (N_1) was determined using the Shannon-Weiner function which is sensitive to the abundance of rare species (Krebs 1999).

$$N_1 = 2^{\,3(p_i)(\log 2 p_i)}$$

p_i = proportion of total sample belonging to *i*th species.

N_1 = number of equally common species in a community.

Statistical Analysis

Data were analyzed using mixed model analysis (Proc Mixed in SAS version 8.2) with year considered as a repeated measure and using autoregressive of order 1 or AR(1) as the covariance structure. This accounts for stronger correlations for nearby times than far-apart times (Littell et al. 1996). Block was considered as a random effect, while treatment was a fixed effect. Mean separation was done using Tukey’s honestly significant difference multiple comparison procedure. Differences were considered statistically significant at an alpha level of 0.05.

RESULTS

Mean annual precipitation for 56 years of data at nearby Woodruff, Utah is 23.9 cm (Utah Climate Summaries 2004). In 2002, precipitation was 88% of normal with the spring period (April-June) being only 68% of normal. Annual precipitation was 93% of normal in 2003, with spring at 94% of normal.

The amount of time to treat the study plots was recorded and converted to the amount of hectares that could be treated per hour. The chain was the most efficient at 11.3 ha/hour and that was with complicated turns in small spaces that would not be required for a large project. Two rubber tired tractors or caterpillars are required to drag the chain, which doubles the cost. Treatment rates for the other treatments were: aerator

2.2 ha/hour, 1-way harrow 2.0 ha/hour, disk and imprinter 1.6 ha/hour, and 2-way harrow 1.1 ha/hour.

Sagebrush

All mechanical treatments greatly reduced sagebrush cover and density (Table 2). The disk and imprinter treatment removed more sagebrush than any other treatment and reduced cover to near zero. Sagebrush cover was higher than 20% for each treatment plot prior to treatment. All mechanical treatments reduced cover to less than 5% and reduced density by about half. Density for the disk and imprinter treatment was significantly ($p < 0.05$) lower than that for all other treatments in 2003, and for all but the 2-way harrow treatment in 2002. Mortality was 98% for the disk and imprinter treatment. The 2-way harrow treatment had the second highest mortality at 67.7% and the other treatments had similar mortality: aerator-fall 54.1%, 1-way harrow 49.5%, aerator-spring 45.2%, and chaining 40.6%. The treatments reduced sagebrush cover by 6-fold, but only reduced density by about half so sagebrush cover should recover within a few years as surviving plants regrow.

Sagebrush height and crown width had few differences among mechanical treatments (Table 2). All of the mechanical treatments (excluding disk and imprinter) left surviving sagebrush plants that were on average 66% the size of untreated sagebrush. Chaining left plants with a crown width of 52.5 cm wide, which was significantly ($p < 0.05$) wider than those that had been harrowed twice (35.6 cm).

Sagebrush vigor increased by the second year after mechanical treatment. There were no differences among mechanical treatments for sagebrush annual leader growth and seed stalk length after the first year (Table 2). In 2003, annual leader growth and seed stalk length were significantly ($p < 0.05$) longer for surviving mechanically-treated shrubs than untreated shrubs (too few shrubs survived the disk and imprinter treatment to sample). Annual leader growth was on average 2.3 cm longer for treated shrubs than untreated shrubs 2 years after treatment. Seed stalks were about 5.5 cm longer for treated shrubs than untreated shrubs after the second growing season. The number of seed stalks per plant for untreated shrubs (91.0 stalks/plant) was significantly ($p < 0.05$) higher than that for untreated shrubs (average of about 40 stalks/plant) for all mechanical treatments except the chain treatment (66.4 stalks/plant) after the second year.

Horizontal obscurity cover was significantly ($p < 0.05$) reduced on average by all mechanical treatments to about 24.4% at 2.5 m, 32.4% at 5 m, and 39.9% at 10 m after the first year (Table 3). In 2003, herbaceous cover increased, which resulted in higher horizontal cover for all mechanical treatments. In that year, the untreated control and the disk and imprinter treatments had higher horizontal obscurity cover than the 2-way harrow treatment. Grasses made up most of the horizontal obscurity for disk and imprinter treatment. At each distance the 2-way harrow treatment had significantly ($p < 0.05$) lower horizontal obscurity cover than the undisturbed control. The fall aerator treatment had lower horizontal obscurity cover than the control at 2.5 m and the 1-way harrow treatment had significantly lower cover than the control at 5 m.

Vegetation, Litter, and Bare Ground Cover

Total vegetation cover for all mechanical treatments was about 75% of that for the undisturbed control after 2 years (Table 3). There were no differences in total vegetation cover among the 6 mechanical treatments. Litter cover was highest for the chain and 1-way harrow treatments (Table 3). The disk and imprinter treatment was the only treatment to have significantly ($p < 0.05$) lower litter cover than the control, which meant it also had the highest percentage of bare ground (Table 3). The disk turned over soil and removed sagebrush, which exposed more bare soil. The land imprinter followed the disk and created flat-bottom shaped impressions in the soil, which should help collect moisture and slow erosion until established vegetation can protect the soil. Bare ground percentages for each of the other 5 mechanical treatments were about equal to the control. In 2003, the bare ground percentage was significantly ($p < 0.05$) lower for all mechanical treatments except the chain treatment, than it was in 2002.

Litter cover was slightly higher for all mechanical treatments than for the control. This mostly came from sagebrush that had been killed during treatment. Not all of the treatments distributed litter evenly. The pipes for the harrow treatments had the tendency to carry sagebrush and even to ride up on the broken-off shrubs until they were all released into numerous and widely distributed large piles. The chain treatment and especially the aerator treatments left dead and broken-off shrubs in place and evenly across the treatment area.

Herbaceous Understory

Total perennial grass cover was similar to the control for all the mechanical treatments in 2002 (Table 4). Cover increased on all mechanical treatments the next year when plants had recovered from the disturbance and responded to near normal spring precipitation. The disk and imprinter treatment had the greatest cover after the second year, and was the only treatment to have significantly ($p < 0.05$) higher cover than the control. In 2003, the disk treatment also had significantly ($p < 0.05$) higher cover than all other mechanical treatments except the 2-way harrow treatment.

Grass and forb species that were present prior to treatment were considered to be residual grasses and forbs. The disk and imprinter treatment was the only mechanical treatment to have negative effects on residual grasses. Density of residual grasses was significantly ($p < 0.05$) lower for the disk and imprinter than for the control and all other mechanical treatments both years (Table 5). The other 5 mechanical treatments had no effect on residual grass density. In 2003, there were no significant ($p > 0.05$) differences between the control and the mechanical treatments for residual grass cover, but the disk and imprinter had significantly ($p < 0.05$) less residual grass cover than the other 5 mechanical treatments (Table 4). Residual grass cover increased significantly ($p < 0.05$) from 2002 to 2003 for all mechanical treatments except the chain treatment in 2003.

Western wheatgrass is a rhizomatous species that responded well to each treatment except the disk, but the spring aerator treatment was the only mechanical treatment to have significantly ($p < 0.05$) higher cover of this species than the control in 2003 (Table 4). Western wheatgrass density was only reduced by the disk and imprinter treatment (Table 5). Sandberg bluegrass is a tufted perennial with a few occasional rhizomes (Welsh et al. 1993). The disk and imprinter treatment significantly ($p < 0.05$) reduced the cover and density of Sandberg bluegrass in both 2002 and 2003 (Tables 4 and 5). For the other 5 mechanical treatments, cover and density for Sandberg bluegrass was about equal to the control for both years.

Establishment of seeded species was most successful for the disk and imprinter treatment. Density of seeded grasses for the disk and imprinter treatment was over 3 times greater than that for any of the other treatments (Table 5). In 2002, cover of seeded grasses for the disk treatment was 5.6%, while the other 5 mechanical treatments averaged 0.3% cover (Table 4). In 2003, cover of seeded grasses for the disk and imprinter treatment and the 2-way harrow treatment increased significantly ($p < 0.05$). The disk and imprinter treatment had 15.1% cover, the 2-way harrow treatment had 2.6% cover, and the other 4 mechanical treatments averaged 1.0% cover. The disk and imprinter treatment had significantly ($p < 0.05$) greater cover than all other mechanical treatments and the control, while the 2-way harrow treatment had significantly ($p < 0.05$) greater cover than the control. No other mechanical treatments had significantly ($p < 0.05$) higher seeded grass cover than the control, which was not seeded and had 0% cover. Seeded grass density remained stable between 2002 and 2003. The disk and imprinter treatment reduced competition from both shrubs and herbaceous species and created safe sites for seeds to establish. Seed was sown just in front of the imprinter, which created furrow-like depressions and from which grasses were seen to emerge. The 2-way harrow treatment, which created the second most soil disturbance, had the second best establishment of seeded species. The 2-way harrow treatment and the disk treatment were the only mechanical treatments to have significantly ($p < 0.05$) higher cover of seeded grasses than the control, but only the disk and imprinter treatment had significantly ($p < 0.05$) higher density than the unseeded control.

'Hycrest' crested wheatgrass and intermediate wheatgrass (*Elymus hispidus*

[Opiz] Meld.) were the most successful seeded species. The disk and imprinter treatment had over 5% cover for each of these species in 2003, which was significantly ($p < 0.05$) higher than all other mechanical treatments (Table 4). The 2-way harrow treatment had significantly ($p < 0.05$) higher cover than the control with 1.5% cover of crested wheatgrass in 2003. Crested and intermediate wheatgrass density for the disk and imprinter treatment was significantly ($p < 0.05$) higher than that of the control both years (Table 5). Crested wheatgrass density for the 2-way harrow treatment was significantly ($p < 0.05$) higher than that of the control in 2003. No other seeded grasses were found in high quantities. Smooth brome was seeded at the heaviest rate but did not establish as well as other species. Smooth brome had about 0.8% cover in the disk treatment in 2003. Orchard grass and Russian wildrye had 2.5% and 0.9% cover, respectively for the disk and imprinter treatment in 2003.

Total perennial forb cover, including residual species and seeded species, was not significantly ($p < 0.05$) different from the control for any mechanical treatments (Table 6). There were very few differences in total perennial forb density (Table 6). In 2003, the 2-way harrow treatment had significantly ($p < 0.05$) higher forb density than the disk and imprinter treatment and the chain treatment.

The disk and imprinter, 1-way harrow, and spring-aerator treatments each had significantly ($p < 0.05$) lower cover of residual perennial forbs than the control in 2003 (Table 6). Only the disk and imprinter treatment had significantly ($p < 0.05$) lower residual forb density than the control (Table 6). Carpet phlox is one of the most common residual forbs. In 2003, the disk and imprinter, the 1-way and 2-way harrows, and spring aerator treatments all had significantly ($p < 0.05$) lower cover than the control, while only the disk and imprinter and the 1-way harrow treatment had lower densities than the control (Table 6).

Establishment of seeded forbs was very low, even though 10.3 kg/ha PLS were seeded to increase diversity in this community. Seeded forb density was highest for the disk and imprinter and 2-way harrow treatments, which also created the most soil disturbance (Table 6). The 2-way harrow treatment had the highest seeded forb density in 2002 with 0.4 plants per $0.25m^2$, but this decreased significantly to 0.2 plants per $0.25m^2$ in 2003.

Blue flax had the highest establishment of all the seeded forbs. The 2-way harrow and disk and imprinter treatments had the highest density of blue flax, which exceeded that of the unseeded control in 2002 (Table 6). No differences in seeded forb density were found among the mechanical treatments or control in 2003 as the disk and imprinter and both harrow treatments had lower densities than the previous year. No other seeded forb was found in sizeable quantities.

The 2-way and 1-way harrow treatments had the highest diversity and species richness compared to all the treatments and the control (Fig. 1). The 2-way harrow treatment had significantly higher diversity and richness than the control in both 2002 and 2003. This is probably because this treatment had a high establishment of seeded species, while not negatively affecting the residual species.

DISCUSSION

Few differences in vegetation response were found among the mechanical treatments with the exception of the disk and imprinter. Although the other 5 treatments substantially reduced sagebrush cover and density, they did leave enough sagebrush for it to continue to be an important component of the community. Two years after treatment, total perennial grass cover and residual grass cover increased, but were not statistically higher than the untreated sagebrush areas (Table 4).

The disk and imprinter had the greatest impact by changing the community from shrub to grass dominance. According to Pechanec et al. (1965) 70 to 99% of big sagebrush can be killed with the use of disks or plows. This study found that 98% of sagebrush was killed by disking. As Parker (1979) noted, plows and disks cause the greatest disturbance for sagebrush ecosystems because they overturn the soil. This allows them to have the greatest affect on seedbed preparation, which can benefit seeding. Plows and disks are restricted to areas that are relatively rock free (Stevens and Monson 2004a).

Wambolt and Payne (1986) noted that plowing left scattered mature plants, which provided seed for re-establishment of sagebrush. In this study, reduced competition and favorable seedbed preparation from plowing increased canopy cover over that from rotocutting, burning, or spraying by the second year after treatment. Our study found that disking produced the lowest canopy cover and density of sagebrush even after the second year.

Disking and imprinting is useful in creating greater herbaceous production. The land imprinter was developed to create micro-depressions in the soil to improve moisture collection and infiltration as well as covering broadcast seed (Dixon 1980). Impressions or furrows create a firm seed bed and are effective in collecting moisture to extend the germination period for seeds. It also can reduce erosion (Stevens and Monson 2004a). Our study found the imprinter to be the most effective treatment in establishing seeded grasses.

Disking and imprinting could also be useful in trying to renovate bottom areas that were once dominated by grasses and forbs, but are now dominated by shrubs. This method would not be recommended for sage grouse wintering or nesting habitat or mule deer winter range, as sagebrush is such an important plant for winter forage and cover for these animals.

One-way chaining effectively thinned sagebrush and increased shrub growth. Chaining seemed to have the least destructive effects on sagebrush and did not negatively affect the existing herbaceous understory. It was the least expensive method as it can cover more ground quickly and can also be used on a wide range of terrain conditions (Pechanec et al. 1965, Parker 1979, Stevens and Monson 2004a). Chaining is ideal for large scale projects. The associated costs of transporting the equipment to and from the project site would be the greatest costs; however large amounts of land can be treated by a chain in a short period of time. Altering the shape of the chain from a "U" shape to "J" can shape change the amount of disturbance, as can widening the distance between the tractors or caterpillars. For this project the tractors were kept about 20 m apart and even with each other resulting in a "U" shaped chain. A "J" shaped chain creates more disturbance. Chaining more than once-over can improve establishment of herbaceous species (Fairchild 1990).

Parker (1979) reported that harrows kill 20 to 70% of sagebrush, with smaller, younger plants surviving. We examined the differences in harrowing once versus twice and found that each thinned sagebrush at about the same rate. Harrowing twice did not significantly ($p > 0.05$) reduce sagebrush cover or density any lower than harrowing only once. It also did not have a greater negative effect on residual understory species, but it did produce higher establishment of seeded species, especially crested wheatgrass. The 2-way harrow disturbed the soil more than the 1-way harrow treatment. The associated increase in bare ground may have helped increased establishment of seeded species. Diversity was also highest for the 2-way harrow as it did not negatively affect the residual species, but increased density of seeded species.

The only difference between the harrow and the other mechanical treatments was slightly better establishment of seeded species for the 2-way harrow, but harrowing twice is about twice as expensive as harrowing once. It took the longest time to treat of any of the mechanical treatments. An advantage of using a harrow is that it can be useful on rocky terrain, where other treatments should not be used (Stevens and Monson 2004a).

The aerator was tested twice to compare fall to spring treatments. It was believed that treating sagebrush in the spring when it is less brittle would be less detrimental. This study did not show any significant ($p > 0.05$) differences between the 2 treatments. Use of the aerator is limited to rock free-ground as rocky terrain can damage it. Aeration may be useful when treating relatively small areas and when release of understory species is desirable and establishment of seeded species is not necessary.

Horizontal obscurity is a measure of lateral cover. This study showed that, although foliar shrub cover was decreased, horizontal obscurity was only decreased by the 2-way harrow treatment at 2.5, 5, and 10 m. DeLong et al. (1995) and Gregg et al. (1994) showed that herbaceous cover was important for successful nesting cover for sage grouse. Tall grass and medium-height shrub cover provided the greatest amount of canopy and lateral cover. Sagebrush thinning may negatively affect sage grouse nesting in the short term (Connelly et al 1991), and should be done only where sufficient nesting habitat is left intact (DeLong et al. 1995). DeLong et al. (1995) recommend that after long term management and sagebrush reestablishment, nesting habitat may be enhanced by an improved balance of shrub and herbaceous components. Gregg et al. (1994) noted that Wyoming big sagebrush habitats with 8-12% shrub cover often support the type of grass cover needed for successful nesting.

Continued research on this project will determine long term effects of these treatments. Other research on sagebrush thinning projects found that sagebrush treated by plowing recovered to the level of the untreated control plots in approximately 10 years, while rotocutting and spraying took 18 years to recover (Watts and Wambolt 1996).

Disturbance of established vegetation could result in weed dominance in areas already infested with weedy species such as cheatgrass. Further research on larger treated areas is needed to determine the response of wildlife to these treatments.

The 5 mechanical treatments, other than the disk and imprinter, were shown to be effective at thinning sagebrush, while maintaining it as a dominant species. All of the treatments can be useful in different situations depending on site conditions and management goals. These treatments could be effective in creating mosaic patterns of sagebrush with parts of the community at different seral stages. While few differences were found in the vegetation response to these treatments, there were differences in cost. Chaining was the least expensive method. Harrowing twice was the most expensive, but did have significantly better establishment of seeded species. The disk and imprinter was most effective at establishing seeded species, but did remove sagebrush from the community structure. Management goals should be evaluated, when considering which treatment to use.

Sagebrush communities with a very poor herbaceous understory and many older, decadent shrubs could benefit from these treatments by increased understory cover and removal of older decadent shrubs. This area had a relatively healthy understory of grasses prior to treatment, while many other sagebrush communities have limited understory. Competition from the residual understory may have prevented the establishment of more seeded species on treatments that did not greatly disturb the soil as did the disk or 2-way harrow. Because disking and imprinting greatly reduced both sagebrush and residual perennial herbaceous species, it is uncertain whether greater establishment of seeded species on this treatment was due to decreases in shrubs, residual herbaceous species, or both. Response to these treatments of a sagebrush community with a very limited perennial herbaceous component needs to be tested in order to determine how much sagebrush reduction is needed for successful revegetation.

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Table 1. Seeded species and pure live seed (PLS) seeding rates for seed mix broadcast into a Wyoming big sagebrush community prior to mechanical treatment in fall 2001 and spring 2002 (aerator only) in northern Utah.

Species	PLS kg/ha
Bluebunch wheatgrass	0.6
Crested wheatgrass - Hycrest	0.6
Intermediate wheatgrass	1.0
Hybrid wheatgrass - NewHY	1.0
Orchard grass - Paiute	1.3
Russian wildrye Bozoisky	1.2
Smooth brome	2.0
Thickspike wheatgrass - Bannock	0.3
Alfalfa - Ladek	2.6
American vetch	0.4
Blue flax	0.5
Rocky Mtn penstemon	0.1
Sainfoin	2.3
Small burnett - Delar	2.4
Western yarrow	0.4
Yellow sweet clover	0.9
Fourwing saltbush	0.7
Total	**18.3**

Table 2. Wyoming big sagebrush characteristics after mechanical treatments applied fall 2001 and spring 2002 (aerator only) in northern Utah.

	Treatment	Canopy cover (%)	plants/ha	Height (cm)	Crown width (cm)	Annual leader growth (cm)	Seed stalk length (cm)	Seed stalks/ plant
2002	Control	25.8 a	2276 a	58.9 a	86.1 a	2.7 d	6.1 e	50.0 bc
	Chain	4.4 b-d	1258 b	39.4 b	50.1 bc	4.2 a-d	11.1 a-d	47.2 bc
	Disk/Imprinter	0.1 f	62 c	-	-	-	-	-
	Harrow 1-way	3.6 b-e	1040 b	38.3 bc	47.0 b-d	4.3 a-d	10.6 a-d	38.0 bc
	Harrow 2-way	1.6 d-f	848 bc	26.2 cd	37.2 cd	4.8 a-c	10.1 a-e	24.7 c
	Aerator-Fall	2.0 c-f	961 b	28.0 b-d	37.6 cd	3.5 b-d	8.5 c-e	17.3 c
	Aerator-Spring	2.5 b-f	1196 b	28.9 b-d	37.6 cd	3.3 cd	9.2 b-e	19.5 c
2003	Control	23.9 a	2211 a	57.7 a	82.5 a	2.9 d	7.6 de	91.0 a
	Chain	5.5 b	1172 b	36.8 b-d	52.5 b	5.0 a-c	13.1 ab	66.4 ab
	Disk/Imprinter	0.3 ef	100 c	-	-	-	-	-
	Harrow 1-way	5.4 bc	1061 b	33.0 b-d	46.5 b-d	5.6 a	12.7 a-c	45.7 bc
	Harrow 2-way	2.2 b-f	1023 b	26.1 cd	35.6 d	5.1 a-c	12.7 a-c	40.9 bc
	Aerator-Fall	2.9 b-f	1004 b	26.0 d	39.1 b-d	5.4 a	14.3 a	39.4 bc
	Aerator-Spring	4.7 b-d	1247 b	27.5 b-d	40.9 b-d	5.1 ab	12.3 a-c	33.9 bc

Within each column and across years, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$).

Table 3. Vegetation attributes after mechanical treatment of a Wyoming big sagebrush community in northern Utah.

	Treatment	Vegetation cover (%)	Litter cover (%)	Bare ground cover (%)	Horizontal obscurity cover (%) 2.5 m[1]	5 m	10 m
2002	Control	36.4 a	30.0 de	33.4 f-i	67.4 a-c	85.9 a-c	98.6 a
	Chain	20.9 df	41.1 a-c	36.3 d-h	29.2 d	39.4 e	47.3 d
	Disk/Imprinter	10.0 g	22.6 e	69.1 a	20.4 d	26.3 e	32.7 d
	Harrow 1-way	18.5 e-g	41.6 ab	43.7 c-fh	25.6 d	35.4 e	42.9 d
	Harrow 2-way	15.6 fg	31.3 c-e	56.0 bc	23.0 d	31.8 e	39.0 d
	Aerator-Fall	16.2 fg	38.0 a-d	46.7 b-e	18.9 d	26.7 e	35.9 d
	Aerator-Spring	15.1 fg	39.0 a-d	45.0 cdfg	29.3 d	34.5 e	41.8 d
2003	Control	35.5 ab	34.6 b-d	33.3 f-i	73.6 ab	89.4 ab	95.4 ab
	Chain	26.3 ce	45.2 a	32.0 hj	53.4 bc	66.4 cd	77.6 bc
	Disk/Imprinter	26.0 c-e	21.6 e	58.2 b	85.5 ab	92.6 a	97.0 ab
	Harrow 1-way	27.7 a-d	47.2 a	33.3 gij	57.2 bc	69.0 cd	77.0 bc
	Harrow 2-way	27.2 b-e	34.1 b-d	42.1 d-h	51.5 c	64.1 d	73.4 c
	Aerator-Fall	26.1 c-e	39.6 a-d	39.1 f-i	52.8 c	70.8 b-d	77.6 bc
	Aerator-Spring	25.6 c-e	43.5 ab	36.5 ehi	60.7 bc	73.5 a-d	78.3 a-c

Within each column and across years, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$).

[1] Square root transformation used for analysis.

Table 4. Mean percent cover of grasses after mechanical treatment of a Wyoming big sagebrush community in northern Utah.

	Treatment	Perennial grasses	Residual grasses	Western wheatgrass	Sandberg bluegrass	Seeded grasses[1]	Crested wheatgrass[2]	Intermediate wheatgrass[3]
2002	Control	9.6 b-g	9.6 a-e	3.7 b-e	4.3 ab	0.0 d	0.0 c	0.0 c
	Chain	8.7 cgh	8.4 b-d	4.0 a-d	2.8 a-c	0.3 d	0.0 c	0.2 c
	Disk/Imprinter	6.9 g	1.3 g	0.7 e	0.4 c	5.6 b	1.5 b	1.4 b
	Harrow 1-way	7.5 egh	7.2 d-f	4.2 a-d	1.9 a-c	0.3 d	0.1 c	0.1 c
	Harrow 2-way	6.6 g	5.8 eg	2.8 c-e	1.9 a-c	0.8 d	0.2 c	0.3 c
	Aerator-Fall	8.0 fgh	7.8 cef	4.9 a-c	2.2 a-c	0.2 d	0.1 c	0.1 c
	Aerator-Spring	7.9 d-h	7.8 b-e	5.0 a-c	2.1 a-c	0.2 d	0.1 c	0.0 c
2003	Control	9.9 b-g	9.9 a-e	3.4 b-e	4.7 a	0.0 d	0.0 c	0.0 c
	Chain	13.3 bd-f	12.2 a-d	4.1 a-d	4.5 ab	1.1 cd	0.4 c	0.6 c
	Disk/Imprinter	21.1 a	5.7 e	1.4 de	1.1 bc	15.1 a	5.3 a	5.7 a
	Harrow 1-way	13.5 b-df	12.5 a-c	5.0 a-c	4.6 a	0.9 cd	0.5 c	0.3 c
	Harrow 2-way	15.3 ab	12.7 a-d	5.3 a-c	4.5 ab	2.6 c	1.5 b	0.8 bc
	Aerator-Fall	13.6 b-e	12.5 abd	6.0 ab	4.3 ab	1.1 cd	0.3 c	0.5 c
	Aerator-Spring	14.8 bc	14.0 a	7.0 a	4.9 a	0.8 cd	0.4 c	0.2 c

Within each column and across years, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$).

[1] Arcsin transformation used for analysis.

[2] Log transformation used for analysis.

[3] Square root transformation used for analysis.

Table 5. Density (plants/0.25 m^2) of grasses after mechanical treatment of a Wyoming big sagebrush community in northern Utah.

	Treatment	Perennial grasses	Residual grasses	Western wheatgrass	Sandberg bluegrass	Seeded grasses	Crested wheatgrass	Intermediate wheatgrass[1]
2002	Control	13.8 a	13.8 a	8.4 a	4.3 ab	0.0 b	0.0 d	0.0 c
	Chain	11.8 a	11.0 a	6.6 ab	3.2 ab	0.8 b	0.1 d	0.6 c
	Disk/Imprinter	5.6 b	1.9 b	1.1 b	0.5 c	3.7 a	1.1 a	1.2 ab
	Harrow 1-way	10.5 a	10.0 a	6.5 ab	2.5 bc	0.5 b	0.1 d	0.2 c
	Harrow 2-way	10.9 a	9.7 a	6.1 ab	2.3 bc	1.1 b	0.2 cd	0.5 bc
	Aerator-Fall	10.8 a	10.6 a	7.4 a	2.4 bc	0.3 b	0.1 d	0.1 c
	Aerator-Spring	11.0 a	10.7 a	6.9 a	3.0 ab	0.3 b	0.1 d	0.0 c
2003	Control	12.3 a	12.3 a	6.9 a	4.6 a	0.0 b	0.0 d	0.0 c
	Chain	12.6 a	11.9 a	6.7 a	3.7 ab	0.5 b	0.1 d	0.3 c
	Disk/Imprinter	5.5 b	2.6 b	1.1 b	0.9 c	2.7 a	0.8 ab	1.0 a
	Harrow 1-way	14.7 a	13.8 a	9.0 a	3.6 ab	0.7 b	0.3 cd	0.2 c
	Harrow 2-way	12.7 a	11.5 a	7.1 a	3.3 ab	1.2 b	0.6 bc	0.4 bc
	Aerator-Fall	14.8 a	14.2 a	9.4 a	4.0 ab	0.6 b	0.1 d	0.4 c
	Aerator-Spring	14.8 a	14.4 a	9.7 a	3.8 ab	0.4 b	0.2 d	0.1 c

Within each column and across years, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$).

[1] Log transformation used for analysis.

Table 6. Percent cover and density (plants/0.25 m^2) of forbs after mechanical treatment of a Wyoming big sagebrush community in northern Utah.

		Cover (%)			Density (plants/0.25m^2)				
	Treatment	Perennial forbs	Residual forbs	Carpet phlox[1]	Perennial forbs	Residual forbs[2]	Carpet phlox	Seeded forbs	Blue flax
2002	Control	3.1 ab	2.9 ab	1.9 ab	4.2 a-d	3.6 a-d	1.2 ab	0.0 e	0.0 ef
	Chain	3.3 ab	2.8 a-c	1.7 a-c	4.1 a-d	3.3 abde	1.1 a-c	0.1 c-e	0.1 c-e
	Disk/Imprinter	2.0 ab	0.4 de	0.0 d	1.4 e	0.8 fg	0.1 d	0.3 ab	0.2 acd
	Harrow 1-way	2.1 ab	1.4 b-e	0.4 cd	5.2 ab	3.6 a-c	0.6 a-d	0.2 b-e	0.1 a-cf
	Harrow 2-way	2.5 ab	1.5 b-e	0.3 d	6.7 a	4.2 a	0.7 a-d	0.4 a	0.3 ab
	Aerator-Fall	2.6 ab	2.3 a-d	1.6 ab	3.3 b-e	2.5 a-e	1.1 a-c	0.0 c-e	0.0 ef
	Aerator-Spring	1.1 b	1.0 c-e	0.4 cd	2.3 de	2.0 a-f	0.5 cd	0.0 c-e	0.0 ef
2003	Control	3.7 ab	3.5 a	2.8 a	3.1 b-e	2.6 a-e	1.3 a	0.0 e	0.0 ef
	Chain	3.1 ab	2.7 a-c	2.2 ab	2.3 de	1.8 cfg	1.1 a-c	0.0 c-e	0.0 ef
	Disk/Imprinter	2.4 ab	0.2 e	0.0 d	1.7 de	0.3 g	0.0 d	0.2 a-c	0.2 be
	Harrow 1-way	1.6 ab	1.2 b-e	0.8 b-d	2.5 c-e	1.6 d-g	0.5 b-d	0.1 c-e	0.1 de
	Harrow 2-way	3.5 ab	2.4 a-c	1.2 bc	5.1 a-c	3.0 b-e	0.7 a-d	0.2 b-d	0.2 c-e
	Aerator-Fall	4.0 a	3.0 ab	2.4 a	4.3 a-d	2.3 a-f	1.3 a	0.1 c-e	0.1 ef
	Aerator-Spring	1.8 ab	1.2 b-e	0.9 b-d	2.5 c-e	1.4 e-g	0.5 a-d	0.0 de	0.0 ef

Within each column and across years, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$).

[1] Log transformation used for analysis.

[2] Square root transformation used for analysis.

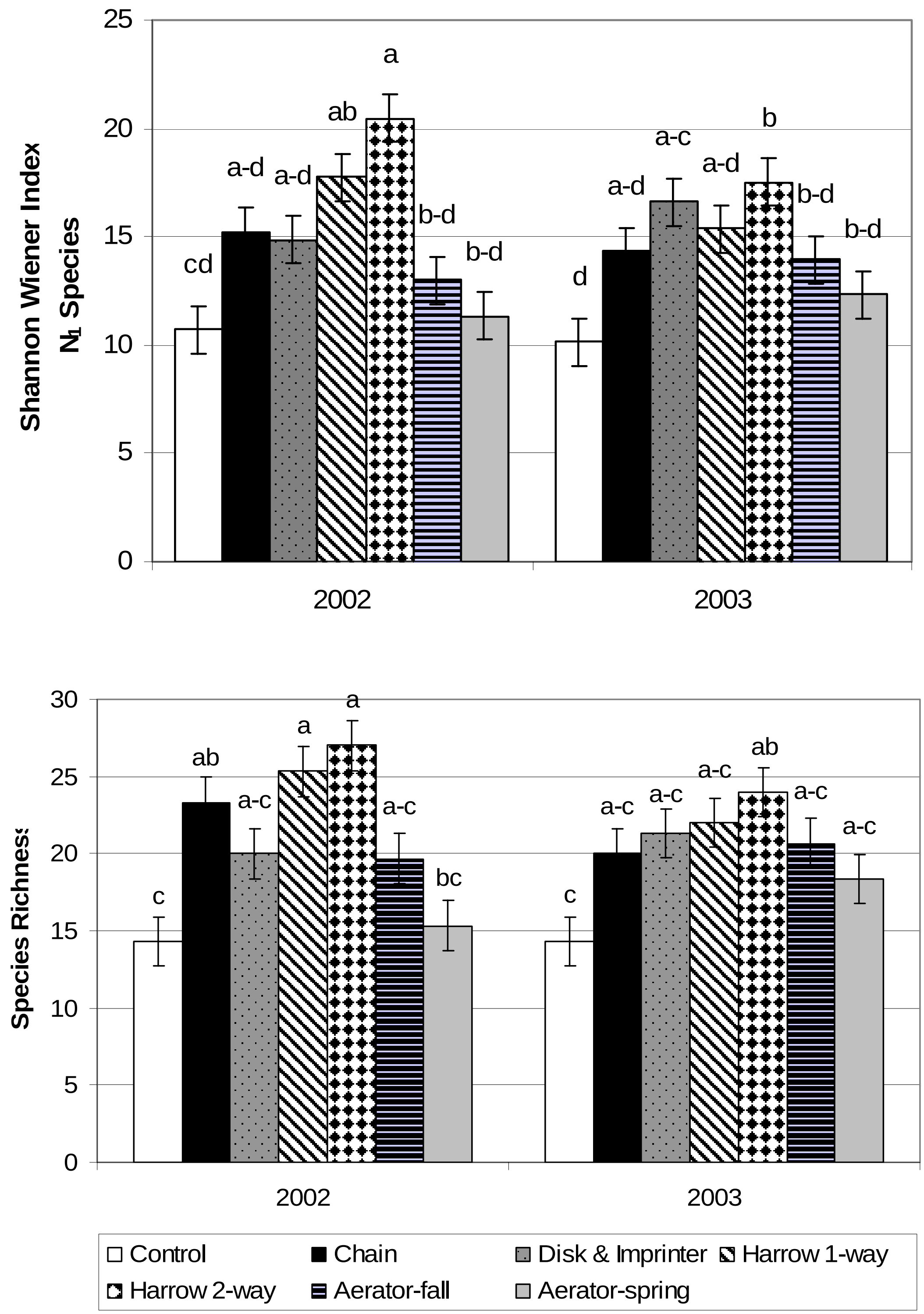

Fig. 1. Shannon Wiener index (above) of species diversity, where N_1 (± SE) is equal to the number of equally common species. Mean (± SE) species richness (below) for each treatment. Different letters indicate a significant difference within and across years ($P < 0.05$).