WYOMING BIG SAGEBRUSH: THE EFFECTS OF CHEMICAL, MECHANICAL, AND PRESCRIBED FIRE TREATMENTS ON VEGETATION AGE CLASS AND DIVERSITY IN THE WYOMING BASIN

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Sagebrush (*Artemisia* spp.) communities in which disturbance regimes have been altered often lack a robust herbaceous understory. Dense, even aged stands of sagebrush, which compete for limited resources, are often attributed to declines in grass and forb cover and diversity. As a means of increasing sagebrush age-class diversity while improving herbaceous characteristics, a number of vegetation treatments have been advocated.

This study was conducted to evaluate the effects of chemical, mechanical, and prescribed fire treatments in a Wyoming big sagebrush community (*Artemisia tridentata* spp. *wyomingensis*) conducted in 2006 near Pinedale, Wyoming. Treatments included the application of tebuthiuron at rates of 0.9 a.i/ha and 1.9 a.i/ha (light and heavy Spike), Dixie harrow, Ely chain, aerator, low mow, medium mow with forb seeding, high mow, and prescribed fire. Grazing was excluded from approximately half of each treatment site.

A Geographic Information Systems (GIS) analysis was also conducted to identify areas where active or passive restoration activities may have the greatest potential for success in the Wyoming portion of the Green River Basin. Two different index models are presented.

The low mow treatment most appreciably reduced sagebrush cover and height while the light Spike treatment resulted in the most minimal reduction of sagebrush cover. Sagebrush height was least affected by the high mow treatment. The prescribed fire treatment had the greatest effect on the reduction of mature sagebrush. Decadent sagebrush was reduced on all sites. Grazing had a minimal effect on sagebrush attributes.

Mean total grass cover increased on all sites except those treated with the aerator and high mow. Total forb cover, species richness, and Shannon-Wiener Index values increased on all plots; however, treatment plots were not significantly different with respect to the control. Herbaceous changes were attributed to differences in year-to year fluctuations and seasonality of sampling. Grazing had a minimal effect on herbaceous cover, height, and diversity.

These first year post-treatment data serve as a baseline upon which further vegetation changes can be gauged. Continued vegetation monitoring is essential in the adequate assessment of treatment efficacy or applicability.

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INTRODUCTION

Since the early 1800s sagebrush (*Artemisia* L. spp.) dominated ecosystems throughout western North America have become increasingly fragmented and altered due to a multitude of land use practices (Dobkin and Sauder 2004). Contemporary threats to sagebrush ecosystems include: urbanization, farmland conversion, recreation, natural resource development, annual weed invasion, and road network expansion (Miller and Eddleman 2001). Sagebrush has been eliminated from several landscapes due to many of these and other factors (Knick et al. 2003). In areas where sagebrush does continue to dominate the landscape, the habitat is often highly degraded. Altered disturbance regimes have caused significant changes in shrub community composition; sagebrush cover and density increases have been attributed to fire suppression and excessive grazing (Miller and Eddleman 2001). Conversely, communities affected by annual grass invasion have experienced more frequent fires, resulting in the concomitant loss of sagebrush. The health and productivity of the herbaceous understory is often negatively affected (Baxter 1998).

The survival of many species, including sage-grouse (*Centrocercus* spp.), mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus)*, and pygmy rabbits (*Brachylagus idahoensis*), is dependent on healthy and diverse sagebrush stands (USDI 2005). Focus is often given to sage-grouse habitat requirements as these birds are true sagebrush-obligates, relying on sagebrush year-round for breeding, nesting, brood-rearing, and foraging (Rowland 2004). While 60 to 80% of all food consumed by sage-grouse is comprised of sagebrush, forbs are particularly important to pre-laying females and young chicks for nutritional needs (Barnett and Crawford 1994; Drut et al. 1994; McAdoo et al. 2002). Ideal sage-grouse habitat includes a sagebrush-steppe mosaic replete with a diverse array of grasses and forbs; varying heights of sagebrush are also desired (Connelly et al. 2000).

A decrease in the herbaceous understory, including grasses and forbs, has been attributed to increases in sagebrush cover (Barnett and Crawford 1994). The maximum canopy cover of Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis*

Beetle &Young) in areas receiving more that 20 cm of precipitation is typically no more than 25-30% (Wyoming Interagency Vegetation Committee 2002). At canopy covers between 12-15% competition may have deleterious effects on the herbaceous component in the understory; for every 1% increase in Wyoming big sagebrush cover there is an estimated 3.8% decrease in understory herbaceous production (Winward 1991). Restoration efforts that strive to diversify sagebrush age class and reduce sagebrush density have been advocated (Barnett and Crawford 1994). While precipitation, understory species, soil properties, and grazing history must be taken into consideration when assessing potential herbaceous yield, some form of sagebrush canopy removal is often required to promote renewed understory productivity (Winward 1991; Welch and Criddle 2003).

This vegetation study is designed to quantify and compare the long-term effects of chemical, mechanical, and prescribed fire treatments on vegetation age class and diversity on the Pinedale Mesa, which is located in the Upper Green River Basin of the Wyoming Basin. While many sagebrush treatments have been individually assessed, few comparative studies have been done to determine which treatments, if any, are most effective at specifically improving vegetation characteristics in Wyoming big sagebrush communities.

A Geographic Information System (GIS) analysis was also conducted to help further delineate areas where sagebrush improvements will be most effective and ecologically beneficial. Ideally, the results of this study will help to guide future restoration and rehabilitation planning within sagebrush landscapes of the Upper Green River Basin .

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CHAPTER II

VEGETATION TREATMENTS EFFECTS IN A WYOMING BIG SAGEBRUSH COMMUNITY

INTRODUCTION

Since the late 1940s, numerous rangeland improvement projects have focused on big sagebrush (*Artemisia tridentata* Nutt.) removal through the use of chemical, mechanical, and prescribed fire treatments (Johnson1969; Britton and Sneva 1983; Wambolt and Payne 1986; Miller and Eddleman 2001). Many of these efforts sought to improve grass production for livestock forage (Vale 1974). According to Wambolt et al. (2001), millions of hectares of sagebrush have been affected by sagebrush treatments over the last 50 years. In more recent times, sagebrush removal has been used in attempts to improve grass and forb abundance in areas where extensive livestock grazing, wildfire suppression efforts, and periods of drought have led to substantial increases in the density and canopy cover of big sagebrush (Olson and Whitson 2002).

Chemical treatments

The herbicide 2,4-D (2,4-dichlorophenoxy acetic acid) was often used in the past as a sagebrush control method (Miller and Eddleman 2001). Effective at greatly reducing sagebrush, this chemical also caused a decrease in broad-leaved species (Olson and Whitson 2002). Often, only grasses remained after the application of 2,4-D. As a consequence, recent restoration projects have turned to the use of the herbicide tebuthiuron [1-(5-tert-butyl-1,3,4-thiadiazol-2-yl)-1,3-dimethylurea](Britton and Sneva 1983). This herbicide, commonly referred to as Spike 20P, works from the roots up; when lightly applied, it is able to selectively thin sagebrush through the inhibition of photosynthetic activity. Tebuthiuron has little impact on other plant species under low application rates. According to Olson and Whitson (2002), when applied at 0.1-0.5 kg active ingredient (a.i.)/ha, only sagebrush plants within a 0.5-m radius of the individual herbicide pellet are affected. Mortality rates comparable to those seen with 2,4-D have been achieved with application of tebuthiuron at 1 and 2 kg a.i./ha rates (Britton and Sneva 1983).

Taking soil conditions and annual precipitation rates into account, different application rates can be prescribed for given restoration goals. Lower precipitation rates and soils with higher sand content have been shown to exacerbate the effects of tebuthiuron. Dow AgroSciences recommends between 1.1 kg a.i./ha and 3.35 kg a.i./ha for a 50-75% reduction in Wyoming big sagebrush at elevations above 1,980 m (Dow AgroSciences 2007).

Sagebrush mortality is affected by soil properties as tebuthiuron does not dissociate in soils with high pH levels (Olson and Whitson 2002). The chemical also binds readily to organic matter and clay particles. As the soils associated with sagebrush ecosystems are typically low in organic matter, clay content is more critical in determining tebuthiuron effectiveness.

McDaniel et al. (2005) studied 8 different Wyoming big sagebrush plots treated exclusively with tebuthiuron. These authors collected canopy cover data and vegetation yield for 20 years post-herbicide application. They found that the number of years favorable for sagebrush establishment was the most significant factor affecting Wyoming big sagebrush recovery. Treatment with tebuthiuron was predicted to last at least 35 years at 6 of the 8 study sites; higher rates of herbicide application extended treatment life.

While not specific to tebuthiuron, other studies have indicated that herbicide treatments typically last between 14 and 17 years in areas not impacted by grazing (Johnson 1969). After 17 years, Johnson (1969) determined that the number of young sagebrush plants in sprayed areas exceeded the number of young plants in the control plot. Fourteen years after spraying, live sagebrush crown area had returned to pre-spraying levels. In a similar study, Watts and Wambolt (1996) found that Wyoming big sagebrush cover exceeded that of the control plot after 10 years. Little research has been done to study the effects of tebuthiuron on long-term plant community structure and function in sagebrush ecosystems (Miller and Eddleman 2001; Olson and Whitson 2002).

Mechanical treatments

Several different mechanisms, including disking, plowing, aerating, mowing, and chaining are available for the mechanical treatment of sagebrush. As opposed to more broad-scale treatments such as prescribed fire, many mechanical treatments can be implemented to avoid sensitive areas. Studies conducted in the 1940s indicated that mechanical rangeland treatments consistently resulted in perennial grass cover increases; several years post-treatment, increases ranging from 200 to 400% have been observed (Barnes 1952; Vale 1974). One-way disc plows, which result in small pits, about 40 cm apart, reduced vegetative cover by about 30%; western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Löve) responded most rapidly to the reduction in competition and tillage (Barnes 1952).

When plows were used for vegetation manipulation, Barnes (1952) found, after examining several different plow furrow width patterns, that 0.6 m was the optimum distance for vegetation establishment; further distances did not result in increased herbaceous yields (Barnes 1952). These initial studies indicated that surviving sagebrush plants provided seed for the re-colonization of disturbed sites (Johnson and Payne 1968). Treatments conducted while sagebrush seed was at maturity also resulted in greater sagebrush re-establishment.

Chaining as a means of sagebrush thinning was first advocated in the 1960s (Fairchild et al. 2005). Chaining also can result in more shrubs being maintained thereby allowing for more seed production potentially beneficial for sagebrush reestablishment. The Ely chain consists of anchor chains with attached steel bars (Stevens and Monsen 2004). Links are welded with railroad rails at every link, every other link, or at every third link. The Ely chain can be drug behind two bulldozers in a "U" shape, half circle, or "J" shaped pattern, with the "U" pattern providing the most vegetation disturbance (Vallentine 1980).

Mowing, which was a more frequently implemented treatment in the past, reduces upright species while retaining low-growing perennials and sprouting species (Vallentine 1980). Unlike many other mechanical treatments, mowing reduces soil impacts.

The pipe, or Dixie harrow is comprised of small diameter, iron spiked pipes which are drug behind a spreader bar (Vallentine 1980). Reductions of big sagebrush on the order of 30-70% have been obtained with this device. According to Vallentine (1980), the Dixie harrow typically uproots 10-20% of bunchgrass species and it only slightly damages sprouting shrubs and annuals. Adequate soil disturbance is obtained for seed coverage.

The Lawson aerator is an apparatus specially designed for soil aeration and the chopping of small brush (Lawson Manufacturing, Inc. 2008). Spiraling horizontal blades can mulch brush from 6 -10 cm in diameter.

As current objectives differ from those strived for in the 1940s, contemporary restoration plans recommend mechanical treatments that use strips on the order of 4-8 m; no more that 20% of the sage-grouse breeding habitat should be treated at any one time

(Connelly et al. 2000). Connelly et al. (2000) advocate retaining relatively high densities of shrub-canopy cover. While older treatments often included seeding with non-native grasses favorable to cattle, any necessary seeding today should be conducted with native grasses and forbs (Northeast Wyoming Sage-Grouse Working Group 2004). Recommended seed mixes include a variety of shrubs, succulent-leaved forbs and taller, cool season grasses. In order to facilitate the most improved herbaceous response, soil treatments which result in minimal soil disturbance have been advocated; modification should only be enough to create moisture retention and storage capabilities (Rauzi 1975).

Olson and Whitson (2002) noted the importance of considering the potential impacts of annual grasses, including field brome (*Bromus arvensis* L.) and cheatgrass (*Bromus tectorum* L.) when planning restoration projects. As these grasses can readily colonize newly disturbed sites, their competitive advantage over native grasses and forbs for a given site should be weighed (Olson and Whitson 2002). Hedrick et al. (1966) commented on the increase in cheatgrass and the decrease in forbs on mechanically and chemically treated sagebrush communities in early seral ecological condition.

Prescribed fire/wildland fire treatments

Since the 1980s, prescribed fire has become a popular tool for sagebrush removal (Bunting et al. 1987). The rise in the use of fire as a management tool has been ascribed to the restriction in use of 2,4-D on public lands (Connelly et al. 2000). Like other treatment methods, the effects of prescribed fire are largely dependent on environmental factors and individual subspecies response. As noted by Bunting et al. (1987), different sagebrush subspecies have very diverse responses to fire; restoration goals should take these unique interactions into consideration.

Wyoming big sagebrush stands are often difficult to treat with prescribed fire due to the paucity of fine fuels in these areas (Bunting et al. 1987). Furthermore, fire spread is often limited due to relatively low cover of sagebrush. Lower fuel loading is attributed to the aridity of the regions in which Wyoming big sagebrush grows; these areas typically receive 18-30 cm precipitation per year (Wrobleski and Kauffman 2003). Accordingly, Wyoming big sagebrush communities experience the longest fire-return intervals of all of the big sagebrush species. The fire-return interval has been estimated between to be between 32-100 years; however, Wright and Bailey (1982) believe that 100 years may signify the lower end of fire frequency within these xeric communities.

After examining fire-scar and recovery evidence, Baker (2006) estimated that the fire rotation for Wyoming big sagebrush is between 100 and 240 years. Fire rotation, defined as the time it takes for fire to burn an entire landscape, is calculated by summing the areas of individual fires on a landscape and dividing the time period by the fraction of the landscape burned (Baker and Ehle 2001). Thus the landscape fire rotations are usually much greater than fire frequency estimates for selected landscape areas. Fire rotation calculations are often considered controversial due to differences in the spatial and temporal scales used for analysis (Morgan et al. 2001).

Wyoming big sagebrush establishes from seed post-fire, however, recurrent fire may eliminate viable seed (Bunting et al. 1987). Fire neither inhibits nor stimulates germination of soil-stored seed (Wyoming Interagency Vegetation Committee 2002). Post-fire recovery in Wyoming big sagebrush communities is often slower than that observed in other big sagebrush subspecies communities; post-fire species diversity increases are also comparatively limited (Bunting et al. 1987). As Wyoming big sagebrush is a mid- to late-seral species, re-establishment post-fire may take upwards of 30 years (Wambolt et al. 2001). Baker (2006) suggests that full recovery may take between 50-120 years.

Wambolt and Payne (1986, p. 315) found that prescribed fire resulted in "essentially no re-establishment" of Wyoming big sagebrush 6 years after burning, despite the availability of seed from nearby shrubs. This treatment did result in increases in bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), Sandberg bluegrass (*Poa secunda* J. Presl), total perennial grasses and total vegetal production. In a comparison of 4 different sagebrush treatments, Watts and Wambolt (1996) also found that burning has the longest impact on Wyoming big sagebrush re-establishment; however, sagebrush growth did return to rates not statistically significantly different from the control plots after 30 years.

Cheatgrass has become a dominate component of Wyoming big sagebrush communities throughout western Idaho, northern Nevada, and Oregon (Bunting et al. 1987). Cheatgrass increases the probability of fire in these ecosystems; historically long fire-return intervals have been shortened to less than ten years in some affected communities (Miller 2002). As a result, sagebrush and native grass species are often eliminated. Over 50% of the native sagebrush steppe has been converted to annual grasslands (Knick 2002). Fires that typically burned in a mosaic pattern now leave little area untouched with few areas remaining post-fire to provide seed for sagebrush, grass, and forb reestablishment (Miller and Eddleman 2001). Bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey) may be the only native perennial bunchgrass species to increase in areas affected by cheatgrass (Bunting et al. 1987). An increase in rabbitbrush (*Chrysothamnus* Nutt. spp.) in Wyoming big sagebrush communities exposed to repeated fire may also occur (Harniss and Murray 1973; Bunting et al. 1987).

Wambolt et al. (2001) stated that empirical evidence supporting the positive effects of fire on sage-grouse habitat is lacking. These authors believe that both short and long-term fire effects are detrimental to sage-grouse habitat requirements as a result of security cover and productivity loss. Harniss and Murray (1973), however, noted the improvement of forage yields given appropriate prescribed fire planning. Burn plots, for example, may need to be partially or fully rested from grazing up to two growing seasons to promote understory growth (Bunting et al. 1987). Subsequent vegetation treatments may also need to be halted for up to 30 years, to assure adequate sagebrush re-establishment. Consideration must be given to a multitude of factors when using prescribed fire as a restoration tool (Bunting et al. 1987; Miller 2002).

Synergistic effects of grazing

Consideration of the synergistic effects of grazing and sagebrush treatment is important since restoration activities on most public lands are unlikely to occur without some level of grazing (S. Schulz, Rangeland Management Specialist, personal communications, October 2007). At the community level, heavy grazing can lead to an increase in the density and cover of shrubs and annual grasses and forbs (Miller and Eddleman 1969). Perennial species, especially forbs, typically decline due to grazing (Vale 1974). The biomass and health of grasses and sedges may also be affected (Vale 1974; Baker 2006). Loeser et al. (2007), reported that high intensity grazing (average grazing event of 200 cow-calf pairs/ha/year for approximately 12 hours) led to a decline in perennial forb cover and an increase in annual plants, especially cheatgrass. A twofold increase in non-native plant cover was found at highly impacted sites following a severe drought. Increased canopy cover of sagebrush and rabbitbrush have been attributed to repeated heavy grazing (Peters and

Bunting 1994). Frischknect and Bleak (1957) found that young sagebrush far outnumbered their older counterparts where grazing use had been consistently heavy.

Heavy fall grazing may push a site more towards a perennial grass/ forb community, while heavy spring and summer use may move a site towards a community more dominated by shrubs, trees, and annual and noxious weeds (Wyoming Interagency Vegetation Committee 2002). Laycock (1967) found that heavy spring grazing caused an increase in sagebrush and cheatgrass; perennial grasses and forbs concomitantly decreased. The decline in perennial grasses and forbs could be attributed to the fact that these species were grazed during their active stages of growth (Laycock 1967). Clearly, species and community responses to grazing may be greatly influenced by climatic fluctuations and/or other landscape scale disturbances (Wyoming Interagency Vegetation Committee 2002; Loeser et al. 2007).

VEGETATION TREATMENTS IN WESTERN WYOMING

This study focused on Wyoming big sagebrush improvement efforts underway in the Upper Green River Basin of the Wyoming Basin in west-central Wyoming. According to winter range vegetation transects conducted by the Bureau of Land Management (BLM) in 1994, the sagebrush community on the Pinedale Mesa lacks age-class diversity, with a large percentage of the sagebrush classified as older, mature or decadent; few young sagebrush plants are present (USDI 2005). The last ecological condition inventory, which was conducted in the mid-1980s determined that over 96% of the area surveyed was in late or mid-seral stage (USDI 2007). The median canopy cover of sagebrush was reported at 21%.

While herbicide treatments were preferred in the 1960s and 1970s, various vegetation manipulations have been conducted around the region since the 1980s (USDI 2007). Prescribed fire is currently the most commonly employed vegetation treatment method. Over 6,500 ha within the Pinedale Anticline Project Area have been treated with herbicide, mechanical methods or prescribed fire since 1988; treatments were often conducted with the goal of improving livestock forage and big game winter habitat (USDI 2007).

In an attempt to offset sagebrush steppe habitat losses incurred during natural gas development, Questar Exploration and Production, one of the primary companies working on the Pinedale Mesa, has been investigating methods of improving existing sagebrush habitat for a number of sagebrush-obligate species including yearlong-greater sage-grouse and wintering mule deer. In addition to providing crucial greater sage-grouse habitat, the area is considered crucial winter range for mule deer, and pronghorn use the Pinedale Mesa throughout much of the year. Crucial winter range is defined as the portion of winter range to which a species is confined during periods of heaviest snow cover (USDI 2007). Numerous other animal species, including pygmy rabbits, badger (*Taxidea taxus*), white-tailed prairie dogs (*Cynomys leucurus*), red fox (*Vulpes vulpes*), coyotes (*Canis latrans*) and a variety of raptor species, are also found on the Pinedale Mesa as well (USDI 2005).

STUDY OBJECTIVES

This study was designed to determine how vegetation treatments affect shrub and herbaceous vegetation characteristics over time. Treatment areas were examined with the following objectives in mind:

- Determine the change in sagebrush cover, density, age-class distribution, and biomass (kg/ha) resulting from each treatment.
- Determine the change in cover of other shrubs after treatment.
- Quantify changes in grass and forb cover and biomass (kg/ha) resulting from each treatment.
- Determine how treatments affected species richness and diversity.

MATERIALS AND METHODS

Study area

The Pinedale Mesa is situated between the Green and New Fork Rivers, south of the town of Pinedale in west-central Wyoming (Fig. 1). The Pinedale Mesa is relatively flat with an elevation of 2,250 m. The Pinedale Mesa encompasses approximately 31,000 ha (USDI 2005). The BLM administers the majority of this area with 30,472 ha under its direction. The State of Wyoming manages 315 ha and an additional 647 ha are privately owned. The Pinedale Mesa is part of the larger Pinedale Anticline Project Area (PAPA), which consists of over 80,000 ha (USDI 2005). Over 600 producing oil and gas wells are currently located within the PAPA boundary.

The region is semi-arid and continental with short, dry summers and long, cold winters. July and August are the hottest months of the year, with December and January being the coldest (Western Regional Climate Center 2007). The January mean temperature is -10.8º C while the mean temperature in July is 15.5º C (Fig. 2). Maximum temperatures, averaged by water year (October - September), have typically been above the 30 year average. Annual precipitation averaged 26.9 cm over the 30 water-year period from 1970-71 through 1999-2000 (USDI 2007). Snowfall averages 147 cm from October to April. Precipitation was consistently below the 30 year average from 2000-2003, indicating drought conditions; however, 2004 and 2005 saw precipitation values above the 30 year average (Fig. 3) (Western Regional Climate Center 2007). Data were compiled from the Pinedale National Weather Service (NWS) Cooperative located at the Pinedale airport.

The project area is dominated by Wyoming big sagebrush. Other shrubs, found in lower densities include: early sage (*Artemisia arbuscula* spp. *longiloba* (Osterh.) L.M. Shulz), yellow rabbitbrush (*Chryosothamnus viscidiflorus* (Hook.) Nutt.), and antelope bitterbrush (*Purshia tridentata* (Pursh) DC).

Grasses found within the project area include: thickspike wheatgrass (*Elymus lanceolatus* Gould), Sandberg bluegrass, bottlebrush squirreltail, western wheatgrass, Letterman's needlegrass (*Achnatherum lettermanii* (Vasey) Barkworth), Indian rice grass (*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barrkworth), and prairie junegrass (*Koeleria macrantha* (Ledeb) J.A. Schultes). Forb species include: pussytoes (*Antennaria* Gaertn. spp.) milkvetch (*Astragalus* L. spp.), phlox (*Phlox* L. spp.), clover (*Trifolium* L. spp.), buckwheat (*Eriogonum* Michx. spp.) and desert yellow fleabane (*Erigeron linearis* (Hook.) Piper).

Within the project area, terrace soils can be found. These soils are nearly level, typically deep and extremely gravely or cobbly sub soils exist in certain locations. Quartzite cobbles, ranging from 10-40 cm in diameter, can be found in numerous locations on the Pinedale Anticline (USDI 2005).

Plot location

During the summer of 2006, ten, 12-ha plots were established on the Pinedale Mesa as study sites (Fig. 1). Plot locations were chosen with the assistance of employees from Questar Exploration and Production to avoid placement within areas of future development. Care was taken to locate plots in areas that were homogeneous. Given the uniform topography of the Pinedale Mesa, differences in aspect and slope were easily minimized. Some plots investigated during initial project planning by the BLM in 2005 were moved due to expected development plans.

Vegetation monitoring was conducted before and after the implementation of the treatments. Pre-treatment monitoring was conducted during July and August of 2006. Post-treatment monitoring commenced during May of 2007. Four permanent, 60-m transects were randomly established in each plot. These transects were marked with rebar stakes and UTM coordinates were taken with a Garmin GPS unit at each start and end point (Appendix A). Each plot had two, approximately 3-ha subplots available for grazing and two, 3-ha subplots where grazing was excluded (Appendix A). Digital photos were taken from each start point (Appendix B). Slope, aspect, and elevation were recorded.

Treatments

Ten different treatments were implemented at the study sites. These treatments included: light tebuthiuron (Spike 20P) treatment, heavy tebuthiuron (Spike 20P) treatment, Dixie harrow, one-way chaining, Lawson aerator, low mowing (10 cm), medium mowing with forb seeding (15 cm), high mowing (35 cm), and prescribed burning. One site served as a control. To exclude grazing from half of each site, every site was subdivided, prior to summer grazing, with electric fencing. Treatments were assigned randomly to plots; however, a ground disruptive treatment was later assigned to another plot as the randomly chosen site had known sage-grouse nesting areas. Although each treatment was implemented at two paired plots, the lack of treatment replication at different sites indicates pseudoreplication as detailed by Hurlbert (1984).

Approximately 11 kg of forb seed was distributed after the medium mowing treatment. The two forbs chosen for planting were: Rocky Mountain penstemon – Bandera (*Penstemon strictus* Benth) and Munro globemallow (*Sphaeralcea munroa* (Dougl.ex Lindl.) Spach ex Gray). Equal parts of each forb were included in the seed mixture. The light Spike plot was treated with Spike 20P at a rate of ~0.9 kg a.i./ha; the heavy Spike plot was treated with ~1.9 kg a.i./ha.

Treatments occurred during the late summer/early fall of 2006. Responsibility for treatment implementation was divided among contributing agencies. BLM employees completed the mowing and prescribed fire treatments while the Wyoming Game and Fish was responsible for treating the Lawson aerator and Dixie harrow plots. The Frontier Company applied the light and heavy tebuthiuron (Spike 20P) treatments. Questar provided the Ely chain and heavy equipment operators. Pre and post-treatment photos at each treatment are provided in Appendix B.

Grazing treatments were subject to cattle drift across the Pinedale Anticline. Approximately 5,000-7,000 cattle are moved across the Anticline each year (USDI 2007). Cattle move north to U.S. Forest Service land at the end of June; return across the Anticline occurs in October. Most livestock use is limited to less than two months a year. As a number of travel routes and water sources are available to stock, there is considerable variability in stock movement from one year to the next.

Vegetation measurements

To assess canopy cover of forbs, grasses, and shrubs the canopy cover class method (Daubenmire 1959) was used. Measurements were taken within each of 20 50 x 50-cm quadrats placed at the 3-m mark and every 3 m thereafter along each 60-m randomly located and oriented line transect. The quadrats were laid to the right of the transect line. All species and ground cover were estimated using cover class categories. The cover classes were defined as: class 1=<1%, 2=1-5%, 3=5-10%, 4=10-25%, 5=25-50%, 6=50-75%, 7=>75%, 8=100%. Any species falling within or hanging over the frame was recorded. Ground cover estimations included the percent cover of litter, rock, and cryptogams. Mosses and lichen were included within the cryptogam category. Bare ground was recorded separately. Average herbaceous height was also measured and recorded for each quadrat.

Cover class midpoints were established to accurately determine the percent cover of each species per transect. Midpoint values are as follows: class 1=0.5%, 2=3%, 3=7.5%, 4=17.5%, 5=37.5%, 6=62.5%, 7=87.5%. Individual cover class values for each species were totaled for each transect. These values for each category were subsequently multiplied by their respective mid-point value. The resulting numbers were averaged to give the percent cover per species and growth form per transect.

Plant specimens were identified, collected, pressed, and stored at the University of Idaho. Nomenclature follows the USDA Plants Database accessed in January 2007 (USDA, NRCS 2008). Plant specimens that were unidentifiable in the field were collected and analyzed at the University of Idaho Stillinger Herbarium. While over 1/3 of the forb species encountered could not be identified to species due to phenological stage or missing flower parts, these species were not often encountered and therefore contributed minimally to total forb cover values.

The line intercept method (Canfield 1941) was also used to estimate canopy cover of sagebrush. The length of all sagebrush touching or falling directly below the 60-m tape was measured. Gaps less than 10 cm were included. If a gap exceeded 10 cm, measurement resumed at the location of the next shrub. Dead shrubs were not measured.

Belt density measurements were taken to estimate sagebrush density. All sagebrush within a 1 m belt to the left of the 60 m transect were counted. Only those sagebrush plants rooted within the belt were counted. Sagebrush height and age classification were also recorded for each plant. Four sagebrush age classes, young, mature, decadent, and dead, were recorded. Young sagebrush were defined as those having basal stems less than 0.6 cm in diameter with simple branching on elongate growth. Mature sagebrush were defined as those plants having complex branching, with more than half of the crown comprised of living wood. The crowns of decadent sagebrush, on the other hand, were more than half dead. Dead plants were classified as those plants showing no sign of living tissue.

To estimate biomass production, five production clippings were taken pre- and post-treatment at 12-m spacing along the transect lines. Pre-and post-treatment clippings were taken in July in order to sample during peak productivity. All vegetation within the quadrat was clipped. The frame was placed 1 m to the right of the transect line. In order to not resample the same area in consecutive years, 1-m was added in each subsequent sampling year. Sagebrush, grass and forb species were collected and bagged separately in paper sacks. Specimens were dried in a fuels oven at 78º C for 24 hours and weighed with an Ohaus 200 digital scale.

Statistical analyses

A two-way analysis of variance (ANOVA) for a completely randomized factorial design was used to analyze data; SAS statistical software (SAS Institute 2004) was used. The two factors included in analyses were treatment and grazing. Due to the presence of zeros, species with inconsistent presence in the plots were aggregated together by growth form. Species with consistent representation were analyzed separately. To account for possible heterogeneity between plots, ANOVA was conducted on the difference between response variables for the two years of data collection. These differences were examined for normality using the PROC UNIVARAITE command of SAS. As outliers existed, data were subsequently examined using a non-parametric, two-way ranked analysis of variance (RANOVA) (Abebe et al. 2001; Crimin et al. 2007).

While similar significance results for ANOVA and RANOVA were reported for the majority of variables, some discrepancies existed. RANOVA results took precedence over ANOVA results in these instances and these variables were subsequently analyzed with RANOVA procedures.

Pairwise differences for variables affected by grazing or grazing by treatment interaction ($P < 0.1$) were reported using Fisher's Protected LSD when RANOVA was employed; Tukey's multiple comparison procedure was used with ANOVA.

Models for response variables that were shown to be unaffected by grazing or grazing by treatment interaction were simplified to a one-way ANOVA or RANOVA for a completely randomized design. RANOVA results again took precedence. Treatment effect was considered significant at an alpha level of 0.05. Tukey's multiple comparison procedure was used to report pair-wise differences for both RANOVA and ANOVA approaches.

Appendix C provides a summary of probability values from PROC GLM and RANOVA for all parameters. The decision to perform a one-way ANOVA using combined data was determined from these data.

RESULTS AND DISCUSSION

Seasonality of sampling and year-to-year differences were thought to have played a considerable role in recorded changes in species cover, biomass and diversity. Pre-treatment data were collected in July and August after many species, especially forbs, had cured out.

Post-treatment data, on the other hand, were collected in early June when most forb species were at their peak production. Differences in methodology and observers were also thought to have contributed to inconsistencies in data reporting.

Sagebrush characteristics

Using the line intercept method, sagebrush cover significantly differed by treatment ($P < 0.0001$) (Appendix C). Cover decreased, on average, from 14.6% cover pre-treatment to 8.7% cover post-treatment (Table 1). As noted by Wambolt and Payne (1986), the line intercept method typically results in lower cover values than those obtained by the cover class method. All treatments, except for the control and the light Spike treatments resulted in a decrease in sagebrush cover. The low mow treatment substantially reduced sagebrush cover from a pre-treatment mean of 11.4% to a post-treatment mean of 1.3%. The medium mow treatment also greatly reduced sagebrush cover from a pre-treatment mean of 17.0% to a post-treatment mean of 3.9%. The high mow treatment had less of an impact on sagebrush cover than other mechanical treatments.

Sagebrush cover examined using the canopy cover class method declined by a mean of 19.1% cover pre-treatment to a mean of 10.9% cover post-treatment (Table 1). Cover was significantly different by treatment ($P = 0.0039$) (Appendix C). Using this method of cover estimation, the low mow treatment again resulted in the greatest reduction of sagebrush cover. Cover decreased from a mean of 17.4% pre-treatment to a mean of 2.8% post-treatment. The aerator and prescribed fire treatments also resulted in considerable reductions in sagebrush cover. The aerator reduced sagebrush cover from a pre-treatment mean of 21.4% to a post-treatment mean of 7.5%. The prescribed fire treatment reduced sagebrush cover from a pre-treatment mean of 28.3% to a post-treatment mean of 10.3%. As reported by Wambolt and Payne (1986), prescribed fire treatments have the ability to destroy or severely deplete stands of Wyoming big sagebrush. While some areas of high mortality were evidenced in our study, it should be noted that due to weather conditions and the patchy distribution of fuels, the fire burned in a mosaic pattern leaving many unburned or partially burned islands of sagebrush throughout the study site.

As Wyoming big sagebrush may not be adversely affected by tebuthiuron until the second or third season following herbicide application, changes in cover on the chemically treated plots may not yet be fully realized (Olson and Whitson 2002; McDaniel et al. 2005).

Sagebrush height declined with respect to the control due to treatments except the high mow (Table 2) and differed significantly between treatments ($P < 0.0001$) (Appendix C). Sagebrush height was most affected by the low and medium mowing treatments. The low mow treatment decreased sagebrush height from a pre-treatment mean height of 26.9 cm to a post-treatment mean height of 9.1cm. The medium mow treatment decreased sagebrush height from a mean pre-treatment height of 24.6cm to a mean post-treatment height of 15.0 cm.

Decreases were seen across all treatments in the density of decadent sagebrush; no decadent sagebrush were counted after treatment on seven plots (Table 3). Low densities of decadent sagebrush remained on the Dixie harrow and high mow treatment sites; density also declined from a mean of 145.8 sagebrush per 1/10 ha to a mean of 129.2 sagebrush per 1/10 ha on the control site. While treatment effect was not significant, density was significantly affected by grazing ($P = 0.0146$) (Appendix C).

Declines in mature sagebrush densities were seen on the chaining, low mow, and prescribed fire sites. Mature sagebrush densities increased on the remaining plots, including the control. Treatment effect was significant at $P = 0.0172$ (Appendix C). The increase in number of mature sagebrush was attributed, in part, to the nature in which many sagebrush plants were affected by the various mechanical treatments. What may have been counted as one sagebrush plant pre-treatment appeared as several separate plants post-treatment due to stem disturbance. Although severely impacted, many chemically treated sagebrush retained some foliage and were therefore counted as mature sagebrush in density tallies. Observer differences may have also contributed to these increase densities.

Young sagebrush densities, which differed significantly by treatment ($P = 0.0002$) (Appendix C), decreased on all plots except for those treated with the Dixie harrow, chaining, high mow, and control (Table 3). The light Spike treatment resulted in the greatest decrease in young sagebrush. The mean pre-treatment density of young sagebrush on the light Spike site was 625.0 plants per 1/10 ha; the mean post-treatment density of young sagebrush was 266.7 plants per 1/10 ha.

Dead sagebrush densities differed significantly by treatment ($P < 0.0001$; Appendix C). The low mow treatment resulted in the greatest reduction of dead sagebrush (154.2 per 1/10 ha to 4.2 per 1/10 ha) (Table 3). The density of dead sagebrush increased on the chaining, high mow, aerator, prescribed fire, and light and heavy Spike treatment plots. The light Spike treatment resulted in the greatest increases in dead sagebrush densities. Dead sagebrush increased from a mean of 50.0 per 1/10 ha pre-treatment to a mean of 358.3 per 1/10 ha post-treatment.

Based on total sagebrush counts, age class distribution did not fluctuate greatly post-treatment across all treatments. Decadent sagebrush decreased 4.7% while young sagebrush decreased 3.3%. Mature sagebrush counts increased 4.4% and dead sagebrush counts increased 3.6%.

Attributed to differences in sampling methodology and year-to-year differences, sagebrush biomass increased on all plots except for those treated with low mow and heavy Spike (Table 4). The greatest increase was seen on the high mow plot. Mean sagebrush biomass increased from 38.0 kg/ha pre-treatment to a mean of 211.6 kg/ha post-treatment. On the control site mean pre-treatment biomass increased from a mean of 39.6 kg/ha to a mean of 104.0 kg/ha post-treatment. Treatment effect was significant at $P = 0.0037$ (Appendix C).

Rabbitbrush was the only other shrub analyzed separately; all other shrubs were present in quantities insufficient for analyses. Rabbitbrush cover increased on all plots; a treatment by grazing interaction was detected ($P = 0.0893$) (Appendix C). Greatest increases were observed on the plot treated with chaining; cover rose from a mean of 2.7% pre-treatment to a mean of 6.0% post-treatment (Table 1). Microsites created by small slash loading left from chaining debris may have proven beneficial to the establishment of rabbitbrush.

Herbaceous species characteristics

Grasses

A total of seven grass species were recorded, however, due to low cover values, two species, Indian ricegrass and western wheatgrass, were only analyzed as part of total grass cover. Predominant grass species were examined separately. Appendices D and E provide mean pre and post-treatment cover (mean ± se) values for all herbaceous species.

Mean total grass cover differed significantly by treatment ($P = 0.0010$) (Appendix C). Average total grass cover increased on all plots except for those treated with high mow and aerator (Table 5). The aerator treatment resulted in the highest decrease in total grass cover

(21.41% to 15.73%) while the Dixie harrow resulted in the highest total grass cover increase (11.02% to 19.41%). An increase was also observed on the control site (14.08% to 19.14%).

Changes in plot cover values for Letterman's needlegrass followed the same pattern as that observed for total grass cover; treatment effect was significant (P = 0.0033) (Appendix C). Declines were observed on the high mow and aerator plots; cover values increased on all other plots with the highest increase (0.23% to 4.59%) observed on the Dixie harrow plot (Table 5).

Bottlebrush squirreltail cover values decreased slightly on the light Spike (2.89% to 2.22%) and aerator (1.33% to 0.83%) treatment sites; however, increases were seen on the remaining plots, with the low mow treatment resulting in the highest cover increase (1.25% to 2.72%) (Table 5). In a sagebrush control study in central Oregon, Hedrick et al. (1966) reported that bottlebrush squirreltail yields increased 100 times more on chemically and rotobeaten plots than on control plots for the first four years post-treatment. While a slight increase in bottlebrush squirreltail was observed on the heavy Spike plot, herbaceous response may be delayed several seasons (Olson and Whitson 2002). As cover did not significantly differ between treatments in our study, changes were attributed to a year-to-year effect.

Bluebunch wheatgrass increased slightly on plots treated with heavy Spike, medium mow, the Dixie harrow, and chaining (Table 5). A slight increase was also observed on the control site (1.96% to 2.14%). The low mow and prescribed fire treatments resulted in lower cover values of bluebunch wheatgrass. While running counter to the results of our study, bluebunch wheatgrass has been found to recover easily post-fire (Bunting et al. 1987). Treatment effect was significant (P = 0.0382); however, as a treatment by grazing interaction was observed (P = 0.0428), the ability to draw conclusions about treatment effect is limited (Appendix C).

Highest declines in Sandberg bluegrass cover values were observed on the aerator plot; low and high mow and light Spike treatments also resulted in slight decreases (Table 5). Increases were seen on all other plots. A significant treatment effect was observed (P = 0.0027) (Appendix C). While not observed in this study, Sandberg bluegrass is often negatively affected immediately post-fire; however, this species is able to reproduce from seed in subsequent post-fire years (Bunting et al. 1987).

Chaining and high mow treatments resulted in small declines in thickspike wheatgrass (*Elymus lanceolatus* Gould); increases in cover were seen on the remaining plots. The largest increase in cover (2.43% to 4.74%) was observed on the prescribed fire plot. A grazing by treatment effect was detected (P = 0.0626) (Appendix C).

The increase in all grass species except for bluebunch wheatgrass post-fire may be due, in part, to time of year in which post-treatment monitoring was conducted. Typically, grass species in xeric Wyoming big sagebrush communities are more sensitive to fire than their more mesic counterparts (Bunting et al. 1987). Wambolt et al. (2001) reported no short or long-term benefits to grasses from prescribed fire operations.

Despite increases in total grass cover on all plots save those treated with high mow and the aerator, grass biomass declined across all treatments except the control and the light Spike treatments (Table 4). The greatest decline in grass biomass was observed on the Dixie harrow site (217.8 kg/ha to 69.2 kg/ha).

Forbs

Although over 25 forb species were recorded over the two years of study, inconsistencies in presence on plots limited individual species analysis to three species. All other forbs were included as part of the total forb cover value. Total forb cover values increased post-treatment (Table 6). A significant difference (P = 0.0134) was found between treatments for total forb cover; however, no significant differences were found between treatments for individual species analyses (Appendix C). The two forbs seeded on the medium mow site were not detected post-treatment.

Total forb cover increased from a mean of 6.59% pre-treatment to a mean of 16.52% post-treatment as a result of the prescribed fire treatment; however, given the increase in forb cover on the control plot (6.89% to 12.46%), increases may be attributed to the timing at which post-treatment vegetation monitoring was conducted. Slight increases in spring precipitation in 2007 likely contributed to increased forb cover as well (Figure 3). Forb diversity is typically limited in Wyoming big sagebrush habitats; fire disturbance typically does little to increase the forb component in these communities (Bunting et al. 1987). Fisher et al. (1996) reported no significant increase in forb abundance following prescribed fire in Wyoming big sagebrush plots in southeastern Idaho. Similarly, Wambolt et al. (2001) reported no definitive short or long-term improvements in forb production post-fire.

Nonetheless, fire may enhance the growth of forbs in some areas (Wrobleski and Kauffman 2003). As it takes time for sagebrush to return post-fire, understory species may benefit from resultant increases in sunlight, water and nutrients. Wrobleski and Kauffman (2003) found morphological and phenological changes in several forb species following prescribed fire in Wyoming big sagebrush plots in southeastern Oregon. Morphological changes observed included the production of a higher number of racemes and flowers in many forb species. Phenological changes noted included the extension of active growth later in to the summer; furthermore, two species were observed to have flowered nearly two weeks earlier.

Although total forb cover increased on the light and heavy Spike sites, respectively, this trend should be considered in light of seasonal moisture fluctuations (Hedrick et al. 1966). Klebenow (1970) noted that that sprayed areas showed a decrease in forb abundance although there was an increase in common dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers) and common salsify (*Tragopogon dubius* Scop.), two plants important to sage-grouse. While these two specific forbs were not encountered in this study, relatively high cover of other forbs palatable to sage-grouse such as Desert yellow fleabane (*Erigeron linearis* (Hook.) Piper), spiny phlox (*Phlox hoodii* Richards) and clover (*Trifolium andium* Nutt. var. *andinum*) was found on the plot treated with heavy Spike.

Desert yellow fleabane values fluctuated slightly due to the different treatments (Table 6). The greatest decrease (6.36% to 4.79%) was recorded for the high mow site. The largest increase (1.52% to 2.41%) was observed on medium mow site. Granite prickly phlox (*Linanthus pungens* (Torr.) J.M. Porter & L.A. Johnson) cover changes also varied between plots; the greatest decrease in cover (4.57% to 2.38%) was recorded on the plot treated with the aerator (Table 6). The largest increase in cover was observed on the control plot (1.10% to 2.20%). Spiny phlox cover increased for all treatments (Table 6). Greatest increases were observed on the aerator and low mow treatment plots.

Forb biomass declines were observed on the chaining, low mow, and aerator treatment sites; biomass increases were observed on all other plots, with the greatest increase on the high mow plot (13.8 kg/ha to 61.0 kg/ha) (Table 4). A grazing by treatment interaction was detected ($P = 0.0871$) (Appendix C).

Herbaceous height

Except for the control treatment, herbaceous height, which included both grass and forb species, decreased due to treatments (Table 2). Treatments effect significantly differed (P = 0.0008); however, this must be considered in light of a grazing by treatment interaction (P = 0.0617) (Appendix C). The prescribed fire treatment resulted in the greatest decrease in herbaceous height (18.8 cm to 11.7 cm).

Ground cover

Total ground cover, which included litter, lichen, cryptogams, and rock, differed significantly by treatment effect at P = 0.0010 (Appendix C). Bare ground decline on all plots post-treatment (Table 7). Bare ground cover was not significantly different between treatments.

Species richness and diversity

Species richness and the Shannon-Wiener diversity index increased across all treatments from 2006 to 2007 (Table 2). Richness increased, on average, from 11 to 18. The greatest number of species (22) was recorded on the Dixie harrow plot. Treatment effect was found to be significantly different (P = 0.0178) (Appendix C). The Shannon-Wiener index was, on average, 0.5897 higher post-treatment; again the Dixie harrow plot had the highest value at 0.8280. Treatment effect was significant at (P = 0.0011). The Shannon-Wiener index was determined using the following equation:

$$H' = -\sum_{i=1}^{S} pi \ln pi$$

Appendix F details all recorded species for both years of study.

Grazing effect

Although few variables indicated a grazing or grazing by treatment effect (Appendix C), a measurable vegetation response due to grazing exclusion may take several years to express (Anderson and Holte 1981). Vegetation changes may be further hampered by aridity or on sites in an early seral state. Courtois et al. (2004) found few changes in vegetation on exclosed sites after 65 years; their work indicated that recovery since heavy repeated grazing is similar under both moderate grazing and the omission of grazing.

Some studies have indicated that grazing, not increased sagebrush canopy, may be responsible for a depleted herbaceous understory. Pearson (1965) reported perennial grass cover to be 17% higher on ungrazed plots than on their grazed counterparts. This herbaceous increase was found despite 23% higher sagebrush canopy cover on the ungrazed sites. Likewise, Anderson and Holte (1981) reported a 20-fold increase in perennial grass cover at a study site in which grazing had been excluded for 25 years. Sagebrush cover had concurrently increased 54% at the study site.

Management implications

This study was designed to examine long-term treatment effects on vegetation characteristics. As discernable changes in community composition take time to manifest, first year post-treatment data serve as a baseline upon which further vegetation changes can be gauged. As such, temporal influences on community response should be considered when determining the efficacy or applicability of a particular treatment. Continued monitoring is essential in the adequate assessment of treatment response. Post-treatment monitoring should continue for a minimum of 10 years (USDI 2006).

Given the lack of statistical significance of the treatment plots with respect to the control, emphasis should again be placed on the role of year-to-year variability and timing of data collection in recorded changes in grass and forb cover and diversity. Slight increases in spring precipitation may have also elicited a herbaceous response unrelated to management.

However, based on first year changes in sagebrush densities, cover and height, coupled with changes in herbaceous cover, height and diversity, the Dixie harrow and heavy Spike treatments may help to accomplish desirable community change. Prescribed fire treatments may also hold promise, provided that a mosaic burn pattern is achievable.

The seral state of the sagebrush community should be adequately assessed before the implementation of any vegetation treatments. Active restoration should not be undertaken without first identifying how treatments will act to ameliorate factors currently limiting vegetation response (Connelly et al. 2000). In areas where vegetation treatments have been determined an appropriate management action, those treatments which result in minimal vegetation community disturbance have been advocated. While certain treatments may result in increased herbaceous yields, the parallel loss of the sagebrush overstory may ultimately have a detrimental effect on community productivity and integrity. Due to the heterogenic habitat needs of many sagebrush obligates, treatments should be placed on the landscape such that adequate year-round habitat is provided.

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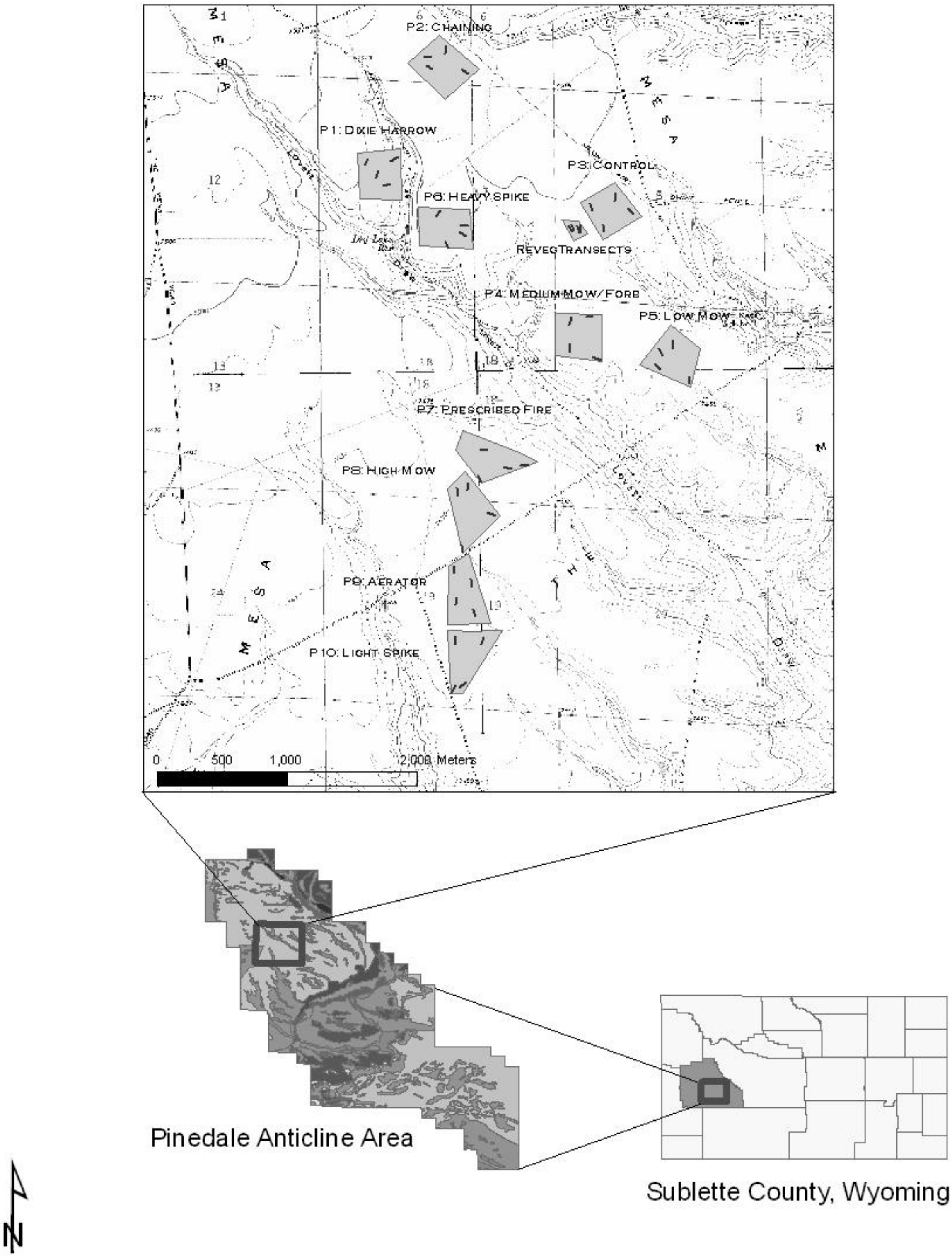

FIG. 1**.** Map of study plots and transects on the Pinedale Mesa, Sublette County, Wyoming.

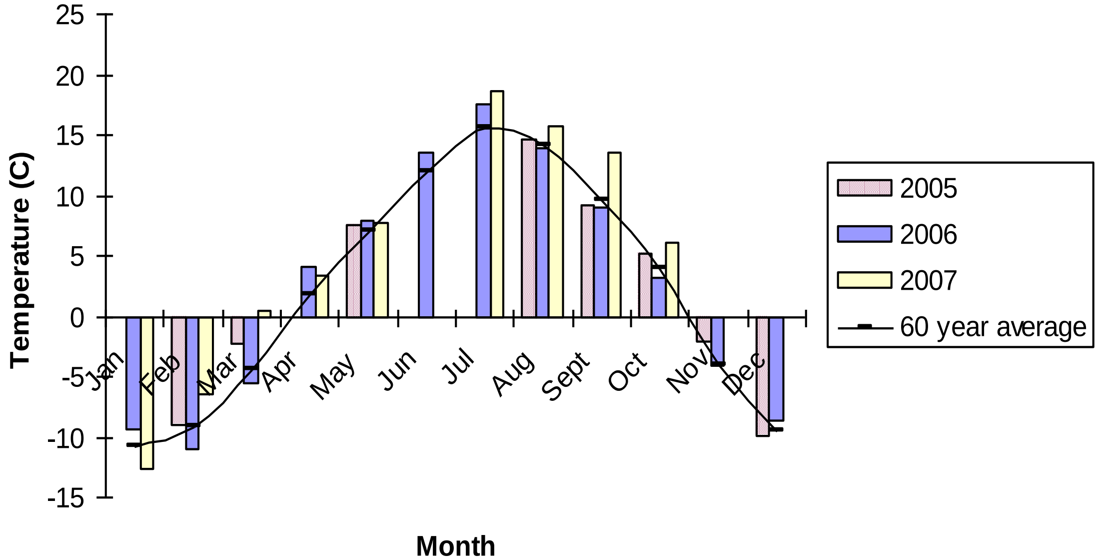

FIG. 2. Mean temperature by month between 2005 and 2007 compared to the 60 year average for a Wyoming big sagebrush community study near Pinedale, Wyoming. Missing bars denote a lack of available data. Data obtained from Western Regional Climate Center.

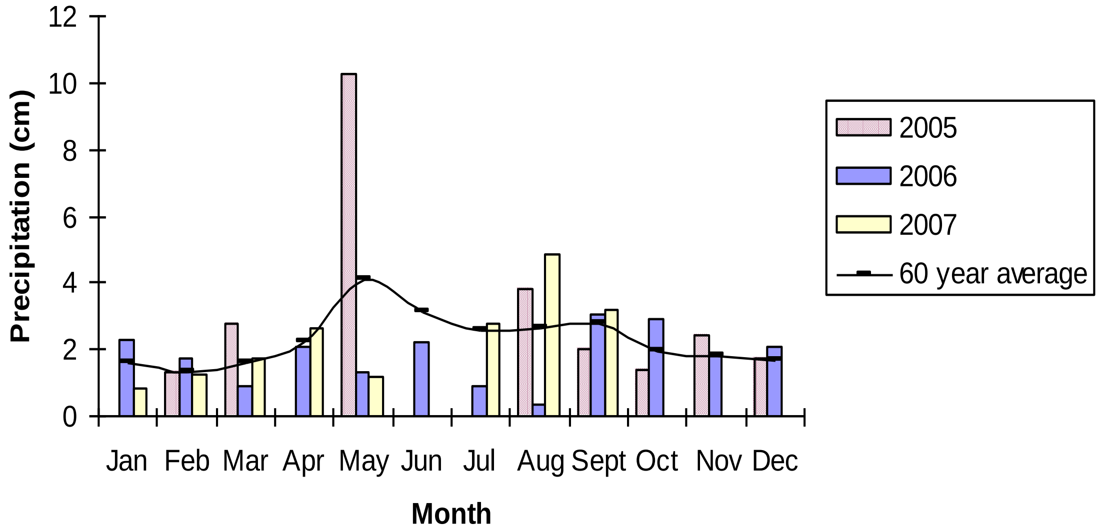

FIG. 3. Mean precipitation by month compared to the 60 year average for a Wyoming big sagebrush community study near Pinedale, Wyoming. Missing bars denote a lack of available data. Data obtained from Western Regional Climate Center.

TABLE 1. Sagebrush and rabbitbrush cover values (mean ±se) and mean differences (2007-2006) after vegetation treatments of a Wyoming big sagebrush community in western Wyoming.

	Artemisia tridentata ssp. *wyomingensis* (Cover Class)			*Artemisia tridentata* ssp. *wyomingensis* (Line Intercept) *			*Chrysothamnus viscidiflorus* (Cover Class)			Shrub Total		
	Cover (%)											
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	21.4 ± 2.0	19.2 ± 4.7	-2.2 a	17.5 ± 2.5	18.2 ± 3.3	0.7 ab	3.1 ± 0.8	3.5 ± 1.0	0.4 a	24.6 ± 1.7	22.8 ± 4.5	-1.9 ab
Heavy Spike	20.3 ± 0.8	11.7 ± 3.3	-8.5ab	15.7 ± 2.1	13.3 ± 1.6	-2.3 abc	2.5 ± 0.9	3.1 ± 1.0	0.7 a	23.1 ± 0.9	15.1 ± 3.6	-8.0 abc
Dixie Harrow	15.9± 1.3	8.9 ± 1.7	-7.0 ab	13.3 ± 1.1	6.8 ± 0.7	-6.5 abc	1.6 ± 0.9	1.74 ± 0.5	0.2 a	17.5 ± 1.1	11.5 ± 2.0	-6.0 abc
Chaining	9.6 ± 2.3	7.8± 1.9	-1.9 a	12.6 ± 0.3	7.1 ± 1.1	-5.5 abc	2.7 ± 0.6	6.0 ± 1.0	3.3 b	12.5 ± 1.9	14.0 ± 2.1	1.5 ab
Aerator	21.4 ± 2.4	7.5 ± 1.3	-13.9 ab	15.4 ± 0.3	5.7 ± 1.6	-9.7 c	2.7 ± 2.4	2.8 ± 0.5	0.2 a	24.1 ± 2.0	10.7 ± 1.2	-13.4 bc
Low Mow	17.4 ± 3.5	2.8 ± 0.2	-14.6 ab	11.4 ± 1.5	1.3 ± 0.4	-10.1 c	1.8 ± 0.6	2.8 ± 0.4	1.0 ab	19.2 ± 3.0	5.7 ± 0.3	-13.5bc
Med. Mow	17.8 ± 4.3	7.6 ± 2.9	-10.2 ab	17.0 ± 0.8	3.9 ± 1.0	-13.1 c	1.5 ± 0.4	2.6 ± 0.9	1.1 ab	19.4 ± 3.9	10.4 ± 2.4	-9.0 abc
High Mow	22.5 ± 5.1	16.0 ± 2.9	-6.5 ab	15.7 ± 1.4	9.5 ± 1.8	-6.2 abc	1.1± 0.5	1.7 ± 0.5	0.6 a	24.0 ± 5.2	18.2 ± 3.3	-5.8 abc
Prescribed Fire	28.3 ± 5.0	10.3 ± 2.6	-18.0 b	17.5 ± 1.7	8.5 ± 2.3	-9.0 c	2.5 ± 1.0	3.2 ± 0.5	0.7 a	31.2 ± 4.8	14.2 ± 2.3	-17.0 c
Control	16.9 ± 1.4	16.9 ± 1.9	0.0 a	10.2 ± 1.5	12.4 ± 1.5	2.2a	4.3 ± 1.4	6.5 ± 0.8	2.3 ab	21.2 ± 4.8	23.6 ± 1.8	2.5 a
Mean	19.1 ± 1.6	10.9 ± 1.6	-8.3	14.6 ± 0.8	8.7 ± 1.6	-6.0	2.4 ± 0.3	3.4 ± 0.5	1.0	21.7 ± 1.6	14.6 ± 1.8	-7.1

Within each column, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$). Line intercept values (*) were computed with RANOVA procedures.

TABLE 2. Sagebrush height, herbaceous height, species richness and Shannon-Wiener Index values (mean ± se) and mean differences (2007-2006) after vegetation treatments of a Wyoming big sagebrush community in western Wyoming.

	Sagebrush Height (cm)			Herbaceous Height (cm)			Species Richness*			Shannon-Wiener Index		
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	21.1 ± 0.3	18.3 ± 0.5	-2.8 abcd	16.1 ± 0.9	11.9 ± 0.5	-4.3 abc	8 ± 0.5	16 ± 1.1	8 b	1.591 ± 0.0	1.985 ± 0.1	0.394 bc
Heavy Spike	23.6 ± 1.8	22.0 ± 1.7	-1.6 abc	14.3 ± 0.8	12.0 ± 0.9	-2.3 abc	11 ± 0.6	17 ± 0.9	6 ab	1.687 ± 0.0	2.228 ± 0.1	0.542abc
Dixie Harrow	23.0 ± 3.6	17.2 ± 3.6	-5.7 abcd	17.6 ± 13.3	12.6 ± 1.2	-5.0 ab	12 ± 1.5	22 ± 1.0	11 a	1.595 ± 0.0	2.423 ± 0.0	0.828 a
Chaining	29.6 ± 0.6	22.8 ± 0.9	-6.9 bcd	13.3 ± 0.6	11.1 ± 0.3	-2.2 bc	12 ± 1.0	19 ± 0.6	7 ab	1.756 ± 0.1	2.296 ± 0.0	0.5393abc
Aerator	22.2 ± 0.8	15.0 ± 11	-7.3 cd	18.6 ± 1.5	12.7 ± 0.7	-6.8 ab	11 ± 1.0	20 ± 1.0	9 ab	1.686 ± 0.0	2.402 ± 0.1	0.7163abc
Low Mow	26.9 ± 1.5	9.1 ± 0.4	-17.7 e	17.9 ±0.7	12.9 ± 0.3	-5.0 ab	9 ± 0.5	19 ± 1.2	10 ab	1.682 ± 0.1	2.444 ± 0.0	0.7623 ab
Med. Mow	24.6 ± 2.1	15.0 ± 1.0	-9.6 d	17.6 ± 1.5	14.5 ± 0.9	-3.1 abc	11 ± 0.6	17 ± 0.9	6 ab	1.773 ± 0.1	2.312 ± 0.1	0.539 abc
High Mow	19.7 ± 0.9	19.8 ± 0.9	0.1 ab	15.7 ± 1.2	12.7 ± 0.7	-3.0 abc	12 ± 0.3	16 ± 0.8	5 ab	1.721 ± 0.1	2.039 ± 0.1	0.318 c
Prescribed Fire	27.8 ± 2.1	22.0 ± 2.4	-5.8 abcd	18.8 ± 0.7	11.7 ± 0.3	-7.1 a	12 ± 0.3	20 ± 1.4	8 ab	1.597 ± 0.1	2.418 ± 0.0	0.821 a
Control	24.3 ± 1.6	25.5 ± 2.1	1.2 a	13.5 ± 0.3	13.8 ± 0.7	0.2 c	11 ± 0.3	18 ± 0.6	7 ab	1.763 ± 0.1	2.200 ± 0.1	0.437 abc
Mean	24.3 ± 1.0	18.7 ± 1.5	-5.6	16.3 ± 0.7	12.5 ± 0.3	-3.9	11 ± 0.4	18 ± 0.6	8	1.685 ± 0.0	2.275 ± 0.1	.590

Within each column, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure (P < 0.05). Richness values (*) computed with one-way RANOVA procedures.

TABLE 3. Density values (mean ± se) by age class and mean differences (2007-2006) after vegetation treatments of a Wyoming big sagebrush community in western Wyoming.

	Decadent (1/10 ha)**			Mature (1/10 ha)*		
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	104.2 ± 22.9	0.0 ± 0.0	-104.2 bc	1358.3 ± 80.7	2479.2 ± 378.7	1120.8 a
Heavy Spike	62.5 ± 17.2	0.0 ± 0.0	-62.5 ab	1558.3 ± 167.4	1900 ± 212.2	341. 7 ab
Dixie Harrow	75.0 ± 22.0	8.3 ± 8.3	-66.7 ab	1520.8 ± 123.9	1862.5 ± 186.4	341.7 ab
Chaining	66.7 ± 18.0	0.0 ± 0.0	-66.7 abc	1270.8 ± 326.1	1200.0 ± 265.7	-70.8 ab
Aerator	108.3 ± 14.4	0.0 ± 0.0	-108.3 bc	1329.2 ± 170.8	1629.2 ± 130.2	300.0 ab
Low Mow	79.2 ± 37.5	0.0 ± 0.0	-79.2 bc	1162.5 ± 25.8	870.8 ± 105.3	-291.7 b
Med. Mow	129.2 ± 34.9	0.0± 0.0	-129.2 c	1462.5 ± 105.7	1545.8 ± 305.8	83.3 ab
High Mow	91.7 ± 21.0	20.8 ± 15.8	-70.8 ab	1254.2 ± 85.9	1412.5 ± 236.8	158.3 ab
Prescribed Fire	91.7 ± 24.1	0.0 ± 0.0	-91.7 bc	1454.2 ± 67.1	1070.8 ± 441.1	-383.3 b
Control	145.8 ± 18.5	129.2 ± 29.9	-16.7 a	1325.0 ± 101.0	2054.2 ± 169.6	729.2 ab
Mean	94.4 ± 8.5	15.8 ± 12.8	-79.6	1369.6 ± 40	1602.5 ± 154.5	232.9
	Young (1/10 ha)*			Dead (1/10 ha)*		
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	625.0 ± 161.9	266.7 ± 65.6	-358.3 b	50.0 ± 15.2	358.3 ± 232.8	308.3 ab
Heavy Spike	79.2 ± 21.9	58.6 ± 10.8	-20.8 a	87.5 ± 18.5	487.5 ± 272.6	400.0 ab
Dixie Harrow	45.8 ± 10.5	91.7 ± 19.8	45.8 a	108.3 ± 40.0	91.7 ± 38.8	-16.7 bcd
Chaining	50.0 ± 11.8	75.0 ± 14.4	25.0 a	95.8 ± 22.9	100.0 ± 15.2	4.2 bcd
Aerator	308.3 ± 92.4	166.7 ± 28.1	-141.7 ab	100.0 ± 22.6	183.3 ± 26.4	83.3 abc
Low Mow	179.2 ± 23.9	154.2 ± 35.6	-25.0 a	154.2 ± 32.2	4.2 ± 4.2	-150.0 cd
Med. Mow	87.5 ± 15.8	83.3 ± 13.6	-4.2 a	133.3 ± 32.6	37.5 ± 21.9	-95.8 d
High Mow	16.7 ± 9.6	70.8 ± 33.6	54.2 a	54.2 ± 4.2	100.0 ± 19.2	45.8 abcd
Prescribed Fire	83.3 ± 24.5	62.5 ± 23.9	-20.8 a	54.2 ± 14.2	283.3 ± 43.0	229.2 a
Control	133.3 ± 32.6	137.5 ± 38.1	4.2 a	104.2 ± 24.9	75.0 ± 25.9	-29.2 bcd
Mean	160.8 ± 58.0	116.7 ± 21.0	-44.2	94.2 ± 11.9	172.1 ± 49.4	77.9

Within each column, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$) (*) or Fisher's Protected LSD ($P < 0.05$) (**). The results for variable dead were computed using one-way RANOVA. Decadent results reflect a significant difference in grazing treatments.

TABLE 4. Vegetation biomass values (mean ± se) and mean differences in vegetation biomass (2007-2006) after vegetation treatments of a Wyoming big sagebrush community in western Wyoming.

	Grass biomass (kg/ha)			Forb biomass (kg/ha)			Sagebrush biomass (kg/ha)		
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	109.4 ± 23.6	157.7 ± 36.8	48.3	16.0 ± 9.3	55.2 ± 11.8	39.2	59.8 ± 19.1	228.9 ± 34.5	169.1 a
Heavy Spike	125.0 ± 35.8	69.7 ± 24.5	-55.3	0.0 ± 0.0	17.1 ± 10.0	17.0	106.8 ± 11.6	63.7 ± 38.8	-43.1 b
Dixie Harrow	217.8 ± 64.1	69.2 ± 13.4	-148.6	37.0 ± 22.7	40.7 ± 14.3	3.7	86.0 ± 18.9	102.1 ± 34.6	16.1 ab
Chaining	119.6 ± 32.8	33.3 ± 6.5	-86.3	28.4 ± 15.9	8.9 ± 3.5	-19.5	53.4 ± 23.4	97.6 ± 44.3	44.2 ab
Aerator	186.6 ± 25.3	130.7 ± 11.7	-55.9	47.8 ± 28.6	41.0 ± 8.1	-6.8	86.6 ± 12.4	138.6 ± 26.4	52.0 ab
Low Mow	166.8 ± 32.7	114.1 ± 12.3	-52.7	48.8 ± 28.2	33.3 ± 18.4	-15.5	70.8 ± 14.3	21.0 ± 9.5	-49.8 b
Med. Mow	221.0 ± 85.8	162.1 ± 19.4	-58.9	20.2 ± 20.2	56.5 ± 12.4	36.3	76.2 ± 22.7	180.9 ± 48.5	104.7 ab
High Mow	138.0 ± 13.4	111.0 ± 17.9	-27.0	13.8 ± 5.3	61.0 ± 10.2	47.2	38.0 ± 7.1	221.6 ± 71.4	173.6 a
Prescribed Fire	158.6 ± 19.6	110.8 ± 29.5	-47.8	22.2 ± 8.9	53.1 ± 19.4	30.9	84.8 ± 10.2	125.9 ± 37.7	41.1 ab
Control	147.6 ± 23.6	157.3 ± 38.8	9.7	3.6 ± 3.6	27.0 ± 10.5	23.4	39.6 ± 11.5	104.0 ± 8.3	64.4 ab
Mean	159.0 ± 12.4	111.6 ± 13.7	-47.4	23.8 ± 5.3	39.4 ± 5.6	15.6	70.2 ± 7.0	127.4 ± 20.5	57.2

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

TABLE 5. Grass cover values (mean ± se) and mean differences in cover of grasses (2007-2006) after vegetation treatments of a Wyoming big sagebrush community in western Wyoming.

	Achnatherum lettermanii *			*Elymus elymoides* *			*Elymus lanceolatus* **		
	Cover (%)								
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	0.89 ± 0.48	1.40 ± 0.83	0.51 ab	2.89 ± 0.71	2.22 ± 0.35	-0.68	3.38 ± 0.23	3.98 ± 0.58	0.60 ab
Heavy Spike	2.78 ± 1.32	2.82 ± 1.13	0.04 ab	0.08 ± 0.04	0.47 ± 0.12	0.39	2.61 ± 0.29	3.13 ± 0.01	0.52 ab
Dixie Harrow	0.23 ± 0.21	4.59 ± 1.78	4.37 a	0.30 ± 0.12	0.49 ± 0.12	0.19	3.30 ± 1.03	3.67 ± 0.50	0.37 b
Chaining	0.68 ± 0.48	3.28 ± 1.15	2.60 ab	0.02 ± 0.01	0.64 ± 0.27	0.63	4.59 ± 1.25	3.63 ± 0.32	-0.96 c
Aerator	5.85 ± 1.96	3.81 ± 1.00	-2.04 b	1.33 ± 0.51	0.83 ± 0.23	-0.50	2.78 ± 0.25	3.19 ± 0.81	0.41 ab
Low Mow	3.53 ± 0.52	4.77 ± 1.08	1.24 ab	1.25 ± 0.26	2.72 ± 0.87	1.47	1.97 ± 0.43	3.74 ± 0.39	1.77 ab
Med. Mow	2.03 ± 0.79	4.49 ± 2.17	2.46 ab	0.00 ± 0.00	0.89 ± 0.27	0.89	3.08 ± 0.49	3.92 ± 0.46	0.84 ab
High Mow	3.13 ± 0.88	2.03 ± 1.06	-1.10 b	0.69 ± 0.16	0.98 ± 0.50	0.29	3.47 ± 0.31	3.45 ± 0.26	-0.02 ab
Prescribed Fire	2.19 ± 0.38	3.11 ± 1.03	0.92 ab	0.84 ± 0.45	1.08 ± 0.43	0.24	2.43 ± 0.47	4.74 ± 0.45	2.31 a
Control	2.70 ± 0.75	3.72 ± 0.87	1.02 ab	0.26 ± 0.07	1.16 ± 0.51	0.89	3.55 ± 0.28	4.36 ± 0.46	0.81 ab
Mean	2.40 ± 0.52	3.40 ± 0.35	1.00	0.77 ± 0.28	1.15 ± 0.23	0.38	3.12 ± 0.23	3.78 ± 0.16	0.66
	Poa secunda *			*Pseudoroegneria spicata* **			Total Grasses		
	Cover (%)								
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	8.49 ± 1.53	8.36 ± 2.29	-0.13 ab	0.00 ± 0.00	0.00 ± 0.00	0.00 bc	16.19 ± 2.69	16.44 ± 3.41	0.26 abc
Heavy Spike	4.11 ± 0.55	6.29 ± 0.24	2.19 ab	1.21 ± 0.63	3.04 ± 0.69	1.84 a	11.65 ± 1.94	15.83 ± 1.16	4.18 abc
Dixie Harrow	5.14 ± 0.86	9.82 ± 0.82	4.69 a	0.54 ± 0.31	0.84 ± 0.32	0.29 b	11.02 ± 2.19	19.41 ± 2.78	8.39 a
Chaining	3.01 ± 0.59	6.68 ± 1.45	3.68 a	0.08 ± 0.08	0.21 ± 0.08	0.13 b	13.66 ± 1.16	14.48 ± 2.64	0.81 abc
Aerator	10.71 ± 1.14	6.95 ± 0.44	-3.76 b	0.00 ± 0.00	0.00 ± 0.00	0.00 b	21.41 ± 2.24	15.73 ± 1.19	-5.68 c
Low Mow	10.21 ± 0.82	9.27 ± 0.74	-0.94 ab	4.47 ± 2.29	2.78 ± 0.62	-1.69 c	21.43 ± 3.05	24.26 ± 0.75	2.84 abc
Med. Mow	7.03 ± 0.72	7.49 ± 1.35	0.46 ab	2.28 ± 0.73	3.79 ± 0.86	1.52 ab	14.86 ± 1.37	20.26 ± 0.82	5.77 ab
High Mow	9.28 ± 1.33	8.51 ± 0.99	-0.78 ab	0.00 ± 0.00	0.01 ± 0.01	0.01 c	17.71 ± 1.02	14.97 ± 2.62	-2.74 bc
Prescribed Fire	7.99 ± 1.13	9.27 ± 1.36	1.28 ab	0.91 ± 0.52	0.31 ± 0.21	-0.59 bc	15.00 ± 1.23	19.14 ± 2.83	4.14 abc
Control	5.39 ± 0.89	9.01 ± 0.63	3.63 a	1.96 ± 0.52	2.14 ± 0.20	0.18 b	14.08 ± 1.08	19.14 ± 2.83	6.34 ab
Mean	7.14 ± 0.83	817 ± 0.39	1.03	1.14 ± 0.45	1.31 ± 0.47	0.17	15.70 ± 1.14	18.13 ± 0.99	2.43

Within each column, means with different letters are significantly different using Tukey’s honestly significant difference multiple comparison procedure ($P < 0.05$) (*) or Fisher’s Protected LSD ($P < 0.05$) (**). *Elymus lanceolatus* and *Pseudoroegneria spicata* differences reflect a significant treatment by grazing interaction.

TABLE 6. Forb cover values (mean ± se) and mean differences in cover of forbs (2007-2006) after vegetation treatments of a Wyoming big sagebrush community in western Wyoming. No significant differences were reported.

	Erigeron linearis			*Linanthus pungens*		
	Cover (%)					
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	0.00 ± 0.00	0.08 ± 0.08	0.08	2.85 ± 1.65	1.44 ± 0.85	-1.41
Heavy Spike	7.19 ± 0.74	60.3 ± 1.04	-1.16	0.36 ± 0.08	0.75 ± 0.26	0.39
Dixie Harrow	1.05 ± 1.00	1.05 ± 0.60	0.00	2.35 ± 0.75	2.27 ± 0.63	-0.08
Chaining	0.85 ± 0.65	0.59 ± 0.27	-0.26	0.93 ± 0.25	0.67 ± 0.18	-0.26
Aerator	0.59 ± 0.35	0.84 ± 0.54	0.25	4.57 ± 1.35	2.38 ± 0.51	-2.19
Low Mow	0.00 ± 0.00	0.19 ± 0.11	0.19	2.22 ± 0.52	2.00 ± 0.71	-0.26
Med. Mow	1.52 ± 0.69	2.41 ± 1.16	0.89	1.19 ± 0.89	1.79 ± 0.87	0.60
High Mow	6.36 ± 3.00	4.79 ± 2.33	-1.56	2.58 ± 1.53	2.38 ± 1.51	-0.20
Prescribed Fire	2.14 ± 0.91	2.53 ± 1.18	0.39	1.23 ± 0.46	1.42 ± 1.04	0.19
Control	0.63 ± 0.28	0.49 ± 0.22	-0.14	1.10 ± 0.39	2.20 ± 1.04	1.10
Mean	2.03 ± 0.82	1.90 ± 0.65	-0.13	1.94 ± 0.39	1.73 ± 0.20	-0.21
	Phlox hoodii			Forb Total		
	Cover (%)					
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	3.06 ± 0.77	3.10 ± 0.79	0.04	6.06 ± 1.50	10.41 ± 1.44	4.36 ab
Heavy Spike	3.07 ± 1.00	3.36 ± 0.82	0.29	10.73 ± 1.60	13.84 ± 1.52	3.12 ab
Dixie Harrow	1.37 ± 0.65	2.41 ± 0.95	1.04	6.13 ± 1.63	13.92 ± 1.73	7.79 ab
Chaining	2.32 ± 1.24	3.39 ± 0.32	1.07	4.83 ± 2.09	11.29 ± 0.78	6.46 ab
Aerator	0.53 ± 0.19	1.88 ± 0.20	1.36	7.01 ± 1.45	11.75 ± 0.38	4.74 ab
Low Mow	1.43 ± 0.76	2.74 ± 0.78	1.32	3.68 ± 0.47	13.22 ± 1.15	9.54 ab
Med. Mow	3.79 ± 1.41	4.41 ± 0.94	0.61	7.49 ± 1.92	14.34 ± 1.38	6.85 ab
High Mow	1.31 ± 0.90	2.19 ± 0.08	0.88	11.88 ± 1.47	14.21 ± 1.38	2.34 b
Prescribed Fire	1.82 ± 0.50	2.74 ± 0.29	0.92	6.59 ± 1.29	16.52 ± 2.39	9.93 a
Control	2.72 ± 0.81	3.73 ± 1.04	1.01	4.55 ± 1.13	12.46 ± 1.78	7.91 ab
Mean	2.14 ± 0.32	2.99 ± 0.24	0.85	6.89 ± 0.83	13.20 ± 0.56	6.30

Within each column, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$). A one-way RANOVA was used to calculate forb total (*) differences

TABLE 7. Cover values (mean ± se) of litter, rock, and cryptogams, and bare ground and mean differences (2007-2006) after vegetation treatments of a Wyoming big sagebrush community in western Wyoming.

	Litter, Rock, and Cryptogams			Bare Ground		
	Cover (%)					
Treatment	Pre-treatment	Post-treatment	Difference	Pre-treatment	Post-treatment	Difference
Light Spike	41.63 ± 2.31	32.16 ± 1.85	-9.47 abc	45.01 ± 3.06	16.35 ± 1.18	-28.66
Heavy Spike	34.63 ± 3.34	34.70 ± 4.4	0.07 abc	36.86 ± 1.96	13.70 ± 2.98	-23.16
Dixie Harrow	22.21 ± 4.44	24.68 ± 2.50	2.47 abc	54.44 ± 3.94	21.09 ± 2.73	-33.35
Chaining	22.93 ± 2.28	28.20 ± 2.30	5.27 ab	44.09 ± 4.38	22.26 ± 0.82	-21.83
Aerator	39.56 ± 1.40	30.75 ± 3.20	-8.81 abc	38.31 ± 2.72	19.11 ± 2.40	-19.21
Low Mow	48.68 ± 4.50	50.12 ± 4.77	1.44 abc	30.26 ± 5.17	8.25 ± 1.05	-22.01
Med. Mow	27.89 ± 1.68	39.07 ± 4.23	11.18 a	33.96 ± 3.90	12.83 ± 2.43	-21.13
High Mow	42.05 ± 3.86	37.26 ± 2.41	-4.79 abc	38.63 ± 6.93	16.66 ± 4.38	-21.98
Prescribed Fire	42.94 ± 1.90	25.49 ± 3.39	-17.46 bc	42.76 ± 1.75	23.64 ± 4.59	-19.12
Control	48.61 ± 4.49	28.59 ± 2.17	-20.03 c	35.08 ± 4.15	12.88 ± 1.22	-22.19
Mean	37.11 ± 3.10	33.10 ± 2.41	-4.01	39.94 ± 2.18	16.68 ± 1.54	-23.26

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

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CHAPTER III

SAGEBRUSH STEPPE RESTORATION – PLANNING AND IMPLEMENTATION

INTRODUCTION

Many land management agencies have begun focusing on rangeland rehabilitation and restoration projects geared towards the improvement of wildlife habitat; however, financial constraints and resource availability often limit the scope of projects (Connelly et al. 2004). Furthermore, some areas once occupied by sagebrush may not respond to restoration efforts due to severe alterations in vegetation, nutrient cycling, soil composition, and disturbance processes (Knick et al. 2003). Geographic information systems (GIS) analysis and modeling are advocated as essential decision and planning tools. Spatial modeling can help to determine which sites are best suited for particular restoration techniques; these areas can subsequently be placed within a regional context (Knick 2002). Based on spatial features, GIS can also be used to more accurately model disturbance factors, such as wildfire and noxious weed infestation, affecting sagebrush habitats.

Given the widespread degradation of sagebrush communities across western North America, the need to place restoration plans within a broader ecological context is tantamount; small-scale, local plans should be encompassed within broader, landscape-scale initiatives (Knick 2002). A hierarchical approach to restoration planning is suggested; regional prioritization should guide local projects. The building of a collective knowledge base with regard to restoration techniques and their applicability at different spatial and temporal scales is also important in the creation of multi-dimensional initiatives across geographic regions (Wisdom et al. 2005b).

Spatial prioritization of sagebrush communities based on their vulnerability to detrimental, and often times, irreversible change is recommended (Wisdom et al. 2000a). Susceptibility is based on a community's resistance to and resiliency from negative disturbance factors such as cheatgrass invasion. Of concern is the transition of a community from one vegetation state to another. Indices used to catalog a site's resistance and resiliency could include, among other factors, precipitation, elevation, temperature, slope, sagebrush taxa, soil characteristics, and level of human activity (Wisdom et al. 2000a).

As sage-grouse are considered a landscape-scale species due to their preference for large, interconnected expanses of sagebrush, sage-grouse habitat restoration plans should pay special attention to broad-scale implementation projects (Connelly et al. 2004). Ideal sage-grouse habitat must include areas uniquely suited for nesting, foraging, wintering, brood-rearing, and loafing (Wisdom et al. 2005b). Fine-scale landscape metrics specific to sage-grouse should also be included as assessment parameters. Information garnered from monitoring efforts, such as population density estimates, mortality estimates, habitat preference, lek location, and population fitness and productivity could contribute significantly to restoration planning (Connelly et al. 2004). Leks are defined as areas in which traditional courtship display and mating occur. They are located in, or adjacent to, sagebrush dominated nesting habitat (Connelly et al. 2004).

To this end, restoration activities should focus on minimizing habitat fragmentation while improving habitat quality. While a minimum sustainable patch size has not been conclusively identified, re-connection of isolated sage-grouse populations or the re-connection of isolated populations with stronghold populations should be a restoration goal (USDI 2004).

Passive or lower impact improvements that remove degradation-causing stresses can be employed to obtain some connectivity goals (Allen 1993). Such activities could include road closures or the changing of grazing strategies on stressed lands. Many active restoration methods, such as those used in this study, however, will undoubtedly result in disturbances that may impact an area for several years, if not decades. Subsequently, the placement of these treatments should be chosen carefully as to minimize cumulative impacts.

While comprehensive assessments were formerly limited due to the lack of available data, there are currently large spatial datasets assessable from a number of websites. SAGMAP (USGS 2002), for example, is a web-based, spatial data set portal dedicated specifically to sage-grouse and sagebrush steppe management in the Intermountain West.

STUDY OBJECTIVES

The goal of this study was to develop index models representing areas within the Green River Basin that may respond positively to restoration activities based on a number of criteria. Ideally, these models may help land managers place localized projects within a broader managerial and ecological framework.

The primary objective of this research was to determine where the implementation of active and passive restoration efforts geared towards improving the general health and sustainability of sagebrush steppe would be most effective and have the greatest potential for success across spatial and temporal scales given single and cumulative disturbance factors.

METHODS

This GIS analysis focused on the Wyoming portion of the Green River Basin. ArcGIS 9.2 (ERSI ArcMap 2006) software was used for analyses. Spatial data sets were obtained from the Wyoming Spatial Data Clearinghouse, the BLM, Wyoming Game and Fish, Wyoming Wildlife Consultants, LLC, and the LANDFIRE website. In an attempt to capture and quantify more specific regional influences and patterns, fine scale data were used when available. Due to limited availability, coarse scale categories were used for certain layers.

To cohesively quantify the combined effects of prior and current human disturbance, animal utilization and sensitivity, and varying environmental factors, a Restoration Suitability Index (RSI) model (Chang 2006) was created for both active and passive restoration scenarios (Whisenant 1999). The weighted linear combination method was used to compute index values for this model. Criterion data were standardized based on an ordinal scale (0-5), with 5 representing the least desirable ranking. The relative importance of each criterion was subsequently evaluated against all other criteria to determine a weight for each given criterion. Final index values were then calculated for each unit area by summing the weighted criterion values and dividing the sum by the total of the weights:

$$I = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

Where I is the index value, n is the number of criteria, w_i is the weight for criterion i, and x_i is the standardized value for criterion i. The raster calculator function in ArcGIS was used to combine and weight the criteria.

Potential sagebrush habitat within the Green River Basin (Steeves and Nebert 1994) was first defined by utilizing the Biophysical Setting layer available from LANDFIRE (USDA 2006a). The Biophysical Setting layer represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement and is based on both the current environment and an estimate of the historic disturbance regime. Raster calculator was used to delineate presence of potential sagebrush habitat based on map unit names. In order to smooth the resulting grid, the majority filter tool in ArcGIS was used three times. The number of cells in the filter kernel was eight, and to produce a more smoothing effect, the replacement threshold was set at half.

Prioritization of active restoration areas within potential sagebrush habitat was developed using nine criteria: road density, presence of development, vegetation treatment completion, seismic testing presence, oil and gas presence, sage-grouse lek presence, land ownership, percent slope, and average annual rainfall (Table 8). Passive restoration prioritization was based on six criteria: road density, sage-grouse lek presence, land ownership, percent slope, average annual rainfall, and big game critical range presence (Table 9). Each factor is described in more detail below. A number of binning techniques were used to standardize data.

Road density was calculated as a proxy for land fragmentation. Road density was calculated using the 1997 Census Bureau Tiger roads file (US Census Tiger Files 1997). To better account for the spatial impact of roads, interstate and state highway roads were first buffered 500 m while county and neighborhood roads were buffered 25 m (Copeland et al. 2005). To calculate the percent area within road buffers per square km, a 1 km polygon fishnet of the Green River Basin was created. A union was then performed between the fishnet grid and the buffered road shapefile. A summary table was created to determine the percentage of each 1-km cell affected by buffering. This table was then joined back to the fishnet coverage to create a 1-km grid where the value of each cell represents the percent area affected by road buffers. Road density was then manually binned into five impact categories. For active restoration, high road density was considered undesirable. For passive restoration, however, high road density was scored low (1) as some of these areas could potentially be targeted for closure or rehabilitation.

To account for heavily developed areas, such as towns, a shapefile identifying developed areas and potential for development of sage-grouse habitat was added to the active model (USDI 2002). While the intent of this analysis was not to model habitat specific to sage-grouse, this file was used as it provided a basin-wide representation of several different development activities. Oil and gas development data were removed from this shapefile as more current oil and gas development data were provided by the Wyoming Oil and Gas Commission. Developed habitat pixels were converted to a raster data set with a 30-m pixel size. Pixels with development were rated as a 5 while undeveloped areas received a score of zero. This layer was not included in the passive restoration analysis.

The oil and gas file provided by the Wyoming Oil and Gas Commission (2008) was subsequently added. Only active wells were used in analysis. Each active well was buffered 400 m (Copeland et al. 2005). The buffered dataset was converted to a raster dataset with 30-m pixels. Cells encompassed by the buffer were classified as 5; cells that were unaffected by the wells received a score of zero. This layer was also excluded from the passive restoration analysis.

While not representative of the entire basin, two layers indicating the completion of previous vegetation treatments and previous seismic exploration were included in the model after conversion to 30-m raster datasets (Wyoming Wildlife Consultants, LLC 2008). Areas impacted by treatments and seismic testing were ranked as 5 while unaffected areas received a ranking of zero. While treatment dates and vegetation response vary for each treatment, all areas affected by treatment were ranked high to account for prior disturbance. These layers were only included in the active restoration scenario.

Land ownership was used to account for areas where a managerial and fiduciary framework for restoration activities may already be in place (Wyoming Gap Analysis 1996). Data were converted to a raster dataset with 30-m pixels. While private land should not be excluded from restoration consideration, private lands were ranked as a 4 as many private land owners lack established means of generating support for restoration . Federal land management agencies received lower scores. The rankings were the same for both passive and active restoration.

To minimize disturbance around known sage-grouse leks during active restoration activities, a shapefile containing known leks, was added to the analysis (Wyoming Game and Fish 2007). All leks were buffered 1,609 m. While larger buffers have been advocated (Connelly et al. 2000, Braun 2007), this number was chosen to reflect the minimal buffer size recommended by the Ecosystem Research Group, a consulting firm responsible for completing a linear regression between lek count trends and distance to nearest well on the Pinedale Anticline (Ecosystem Research Group 2006). The buffered data set was subsequently turned into a 30-m grid. While lek areas received a high score in the active restoration analysis, lek areas were targeted for passive restoration.

A shapefile presenting big game crucial range in Wyoming (Wyoming Open Spaces Initiative 2002) was included in the passive restoration model. This data layer represents the crucial range of pronghorn, elk, mule deer, white-tailed deer (*Odocoileus virinianus*), and moose (*Alces alces*).

Average annual precipitation for the Green River Basin was included in both analyses (Daly and Taylor 1997). Five precipitation classes were designated for the converted 30-m raster dataset. Areas receiving higher amounts of annual precipitation were scored lower than those receiving minimal precipitation.

Slope, which was derived from the LANDFIRE 30-m elevation grid (USDA 2006b), was designed into one of five classes. Steeper slopes were scored high while flat areas were scored 1. This layer was used in both analyses.

Given the number of factors included in the model, most variables were weighted similarly. For the active restoration analysis, road density and oil and gas development were both weighted 15% each; the remainder of the variables were each weighted 10% (Table 9). In the passive restoration scenario, precipitation was weighted 30%, big game crucial range presence was weighted 20%, lek presence was weighted 20%, and slope, roads, and ownership were all weighted at 10% (Table 10).

RESULTS AND DISCUSSION

Data reliability and standardization is of concern as multiple data sources from multiple years were used (Copeland et al. 2006). Furthermore, it should be recognized that some data were limited in geographic representation. The prior treatment and seismic test layers, for example, were limited to the northern half of the Basin. While effort was taken to use the most current datasets, given the number of land use changes occurring within the region, periodic updates to the model would be necessary to improve accuracy.

Active and passive restoration scenarios are presented in Figures 4 and 5. Active restoration is limited in areas affected by oil and gas development. Areas that that were previously affected by seismic testing and vegetation treatments would also receive lower prioritization due to prior disturbance. As indicated by Figure 5, however, passive restoration could be used in areas where further disturbance is undesirable, especially in locations where annual precipitation is adequate. Less invasive techniques, which are technically classified as active restoration, may also be appropriate in previously disturbed areas. Site reclamation through seeding, for example, may elicit a desirable vegetative response. Depending on the current seral state of the community, a combination of both methods could potentially be employed in certain areas to achieve management objectives (Allen 1993).

One of the benefits of the index model is the relative simplicity of data addition and manipulation. Soils data, for example, could be included as more fine-scale mapping is completed for the state of Wyoming; model efficacy on a more localized scale could subsequently be improved. These models can also be easily re-configured to accommodate unique management goals and objectives. Data layers can be added and subtracted as deemed necessary and different index weights can be easily changed for each raster layer based on its perceived importance for a designated area. The figures presented here represent two potential restoration scenarios out of a number of possibilities.

The necessary site specificity of restoration planning is recognized; however, it is our hope that landscape scale models such as these will help managers in deciding how best to prioritize sites given limited resources and funding. These models could also help to place restoration activities within a broader spatial context (Wisdom et al. 2005b). Due to the complex habitat needs of many sagebrush-obligates, restoration projects may have little impact if they are not placed within a broader spatial context that encompasses heterogeneous landscapes affected by a multitude of land uses.

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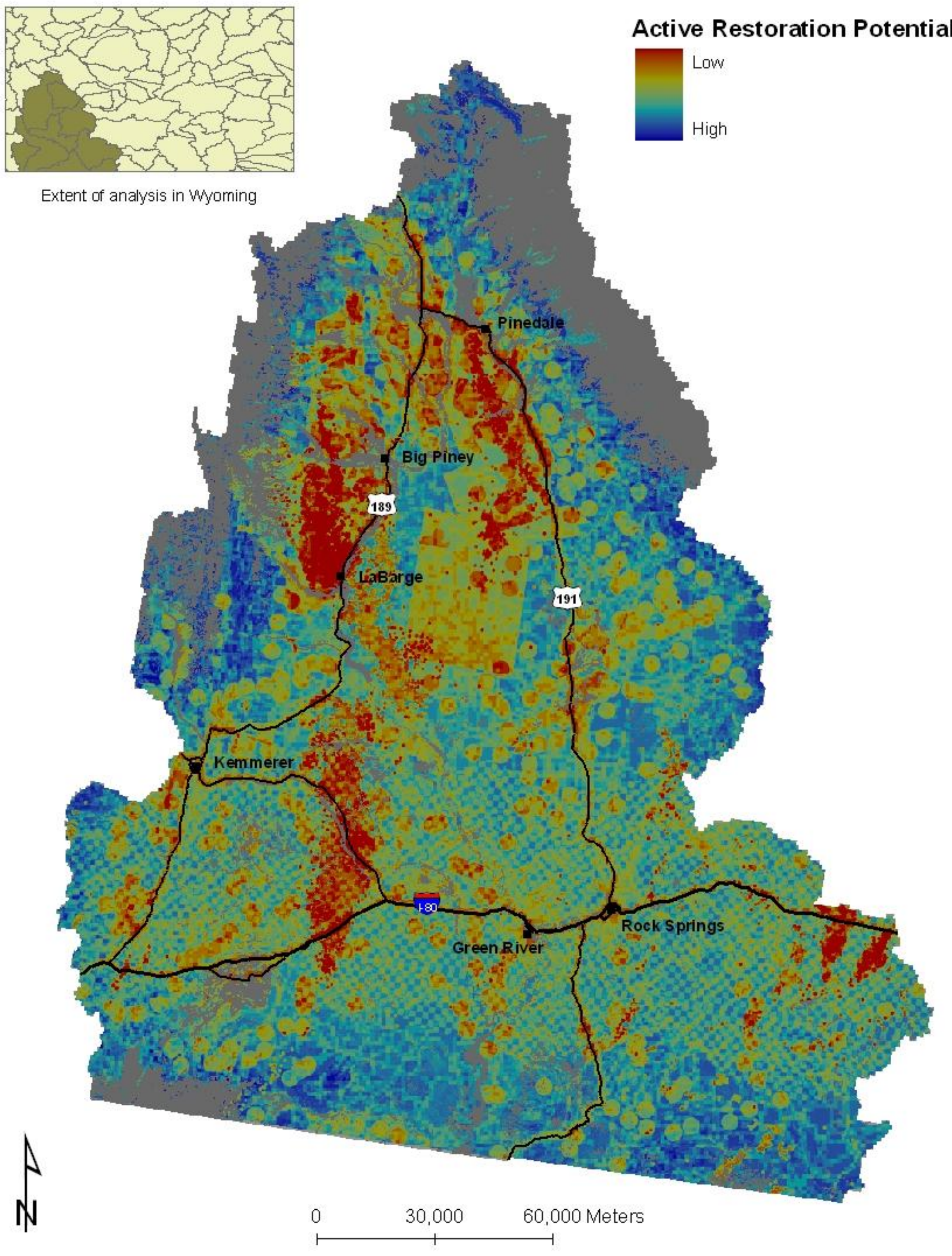


FIG.4. Active Restoration Suitability Index (RSI) model for Green River Basin, Wyoming.

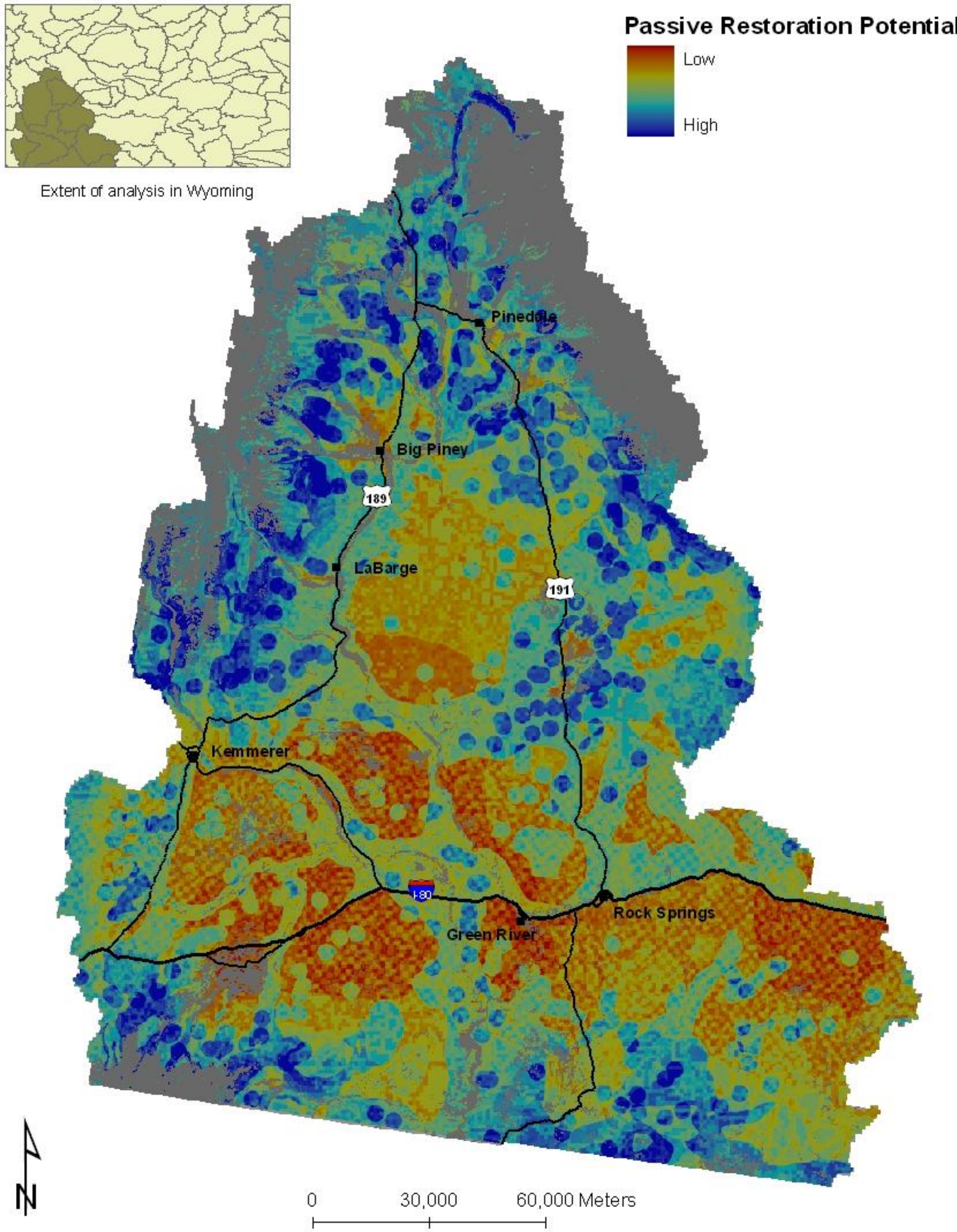


FIG.5. Passive Restoration Suitability Index (RSI) model for Green River Basin, Wyoming.

TABLE 8. Restoration parameter and weights for active Restoration Suitability Index (RSI), Green River Basin, Wyoming.

Road Density		Precipitation		Slope		Land Ownership		Prior Treatment		Seismic Testing		Oil and Gas Presence		Lek Presence		Development	
Weighted .15		Weighted .10		Weighted .10		Weighted .10		Weighted .10		Weighted .10		Weighted .15		Weighted .10		Weighted .10	
Score	Road Density per Cell	Score	Range (cm)	Score	Slope (%)	Score	Ownership Category	Score	Prior Treatment	Score	Seismic Testing	Score	Oil and Gas Presence	Score	Lek Presence	Score	Development
0	0	0	>41	0	>80	0	Other	0	No	0	No	0	No	0	No	0	No
1	5	1	36-41	1	0-5	1	BLM/State	1	Yes	1	Yes	1	Yes	1	Yes	1	Yes
2	10	2	30-36	2	5-15	2	FS/NRA										
3	25	3	25-30	3	15-25	3	State Lands										
4	50	4	20-25	4	25-40	4	Private										
5	100	5	15-20	5	40-80	5	Wilderness										

TABLE 9. Restoration parameter and weights for passive Restoration Suitability Index (RSI), Green River Basin, Wyoming.

Road Density		Precipitation		Slope		Land Ownership		Big Game Critical Range		Lek Presence	
Weighted .10		Weighted .30		Weighted .10		Weighted .10		Weighted .20		Weighted .20	
Score	Road Density per Cell	Score	Range (cm)	Score	Slope (%)	Score	Ownership Category	Score	Critical Range Presence	Score	Lek Presence
1	0	0	>41	0	>80	0	Other	5	No	5	No
5	5	1	36-41	1	0-5	1	BLM/State	1	Yes	1	Yes
4	10	2	30-36	2	5-15	2	FS/NRA				
3	25	3	25-30	3	15-25	3	State Lands				
2	50	4	20-25	4	25-40	4	Private				
1	100	5	15-20	5	40-80	5	Wilderness				

APPENDIX A. Coordinates (UTM) of research transect locations for Wyoming big sagebrush community treatment plots located near Pinedale, Wyoming. All UTM coordinates are reported in Zone 12N of NAD83. F denotes fencing; U denotes unfenced transect.

Site	Fencing	Transect	Easting	Northing	Bearing (°)
Plot 1	F	Start 1-1	4735302	591175	215
		End 1-1	4735257	591144	
	F	Start 1-2	4735210	591252	195
		End 1-2	4735152	591236	
	U	Start 1-3	4735280	591345	58
		End 1-3	4735317	591404	
	U	Start 1-4	4735106	591347	252
		End 1-4	4735087	591288	
Plot 2	U	Start 2-1	4735991	591671	295
		End 2-1	4736015	591620	
	F	Start 2-2	4735955	591944	304
		End 2-2	4735991	591891	
	F	Start 2-3	4736112	591771	1
		End 2-3	4736176	591772	
	U	Start 2-4	4736078	591605	74
		End 2-4	4736094	591660	
Plot 3	U	Start 3-1	4735034	593079	184
		End 3-1	4734973	593075	
	F	Start 3-2	4734954	592881	155
		End 3-2	4734900	592906	
	F	Start 3-3	4734736	592995	348
		End 3-3	4734795	592982	
	U	Start 3-4	4734876	593216	314
		End 3-4	4734916	593174	
Plot 4	F	Start 4-1	4734022	592719	16
		End 4-1	4734085	592737	
	U	Start 4-2	4734084	592844	96
		End 4-2	4734078	592904	
	U	Start 4-3	4733748	592969	295
		End 4-3	4733779	592904	
	F	Start 4-4	4733816	592729	360
		End 4-4	4733879	592729	
Plot 5	F	Start 5-1	4733565	593647	5
		End 5-1	4733623	593652	
	F	Start 5-2	4733903	593525	184
		End 5-2	4733843	593521	
	U	Start 5-3	4733839	593413	148
		End 5-3	4733789	593444	
	U	Start 5-4	4733725	593384	141
		End 5-4	4733680	593421	
Plot 6	F	Start 6-1	4734784	591944	268
		End 6-1	4734782	591887	
	U	Start 6-2	4734903	591735	223
		End 6-2	4734857	591692	
	U	Start 6-3	4734614	591796	332
		End 6-3	4734666	591768	

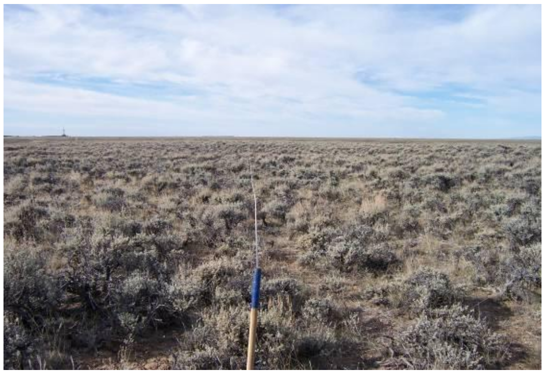
APPENDIX A Continued.

Site	Fencing	Transect	Easting	Northing	Bearing (°)
	F	Start 6-4	4734707	591930	301
		End 6-4	4734739	591877	
Plot 7	U	Start 7-1	4733065	592094	259
		End 7-1	4733054	592037	
	U	Start 7-2	4732808	592044	337
		End 7-2	4732866	592019	
	F	Start 7-3	4732931	592220	108
		End 7-3	4732912	592280	
	F	Start 7-4	4732935	592345	83
		End 7-4	4732942	592406	
Plot 8	F	Start 8-1	4732268	591898	359
		End 8-1	4732327	591897	
	U	Start 8-2	4732554	592158	289
		End 8-2	4732576	592095	
	U	Start 8-3	4732800	591948	189
		End 8-3	4732746	591939	
	F	Start 8-4	4732765	591858	176
		End 8-4	4732704	591862	
Plot 9	U	Start 9-1	4732002	591977	351
		End 9-1	4732062	591968	
	F	Start 9-2	4732159	591842	187
		End 9-2	4732109	591836	
	F	Start 9-3	4731924	591854	189
		End 9-3	4731863	591844	
	U	Start 9-4	4731773	592002	346
		End 9-4	4731829	591988	
Plot 10	U	Start 10-1	4731191	591823	23
		End 10-1	4731246	591846	
	F	Start 10-2	4731222	591878	47
		End 10-2	4731270	591929	
	F	Start 10-3	4731615	592067	203
		End 10-3	4731563	592045	
	U	Start 10-4	4731622	591848	180
		End 10-4	4731560	591848	

APPENDIX B. Photos taken at each of the 10 study plots at permanent photopoint locations within fixed plot sampling locations for a Wyoming big sagebrush treatment study near Pinedale, Wyoming

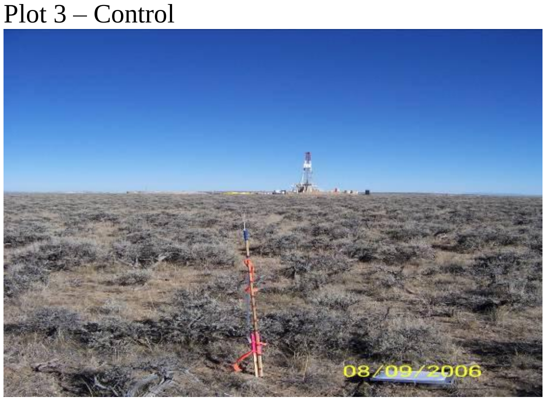
Pre-treatment

Plot 1 – Dixie Harrow

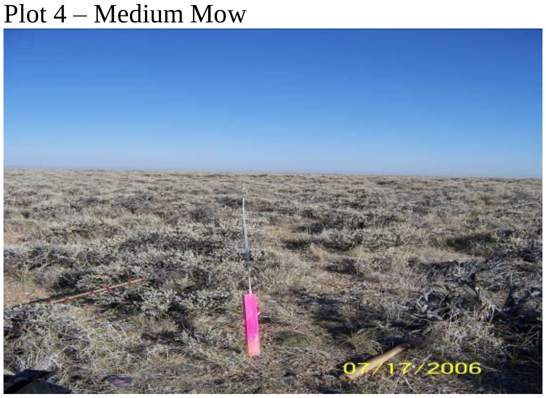


Plot 2 – Chaining

Plot 3 – Control

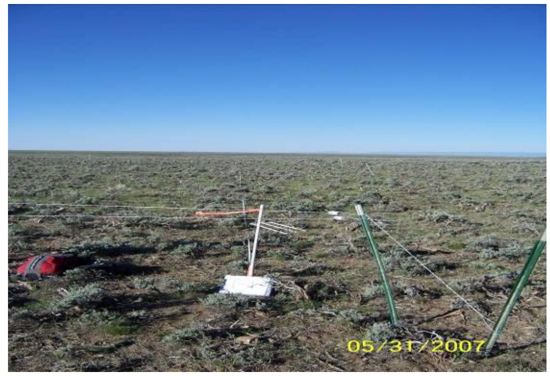


Plot 4 – Medium Mow

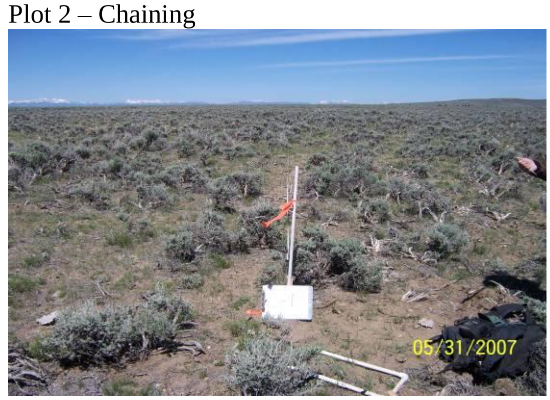


Post-treatment

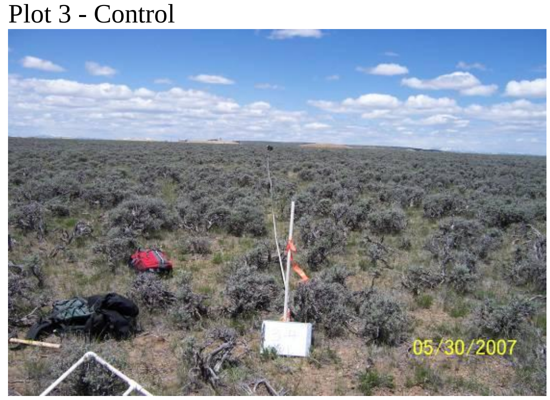
Plot 1 – Dixie Harrow



Plot 2 – Chaining



Plot 3 - Control



Plot 4 – Medium Mow

Pre-treatment

Plot 5 - Low Mow

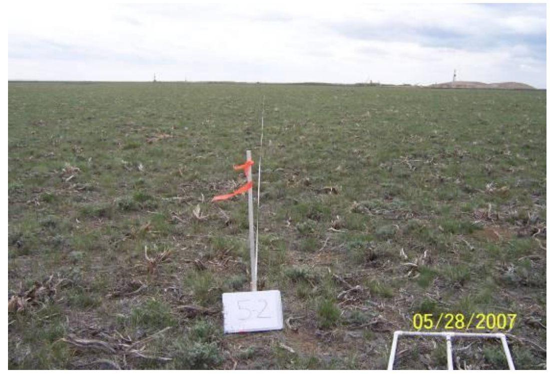
Plot 6 – Heavy Spike

Plot 7 – Prescribed Fire

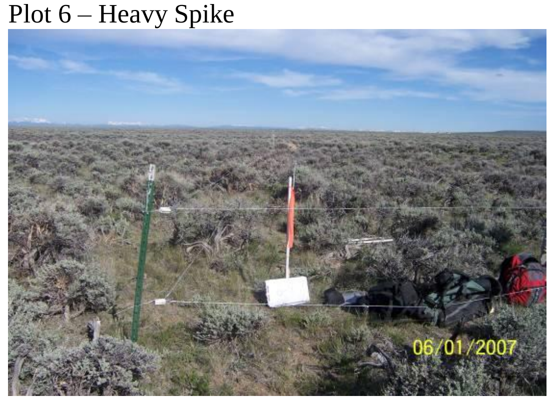
Plot 8 – High Mow

Post-treatment

Plot 5 - Low Mow



Plot 6 – Heavy Spike



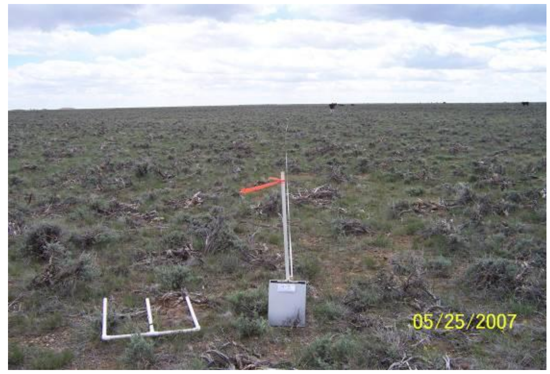
Plot 7 – Prescribed Fire

Plot 8 – High Mow

Pre-treatment	**Post-treatment**

Plot 9 – Aerator

Plot 9 – Aerator



Plot 10 – Light Spike

Plot 10 – Light Spike

APPENDIX C. Summary of probability values from PROC GLM and RANOVA for parameters sampled in 2006 and 2007 in a Wyoming big sagebrush community study near Pinedale, Wyoming. PROC GLM and RANOVA were run on the difference between sampling years. Two-way p-values utilized are denoted by *. One way p-values are provided for analyses in which no grazing or treatment by grazing interaction were detected

Parameter	Trt Effect		Grazing Effect		Trt by Grazing Interaction		One-way P values utilized	
	Least Squares	Wilcoxon R	Least Squares	Wilcoxon R	Least Squares	Wilcoxon R	One-way ANOVA	One-way RANOVA
Individual Grass Species:								
Achnatherum lettermanii	0.0051	0.0153	0.6433	0.8840	0.2896	0.4295	0.0033	
Elymus elymoides	0.2425	0.3302	0.8422	0.9984	0.9540	0.9104	0.0983	
Elymus lanceolatus	0.0886	0.1560	0.4293	0.8000	0.1329	0.0626*		
Poa secunda	0.0089	0.0142	0.3388	0.5177	0.6443	0.3388	0.0027	
Pseudoroegneria spicata	0.0851	0.0382	0.8646	0.8327	0.0673	0.0428*		
Individual Forb Species:								
Erigeron linearis	0.3342	0.2273	0.9241	1.000	0.8161	0.9163	0.2043	
Linanthus pungens	0.0929	0.1523	0.7427	1.000	0.5706	0.5700	0.0549	
Phlox hoodii	0.9685	0.7884	0.7441	0.9970	0.8866	0.7090	0.9438	
Individual Shrub Species:								
Artemisia tridentata wyomingensis (cover class)	0.0238	0.0114	0.3826	0.9970	0.9449	0.9435	0.0039	
Artemisia tridentata wyomingensis (line intercept)	<0.0001	<0.0001	0.5353	0.1456	0.0005	0.1570		<0.0001
Chrysothamnus viscidiflorus	0.0053	0.0069	0.9295	1.000	0.0893*	0.0537		
Group Values:								
Total Grasses	<0.0001	0.0034	0.7328	1.000	0.6895	0.1498	0.0010	
Total Forbs	0.1076	0.0473	0.9122	1.000	0.6010	0.5187		0.0134
Total Shrubs	0.0096	0.0039	0.4539	0.8667	0.9012	0.8348	0.0012	
Ground Cover	0.0097	0.0080	0.2786	0.4211	0.9760	0.9484	0.0010	
Bare Ground	0.3155	0.3371	0.7248	0.8590	0.3555	0.4520	0.3149	
Biomass Values:								
Grass	0.2413	0.2163	0.4387	0.5952	0.5905	0.3683	0.1856	
Forb	0.2369	0.2650	0.8973	1.000	0.0871*	0.0609		
Sage	0.0067	0.0024	0.2955	0.8190	0.4055	0.2423	0.0037	
Sagebrush Density Values:								
Decadent	0.1185	0.0563	0.0103	0.0146*	0.4224	0.1570		
Mature	0.0199	0.0104	0.4555	0.7885	0.2943	0.1042	0.0172	
Young	0.0009	0.0001	0.1678	0.2871	0.5702	0.4837	0.0002	
Dead	0.0984	0.0008	0.4354	0.6516	0.7264	0.7812		<0.0001

APPENDIX C Continued.

Parameter	Trt Effect		Grazing Effect		Trt by Grazing Interaction		One-way P values utilized	
	Least Squares	Wilcoxon R	Least Squares	Wilcoxon R	Least Squares	Wilcoxon R	One-way ANOVA	One-way RANOVA
Height:								
Sagebrush Height	<0.0001	<0.0001	0.9074	0.9976	0.6897	0.6558	<0.0001	
Herbaceous Height	0.0008	0.0007	0.4695	0.5391	0.0959*	0.0617		
Species Diversity:								
Richness	0.0180	0.2455	0.2618	0.5351	0.7139	0.9465		0.0178
Shannon-Wiener Index	0.0046	0.0064	0.1853	0.5010	0.7250	0.7003	0.0011	

APPENDIX D. Percent average pre-treatment species cover (mean ± se) for Wyoming big sagebrush community study near Pinedale, Wyoming. The cover class method was used to compute values.

	Treatments (1-5)				
Growth form/species	**Dixie Harrow**	**Chaining**	**Control**	**Med. Mow w/ Forb**	**Low Mow**
Grasses:					
Achnatherum hymenoides	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.438 ± 0.253	0.000 ± 0.000
Achnatherum lettermanii	0.225 ± 0.208	0.675 ± 0.484	2.700 ± 0.753	2.031 ± 0.793	3.525 ± 0.521
*Elymus elymoide*s	0.300 ± 0.181	0.019 ± 0.012	0.263 ± 0.0665	0.000 ± 0.000	1.250 ± 0.260
Elymus lanceolatus	3.300 ± 1.027	4.594 ± 1.248	3.550 ± 0.284	3.081 ± 0.485	1.969 ± 0.425
Pascopyrum smithii	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Poa secunda	5.138 ± 0.861	3.006 ± 0.590	5.388 ± 0.898	7.031 ± 0.718	10.213 ± 0.818
Pseudoroegneria spicata	0.544 ± 0.308	0.081 ± 0.081	1.956 ± 0.518	2.275 ± 0.733	4.469 ± 2.292
Forbs:					
Agoseris glauca var. *dasycephala*	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Allium spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Antenaria microphylla	0.000 ± 0.000	0.094 ± 0.094	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Arabis hirsuta var. pycnocarpa	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Arenaria spp.	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus purshii	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus spp. low	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus spp. tall	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Carex spp.	0.006 ± 0.006	0.000 ± 0.000	0.006 ± 0.006	0.038 ± 0.038	0.000 ± 0.000
Castilleja angustifolia	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cordylanthus ramosus	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cryptantha flavoculata	0.000 ± 0.000	0.269 ± 0.119	0.000 ± 0.000	0.563 ± 0.099	0.038 ± 0.038
Cymopterus nivalis	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Erigeron engelmanni	0.006 ± 0.006	0.006 ± 0.006	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Erigeron linearis	1.050 ± 1.001	0.850 ± 0.651	0.631 ± 0.277	1.519 ± 0.686	0.000 ± 0.000
Eriogonum brevicaule	1.156 ± 0.516	0.219 ± 0.219	0.094 ± 0.094	0.350 ± 0.302	0.00 0± 0.000
Eriogonum ovalifolium	0.038 ± 0.038	0.038 ± 0.038	0.000 ± 0.000	0.038 ± 0.038	0.000 ± 0.000
Lewisia pygmaea	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Linathus pungens	2.350 ± 0.754	0.931 ± 0.245	1.100 ± 0.389	1.194 ± 0.886	2.219 ± 0.515
Lomatium triternatum	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Microseris nutans	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Phlox hoodii	1.369 ± 0.650	2.319 ± 1.241	2.719 ± 0.814	3.794 ± 1.414	1.425 ± 0.764
Phlox longifolia	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Phlox multiflora	0.094 ± 0.094	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

APPENDIX D Continued.

	Treatment				
Growth form/species	**Dixie Harrow**	**Chaining**	**Control**	**Med. Mow w/ Forb**	**Low Mow**
Salsola tragus	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Schoenocrambe linifolia	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Trifolium andinum var. *andinum*	0.019 ± 0.006	0.013 ± 0.007	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown 1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Big Green Base	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Blue Lomatium	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Forb 1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Forb 2	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown New Fuzzy Forb	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Penstemon	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Viney Weed	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Weed	0.000 ± 0.000	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Vicia spp.	0.000 ± 0.000	0.050 ± 0.042	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Shrubs:					
Artemisia arbuscula	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Artemisia tridentata wyomingensis	15.869 ± 1.399	9.625 ± 2.255	16.869 ± 1.442	17.794 ± 4.261	17.356 ± 3.526
Chrysothamnus viscidiflorus	1.588 ± 0.896	2.719 ± 0.593	4.250 ± 1.425	1.525 ± 0.437	1.800 ± 0.596
Krascheninnikovia lanata	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.094 ± 0.094	0.038 ± 0.038
Opuntia spp.	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Tetradymia canescens	0.000 ± 0.000	0.131 ± 0.131	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000
Ground Cover:					
Grazed Grass	1.510 ± 0.490	5.288 ± 1.007	0.219 ± 0.219	0.000 ± 0.000	0.000 ± 0.000
Bareground	54.444 ± 3.936	44.088 ± 4.382	35.075 ± 4.152	33.963 ± 3.898	30.256 ± 5.170
Litter	14.831 ± 2.610	19.081 ± 2.049	43.688 ± 4.495	21.381 ± 1.998	43.944 ± 5.061
Rock	7.306 ± 4.007	3.813 ± 0.301	4.925 ± 0.360	6.506 ± 0.558	4.731 ± 0.827
Lichen	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cryptogams	0.075 ± 0.043	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

APPENDIX D Continued.

Growth form/species	Treatments (6-10)				
	Heavy Spike	**Prescribed Fire**	**High Mow**	**Aerator**	**Light Spike**
Grasses:					
Achnatherum hymenoides	0.000 ± 0.000	0.094 ± 0.094	0.188 ± 0.108	0.000 ± 0.000	0.000 ± 0.000
Achnatherum lettermanii	2.781 ± 1.320	2.194 ± 0.384	3.125 ± 0.881	5.850 ± 1.957	0.888 ± 0.479
*Elymus elymoide*s	0.075 ± 0.043	0.838 ± 0.449	0.694 ± 0.163	1.325 ± 0.512	2.894 ± 0.709
Elymus lanceolatus	2.613 ± 0.291	2.431 ± 0.474	3.469 ± 0.308	2.781 ± 0.254	3.375 ± 0.227
Pascopyrum smithii	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Poa secunda	4.106 ± 0.548	7.994 ± 1.131	9.281 ± 1.334	10.713 ± 1.141	8.494 ± 1.533
Pseudoroegeneria spicata	1.206 ± 0.631	0.906 ± 0.524	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Forbs:					
Agoseris glauca var. *dasycephala*	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Allium spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Antenaria microphylla	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Arabis hirsuta var. pycnocarpa	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Arenaria spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus purshii	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus spp. low	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus spp. tall	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Carex spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Castilleja angustifolia	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cordylanthus ramosus	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cryptantha flavoculata	0.038 ± 0.038	0.375 ± 0.219	0.000 ± 0.000	0.250 ± 0.150	0.075 ± 0.075
Cymopterus nivalis	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Erigeron engelmanni	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Erigeron linearis	7.188 ± 0.741	2.144 ± 0.906	6.356 ± 3.000	0.588 ± 0.345	0.000 ± 0.000
Eriogonum brevicaule var. *micranthum*	0.038 ± 0.038	0.313 ± 0.313	0.488 ± 0.185	0.600 ± 0.551	0.075 ± 0.075
Eriogonum ovalifolium	0.038 ± 0.038	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Lewisia pygmaea	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Linathus pungens	0.356 ± 0.077	1.225 ± 0.462	2.581 ± 1.531	4.569 ± 1.352	2.850 ± 1.646
Lomatium triternatum	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Microseris nutans	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Phlox hoodii	3.069 ± 0.992	1.819 ± 0.498	1.313 ± 0.903	0.525 ± 0.186	3.056 ± 0.768
Phlox longifolia	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Phlox multiflora	0.000 ± 0.000	0.206 ± 0.160	0.988 ± 0.381	0.375 ± 0.233	0.000 ± 0.000

APPENDIX D Continued.

	Treatments (6-10)				
Growth form/species	**Heavy Spike**	**Prescribed Fire**	**High Mow**	**Aerator**	**Light Spike**
Salsola tragus	0.000 ± 0.000	0.469 ± 0.469	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Schoenocrambe linifolia	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Trifolium andinum var. *andinum*	0.000 ± 0.000	0.006 ± 0.006	0.000 ± 0.000	0.006 ± 0.006	0.000 ± 0.000
Unknown 1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Big Green Base	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Blue Lomatium	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Forb 1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Forb 2	0.000 ± 0.000	0.000 ± 0.000	0.075 ± 0.075	0.000 ± 0.000	0.000 ± 0.000
Unknown New Fuzzy Forb	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Penstemon	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Viney Weed	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Weed	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Vicia spp.	0.000 ± 0.000	0.000 ± 0.000	0.075 ± 0..075	0.000 ± 0.000	0.000 ± 0.000
Shrubs:					
Artemisia arbuscula	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Artemisia tridentata wyomingensis	20.256 ± 0.767	28.325 ± 4.983	22.469 ± 5.128	21.431 ± 2.369	21.394 ± 2.032
Chrysothamnus viscidiflorus	2.481 ± 0.863	2.519 ± 0.952	1.131 ± 0.498	2.669 ± 0.415	3.100 ± 0.775
Opuntia spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Krascheninnikovia lanata	0.350 ± 0.242	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Tetradymia canescens	0.000 ± 0.000	0.350 ± 0.350	0.394 ± 0.187	0.000 ± 0.000	0.131 ± 0.131
Ground Cover:					
Grazed Grass	0.869 ± 0.329	0.544 ± 0.219	0.950 ± 0.659	0.744 ± 0.235	0.538 ± 0.311
Bareground	36.863 ± 1.957	42.750 ± 1.750	38.631 ± 6.930	38.313 ± 2.720	45.006 ± 3.057
Litter	25.000 ± 3.078	38.900 ± 2.304	36.369 ± 4.645	36.750 ± 1.680	37.625 ± 22.377
Rock	9.631 ± 1.702	3.838 ± 0.480	5.681 ± 2.140	2.806 ± 0.534	4.000 ± 0.632
Lichen	0.000 ± 0.000	0.206 ± 0.206	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cryptogams	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

APPENDIX E. Percent average post-treatment species cover (mean ± se) for Wyoming big sagebrush community study near Pinedale, Wyoming. The cover class method was used to compute values.

	Treatments (1-5)				
Growth form/species	**Dixie Harrow**	**Chaining**	**Control**	**Med. Mow w/ Forb**	**Low Mow**
Grasses:					
Achnatherum hymenoides	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Achnatherum lettermanii	4.594 ± 1.778	3.275 ± 1.152	3.719 ± 0.872	4.488 ± 2.172	4.769 ± 1.083
Elymus elymoides	0.488 ± 0.117	0.644 ± 0.270	1.156 ± 0.508	0.894 ± 0.266	2.719 ± 0.874
Elymus lanceolatus	3.669 ± 0.504	3.631 ± 0.316	4.356 ± 0.460	3.919 ± 0.461	3.738± 0.393
Pascopyrum smithii	0.000 ± 0.000	0.038 ± 0.038	0.038 ± 0.038	0.038 ± 0.038	0.994 ± 0.510
Poa secunda	9.825 ± 0.816	6.681 ± 1.447	9.013 ± 0.627	7.494 ± 1.353	9.269 ± 0.744
Pseudoroegeneria spicata	0.838 ± 0.321	0.206 ± 0.083	2.138 ± 0.204	3.794 ± 0.857	2.775 ± 0.615
Forbs:					
Agoseris glauca var. *dasycephala*	0.119 ± 0.118	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Allium spp.	0.075 ± 0.075	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Antenaria microphylla	0.075 ± 0.043	0.094 ± 0.094	0.000 ± 0.000	0.281 ± 0.169	0.000 ± 0.000
Arabis hirsuta var. pycnocarpa	0.113 ± 0.113	0.125 ± 0.083	0.025 ± 0.010	0.088 ± 0.052	0.356 ± 0.163
Arenaria spp.	0.000 ± 0.000	0.000 ± 0.000	0.0000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus purshii	0.113 ± 0.038	0.038 ± 0.038	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000
Astragalus spp. low	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus spp. tall	0.469 ± 0.180	1.181 ± 0.392	0.663 ± 0.078	0.681 ± 0.457	0.456 ± 0.117
Carex spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Castilleja angustifolia	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cordylanthus ramosus	0.313 ± 0.163	0.169 ± 0.124	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cryptantha flavoculata	0.094 ± 0.938	0.169 ± 0.124	0.000 ± 0.000	0.850 ± 0.354	0.038 ± 0.038
Cymopterus nivalis	0.250 ± 0.113	0.175 ± 0.121	0.263 ± 0.072	0.006 ± 0.006	0.194 ± 0.044
Erigeron engelmanni	0.038 ± 0.038	0.075 ± 0.043	0.044 ± 0.036	0.038 ± 0.038	0.000 ± 0.000
Erigeron linearis	1.050 ± 0.603	0.594 ± 0.272	0.488 ± 0.218	2.406 ± 1.161	0.188 ± 0.108
Eriogonum brevicaule	1.213 ± 0.631	0.000 ± 0.000	0.094 ± 0.094	0.000 ± 0.000	0.000 ± 0.000
Eriogonum brevicaule var. *micranthum*	0.094 ± 0.094	0.000 ± 0.000	0.000 ± 0.000	0.075 ± 0.043	0.038 ± 0.038
Lewisia pygmaea	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Linathus pungens	2.269 ± 0.631	0.669 ± 0.176	2.200 ± 1.043	1.794 ± 0.869	1.963 ± 0.714
Lomatium triternatum	0.325 ± 0.277	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Microseris nutans	1.119 ± 1.119	0.363 ± 0.257	0.581 ± 0.288	0.188 ± 0.142	0.500 ± 0.145
Phlox hoodii	2.406 ± 0.946	3.388 ± 0.319	3.731 ± 1.043	4.406 ± 0.940	2.744 ± 0.778
Phlox longifolia	1.019 ± 0.318	0.581 ± 0.213	1.394 ± 0.308	1.088 ± 0.741	3.669 ± 0.685
Phlox multiflora	0.263 ± 0.263	0.075 ± 0.075	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

APPENDIX E Continued.

	Treatments (1-5)				
Growth form/species	**Dixie Harrow**	**Chaining**	**Control**	**Med. Mow w/ Forb**	**Low Mow**
Salsola tragus	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Schoenocrambe linifolia	0.000 ± 0.000	0.075 ± 0.075	0.038 ± 0.038	0.000 ± 0.000	0.188 ± 0.094
Trifolium andinum var. *andinum*	2.388 ± 0.335	3.231 ± 0.755	2.906 ± 0.621	2.438 ± 0.725	2.831 ± 0.781
Unknown 1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Big Green Base	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.044 ± 0.044
Unknown Blue Lomatium	0.038 ± 0.038	0.119 ± 0.077	0.000 ± 0.000	0.000 ± 0.000	0.006 ± 0.006
Unknown Forb 1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.006 ± 0.006	0.000 ± 0.000
Unknown Forb 2	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown New Fuzzy Forb	0.000 ± 0.000	0.094 ± 0.094	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Penstemon	0.006 ± 0.006	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Viney Weed	0.000 ± 0.000	0.038 ± 0.038	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Weed	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Vicia spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Shrubs:					
Artemisia arbuscula	0.519 ± 0.187	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Artemisia tridentata wyomingensis	8.900 ± 1.648	7.775 ± 1.882	16.850 ± 1.916	7.631 ± 2.911	2.769 ± 0.204
Chrysothamnus viscidiflorus	1.744 ± 0.503	6.025 ± 0.996	6.500 ± 0.812	2.600 ± 0.886	2.788 ± 0.398
Krascheninnikovia lanata	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.188 ± 0.142	0.038 ± 0.038
Opuntia spp.	0.219 ± .219	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Tetradymia canescens	0.131 ± 0.089	0.188 ± 0.188	0.263 ± 0.089	0.000 ± 0.000	0.075 ± 0.043
Ground Cover:					
Grazed Grass	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Bareground	21.094 ± 2.727	22.263 ± 0.824	12.881 ± 1.218	12.831 ± 2.434	8.250 ± 1.051
Litter	17.606 ± 2.963	23.588 ± 2.682	23.506 ± 1.592	32.831 ± 5.088	46.563 ± 4.984
Rock	7.075 ± 1.593	4.613 ± 0.467	5.063 ± 0.646	6.238 ± 1.093	3.556 ± 0.433
Lichen	0.000 ± 0.000	0.000 ± 0.000	0.019 ± 0.019	0.000 ± 0.000	0.000 ± 0.000
Cryptogams	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

APPENDIX E Continued.

	Treatments (6-10)				
Growth form/species	**Heavy Spike**	**Prescribed Fire**	**High Mow**	**Aerator**	**Light Spike**
Grasses:					
Achnatherum hymenoides	0.000 ± 0.000	0.094 ± 0.094	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Achnatherum lettermanii	2.819 ± 1.134	3.113 ± 1.031	2.025 ± 1.057	3.806 ± 1.001	1.400 ± 0.823
*Elymus elymoide*s	0.469 ± 0.116	1.081 ± 0.433	0.981 ± 0.496	0.825 ± 0.227	2.219 ± 0.349
Elymus lanceolatus	3.131 ± 0.077	4.744 ± 0.450	3.450 ± 0.262	3.194 ± 0.807	3.975 ± 0.581
Pascopyrum smithii	0.075 ± 0.075	0.525 ± 0.233	0.000 ± 0.000	0.956 ± 0.286	0.488 ± 0.197
Poa secunda	6.294 ± 0.239	9.269 ± 1.360	8.506 ± 0.994	6.950 ± 0.439	8.363 ± 2.287
Pseudoroegeneria spicata	3.044 ± 0.693	0.313 ± 0.207	0.006 ± 0.006	0.000 ± 0.000	0.000 ± 0.000
Forbs:					
Agoseris glauca var. *dasycephala*	0.075 ± 0.075	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Allium spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Antenaria microphylla	0.000 ± 0.000	0.000 ± 0.000	0.038 ± 0.038	0.075 ± 0.043	0.000 ± 0.000
Arabis hirsuta var. pycnocarpa	0.006 ± 0.006	0.056 ± 0.036	0.044 ± 0.044	0.219 ± 0.062	0.088 ± 0.044
Arenaria spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus purshii	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Astragalus spp. low	0.000 ± 0.000	0.113 ± 0.113	0.463 ± 0.264	0.000 ± 0.000	0.175 ± 0.130
Astragalus spp. tall	0.863 ± 0.204	1.925 ± 0.358	0.231 ± 0.231	0.631 ± 0.170	0.244 ± 0.143
Carex spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Castilleja angustifolia	0.006 ± 0.006	0.000 ± 0.000	0.000 ± 0.000	0.013 ± 0.007	0.000 ± 0.000
Cordylanthus ramosus	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cryptantha flavoculata	0.150 ± 0.087	0.344 ± 0.217	0.038 ± 0.038	0.113 ± 0.038	0.006 ± 0.006
Cymopterus nivalis	0.000 ± 0.000	1.000 ± 0.406	0.588 ± 0.368	0.513 ± 0.144	0.431 ± 0.332
Erigeron engelmanni	0.119 ± 0.031	0.038 ± 0.038	0.000 ± 0.000	0.019 ± 0.006	0.000 ± 0.000
Erigeron linearis	6.025 ± 1.042	2.531 ± 1.185	4.794 ± 2.327	0.838 ± 0.543	0.075 ± 0.075
Eriogonum brevicaule var. *micranthum*	0.094 ± 0.094	0.388 ± 0.388	0.113 ± 0.072	0.044 ± 0.044	0.000 ± 0.000
Eriogonum ovalifolium	0.294 ± 0.197	0.175 ± 0.130	0.250 ± 0.117	0.113 ± 0.072	0.075 ± 0.043
Lewisia pygmaea	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Linathus pungens	0.750 ± 0.256	1.419 ± 1.038	2.381 ± 1.511	2.375 ± 0.506	1.444 ± 0.853
Lomatium triternatum	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Microseris nutans	0.281 ± 0.234	0.431 ± 0.242	0.125 ± 0.078	0.819 ± 0.180	0.131 ± 0.062
Phlox hoodii	3.356 ± 0.816	2.738 ± 0.290	2.188 ± 0.075	1.881 ± 0.199	3.100 ± 0.789
Phlox longifolia	0.075 ± 0.075	1.844 ± 0.257	0.481 ± 0.168	0.631 ± 0.148	0.831 ± 0.190
Phlox multiflora	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

APPENDIX E Continued.

	Treatments (6-10)				
Growth form/species	**Heavy Spike**	**Prescribed Fire**	**High Mow**	**Aerator**	**Light Spike**
Salsola tragus	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Schoenocrambe linifolia	0.000 ± 0.000	0.150 ± 0.061	0.000 ± 0.000	0.000 ± 0.000	0.119 ± 0.077
Trifolium andinum var. *andinum*	1.750 ± 0.437	3.163 ± 0.515	2.481 ± 0.416	3.463 ± 0.176	3.619 ± 0.400
Unknown 1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.038± 0.038
Unknown Big Green Base	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Blue Lomatium	0.000 ± 0.000	0.206 ± 0.095	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Forb 1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Forb 2	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown New Fuzzy Forb	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Penstemon	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Viney Weed	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Unknown Weed	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Vicia spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.006 ± 0.006	0.000 ± 0.000
Shrubs:					
Artemisia arbuscula	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Artemisia tridentata wyomingensis	11.738 ± 3.254	10.331 ± 2.557	16.019 ± 2.907	7.500 ± 1.281	19.225 ± 4.741
Chrysothamnus viscidiflorus	3.131 ± 0.964	3.169 ± 0.534	1.7000± 0.457	2.844 ± 0.526	3.500 ± 0.974
Krascheninnikovia lanata	0.219 ± 0.219	0.000 ± 0.000	0.256 ± 0.256	0.000 ± 0.000	0.000 ± 0.000
Opuntia spp.	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Tetradymia canescens	0.006 ± 0.006	0.675 ± 0.395	0.206 ± 0.048	0.350 ± 0.302	0.038 ± 0.038
Ground Cover:					
Grazed Grass	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Bareground	13.700 ± 2.985	23.638 ± 4.589	16.656 ± 4.380	19.106 ± 2.395	16.350 ± 1.184
Litter	26.744 ± 4.418	19.363 ± 2.880	30.006 ± 2.272	25.475 ± 3.644	25.056 ± 2.436
Rock	7.956 ± 0.939	5.956 ± 0.609	6.994 ± 0.872	5.275 ± 0.857	7.100 ± 1.331
Lichen	0.000 ± 0.000	0.169 ± 0.169	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Cryptogams	0.000 ± 0.000	0.000 ± 0.000	0.263 ± 0.177	0.000 ± 0.000	0.000 ± 0.000

APPENDIX F. Plant master list with plant symbol, common name, family, duration, and nativity. Nomenclature based on USDA PLANTS Database.

	Plant Symbol	Common Name	Family	Perennial/ Annual	Native/ Introduced
Grasses:					
Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth	ACHY	Indian ricegrass	Poaceae	P	N
Achnatherum lettermanii (Vasey) Barkworth	ACLE9	Letterman's needlegrass	Poaceae	P	N
Elymus elymoides Swezey	ELEL5	bottlebrush squirreltail	Poaceae	P	N
Elymus lanceolatus Gould	ELLA3	thickspike wheatgrass	Poaceae	P	N
Pascopyrum smithii (Rydb.) A. Löve	PASM	western wheatgrass	Poaceae	P	N
Poa secunda J. Presl	POSE	Sandberg bluegrass	Poaceae	P	N
Pseudoroegneria spicata (Pursh) A. Löve	PSSP6	Bluebunch wheatgrass	Poaceae	P	N
Forbs:					
Agoseris glauca (Pursh) Raf. var. dasycephala (Torr. & Gray) Jepson	AGGLD	pale agoseris	Asteraceae	P	N
Allium L. *spp.*	ALLIU	wild onion	Liliaceae	P	N
Antenaria microphylla Rydb.	ANMI3	littleleaf pussytoes	Asteraceae	P	N
Arabis hirsuta (L.) Scop var. *pycnocarpa* (M. Hopkins) Rollins	ARHIP	creamflower rockcress	Brassicaceae	A	N
Arenaria L. spp.	ARENA	sandwort	Caryophyllaceae	P	N
Astragalus purshii Dougl. ex Hook	ASPU9	woolypod milkvetch	Fabaceae	P	N
Castilleja angustifolia (Nutt.) G. Don	CAAN7	Northwest Indian paintbrush	Scrophulariaceae	P	N
Cordylanthus ramosus Nutt. Ex Benth	CORA5	bushy bird's beek	Scrophulariaceae	A	N
Cryptantha flavoculata (A. Nels.) Payson	CRFL6	roughseed crypthanta	Boraginaceae	P	N
Cymopterus nivalis S. Wats	CYNI3	snowline spring parsley	Apiaceae	P	N
Erigeron engelmanni A. Nels.	EREN	Englemann's fleabane	Asteraceae	P	N
Erigeron linearis (Hook.) Piper	ERLI	desert yellow fleabane	Asteraceae	P	N
Eriogonum brevicaule Nutt. var. *micranthum* (Nutt.) Reveal	ERBRM	shortstem buckwheat	Polygonaceae	P	N
Eriogonum ovalifolium Nutt. var. *ovalifolium*	EROV05	cushion buckwheat	Polygonaceae	P	N
Lewisia pygmaea (Gray) B.L. Robins.	LEPY2	alpine lewisia	Portulacaceae	P	N
*Linanthus pungens (*Torr.) J.M. Porter & L.A. Johnson	LIPU11	granite prickly phlox	Polemoniaceae	P	N
Lomatium triternatum (Pursch) Coult. & Rose	LOTR2	nineleaf biscuitroot	Apiaceae	P	N
Microseris nutans (Hook.) Schultz-Bip.	MINU	nodding microceris	Asteraceae	P	N
Phlox hoodii Richards	PHHO	spiny phlox	Polemoniaceae	P	N
Phlox longifolia Nutt.	PHLO2	long leaf phlox	Polemoniaceae	P	N
Phlox multiflora A. Nels.	PHMU3	flowery phlox	Polemoniaceae	P	N
Salsola tragus L.	SATR12	Russian thistle	Chenopodiaceae	A	I
Schoenocrambe linifolia (Nutt.) Greene	SCLI	flaxleaf plainsmustard	Brassicaceae	P	N
Trifolium andinum Nutt. var. *andinum*	TRANA3	Intermountain clover	Fabaceae	P	N

APPENDIX F Continued.

	Plant Symbol	Common Name	Family	Perennial/ Annual	Native/ Introduced
Shrubs:					
Artemisia arbuscula Nutt. ssp. longiloba (Ostern.) L.M. Shulz	ARARA	little sagebrush	Asteraceae	P	N
Artemisia tridentata Nutt. *wyomingensis* Beetle & Young	ARTRW8	Wyoming big sagebrush	Asteraceae	P	N
Chrysothamnus viscidiflorus (Hook.) Nutt.	CHVI8	yellow rabbitbrush	Asteraceae	P	N
Krascheninnikovia lanata (Pursh) A.D.J. Meeuse & Smit	KRLA2	winterfat	Chenopodiaceae	P	N
Opuntia Mill. spp.	OPUNT	pricly cactus	Cactaceae	P	N
Tetradymia canescens DC.	TECA2	spineless horsebrush	Asteraceae	P	N
Unknown species:					
unk Big Green Base (5-4)	-	-	-	-	-
unk 1	-	-	-	-	-
unk *Astragalus* L. spp. low	-	-	-	-	-
unk *Astragalus* L. spp. tall	-	-	-	-	-
unk Blue Lomatium	-	-	-	-	-
unk *Carex* L. spp.	-	-	-	-	-
unk Forb 1 (4-2)	-	-	-	-	-
unk Forb 2 (2006)	-	-	-	-	-
unk New Fuzzy Forb	-	-	-	-	-
unk *Penstemon* Schmidel spp.	-	-	-	-	-
unk *Vicia* L. spp.	-	-	-	-	-
unk Viney Weed	-	-	-	-	-
unk Weed (2006)	-	-	-	-	-