Evaluating Treatments for Native Grassland Restoration

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INTRODUCTION

Background

The Great Plains biome has long been known for its vast landscapes of rolling grasslands. Today, the native grasslands remaining in this region are considered among the ecosystems at greatest risk in the United States (Samson and Knopf 1994, 1996, Noss 1995, Samson et al. 2004). This is primarily due to their direct conversion to croplands and other agricultural uses, as well as the indirect effects of changes to historical ecosystem processes and dynamics (Vodehnal and Haufler 2008, Fuhlendorf et al. 2012) and the spread of invasive species (Koper et al. 2010, Sinkins and Otfinowski 2012). The resulting cumulative changes in native ecosystem diversity have been dramatic, and the corresponding impacts to biodiversity have been of increasing concern to wildlife professionals, among others. For example, various species of grassland birds, particularly those adapted to grasslands of intermediate to tall heights have shown precipitous declines in the recent past (Samson and Knopf 1994, Knopf 1996, Samson et al. 2004). As a group, grassland birds in North America are declining faster than any other (Sauer et al. 2011), though less is known about the impacts of grassland losses on other species groups such as insects (Arenz and Joern 1996). Due to these concerns, the South Dakota Wildlife Action Plan (SDWAP) (www.sdgfp.info/Wildlife/Diversity/Comp_Plan.htm) and the Nebraska Wildlife Action Plan (NWAP) (www.ngpc.state.ne.us/wildlife/programs/legacy) set goals for restoring native grassland diversity in order to maintain the biodiversity of each state. Of the 90 species of greatest conservation need identified in the SDWAP, 26 species are associated with grassland ecosystems, with 16 species at risk from reductions in amounts of the specific native grassland ecosystems on which they depend. Of the 80 Tier I species of greatest conservation need identified in the NWAP, 34 species are associated with grassland ecosystems.

Current estimates of grassland loss based on satellite mapping have shown substantial reductions in amounts of grassland ecosystems. However, such coarse scale analyses only reveal part of the picture. Finer scale analyses that consider the true diversity of ecosystems occurring historically reveal a far more serious loss of functional ecosystems. For example, a study conducted to help implement the SDWAP in the Missouri Coteau (EMRI report to SDGFP 2008) documented that a high percentage of native ecosystems present historically are now absent from this landscape, particularly those occurring on high agriculturally productive sites such as loamy soils. A study conducted in the Thunder Basin of Wyoming (Haufler et al. 2008; www.emri.org) revealed similar high levels of ecosystem loss. Where native ecosystems still remain, many sites had high levels of exotic species, a finding also reported by Cully et al. (2003). Sinkins and Otfinowski (2012) found grazed native ecosystems invaded by exotic grasses often retained these exotics even 40 years after grazing was removed. These and other studies demonstrate the extent and severity of these ecosystem changes as well as the tremendous need to not only halt the loss of these systems but to restore native grassland ecosystem diversity.

Recognizing the severity of grassland declines, the North American Grouse Partnership (NAGP) launched a large collaborative effort to develop a grassland conservation plan focusing on providing native grassland ecosystem diversity, and used prairie grouse, specifically lesser prairie-chickens (*Tympanuchus* *pallidicinctus)*, greater prairie-chickens (*T. cupido*) and sharp-tailed grouse (*T. phasianellus*) as flagship species to demonstrate restoration needs, amounts, and distributions. The resulting Grassland Conservation Plan for Prairie Grouse (Grassland Plan) (Vodehnal and Haufler 2008) was adopted for implementation by the Association of Fish and Wildlife Agencies (AFWA) in 2008. This plan sets conservation goals for native grassland ecosystem diversity across the Major Land Resource Areas (MLRA's) (USDA Natural Resources Conservation Service 2006) of the Great Plains covering 550 million acres of the U.S. and Canada. Efforts to implement this plan are supported by a large number of cooperating agencies and organizations.

Grasslands in South Dakota and Nebraska primarily occur within the northern mixed prairie and sandhills prairie as mapped by Kuchler (1985). Northern mixed grass ecosystems support western wheatgrass (*Pascopyrum smithii)* and depending on location, mixed with needle-and-thread (*Hesperostipa comate*), green needlegrass (*Nassella viridula*), and porcupine grass (*Hesperostipa spartea*) as additional cool season or C_3 species, and blue grama (*Bouteloua gracilis*) as an associated warm season or C_4 species. Many remaining grassland areas within the northern mixed grass prairie have been invaded by Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) (Bragg and Steuter 1996, Haufler et al. 2008; www.emri.org). The sandhills prairie is part of the northern tallgrass prairies and differs from the northern mixed prairie since it is primarily dominated by C_4 grass species including big blustem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), sand bluestem (*A. hallii*), blue grama, hairy grama (*B. hirsute*), prairie sandreed (*Calamovilfa longifolia*) and sand dropseed (*Sporobolus cryptandrus*), with lesser amounts of the C_3 grass species, needle-and-thread.

Fire was a primary disturbance process in the northern mixed prairie (Bragg and Steuter 1996). Ode et al. (1980) and Whisenant (1990) noted in the absence of fire, exotic cool season grasses such as smooth brome, Kentucky bluegrass, and Japanese (field) brome (*Bromus japonicas*) can invade. Grazing was also a primary process influencing plant species at a site, with big bluestem, little bluestem, indiangrass (*Sorghastrum nutans*), and green needlegrass usually decreasing with grazing pressure, and blue grama, ironweed (*Vernonia baldwinii*), ragweed (*Ambrosia* spp.), and curlycup gumweed (*Grindelia squarrosa)* usually increasing with grazing pressure (Branson and Weaver 1953, Brand and Goetz 1986).

The SDWAP and the Grassland Plan focus on maintaining and restoring native grassland ecosystem diversity across ecological sites within a Major Land Resource Area (MLRA), as classified by NRCS. The NWAP used a different classification system, but has the same goal of restoring native grassland diversity. The SDWAP and the Grassland Plan include descriptions of historical state and transition models for each ecological site, or groupings of ecological sites, within a MLRA. These models illustrate the historical influence of grazing and fire, as well as their interactions, on the plant community of a given ecological site. Understanding these relationships provides the ability to describe the full range of functional native grassland ecosystems. An assumption of these plans was that without attention to ecological relationships and identification of specifically needed ecosystems, the effectiveness of grassland conservation efforts would be greatly reduced, resulting in questionable outputs in terms of biodiversity conservation. Understanding reference conditions and how current vegetation conditions differ due to past grazing practices, changes to fire regimes, invasion by exotic species, changing climate and drought patterns, and other factors will be critical if sustainable plant communities and biodiversity are to be maintained.

In South Dakota, a challenge for restoration is maintaining the native grass communities dominated by C_3 grasses while discouraging the dominance of exotic cool season grasses including Kentucky bluegrass and smooth brome. Additional challenges include invasion of some sites by cheatgrass (*Bromus tectorum*) and field brome, expansion and maintenance of blue grama dominance due to domestic grazing influences, and spread of redcedar (*Juniperus virginianus*) due to fire exclusion. In Nebraska, a primary challenge is reversing the impacts of fire exclusion causing an increase in redcedar and other woody species, as well as reversing invasion of various exotic species including cheatgrass.

A primary purpose of this project was to demonstrate how the SDWAP, NWAP, and Grassland Plan can be implemented on working lands of willing agricultural producers using innovative incentive-based programs and practices to restore native grasslands while respecting and addressing the needs of the producer. Innovative combinations of practices were applied and monitored to document both conservation gains and productivity of treated sites.

This project partnered with a number of agencies and organizations, including South Dakota Department of Game, Fish, and Parks (SDGFP), Nebraska Game and Parks Commission (NGPC), USFWS, North American Grouse Partnership (NAGP), South Dakota Grassland Coalition, Ducks Unlimited, The Nature Conservancy, Pheasants Forever, the Theodore Roosevelt Conservation Partnership, and others. Matching funding was provided by SDGF&P, NGPC, and the Nebraska Chapter of the NAGP.

Project Objectives

The objective of this project was to initiate on-the-ground conservation of native grassland ecosystems consistent with the objectives of the SDWAP, the NWAP, and the Grassland Conservation Plan. Specifically, agricultural producers in South Dakota and Nebraska were identified who were willing to allow the application of restoration treatments to selected areas within their ownership. This project demonstrated to the broader community of producers the benefits which can be achieved through these conservation efforts, and showed how an expanded and continuing incentive-based program can be put into place to adopt similar practices on additional lands.

METHODS

Site Selection

Agricultural producers willing to be cooperators on this project were identified in both South Dakota and Nebraska with assistance from SDGFP, NGPC, Pheasants Forever, USFWS Partners for Fish and Wildlife Program, the South Dakota Grasslands Coalition, and others. Producers with the ability to make the largest contribution to the project objectives and a high likelihood of providing the best example of grassland restoration were preferred. For each selected EQIP eligible producer, a management plan was developed for the areas of the property meeting both the project and producer's objectives. Treatments were coordinated by project personnel with agreement from each producer. Treatments developed for a particular site were based on consideration of the underlying ecological site, current condition on the site, and the targeted restoration condition.

The desired native ecosystem conditions were described based on the ecological site(s) in the selected treatment area. The specific historical state selected to serve as a reference community was the state with the least representation on the landscape today, when compared with historical amounts, which in most cases was the plant community influenced by a light grazing regime combined with a relatively frequent fire regime. A description of the reference community in terms of its composition, structure, and desired processes to be restored was developed using Ecological Site Descriptions (http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecoscience/desc/). Targeting the light grazing/frequent fire plant community as a preferred state for setting restoration goals is further supported by the large number of species of concern associated with these historical grassland conditions. Various management practices were evaluated and identified as treatment options to move a site towards the desired composition, structure, and processes of the reference plant community. Management practices employed included prescribed fire, herbicide control of exotic and noxious weeds including cheatgrass and field brome, mechanical removal of redcedar, planting with desired native grass and forb species, and prescribed grazing designed to favor the light grazing plant community implemented through a 10-year grazing plan administered by the partnering state agency to maintain the desired conditions. Each specific site was evaluated to determine the practice, or combination of practices, expected to produce the desired conditions and that also were compatible with the operations of the producer.

Where possible, pre and post-treatment vegetation monitoring of sites was conducted to determine treatment effectiveness and to document the responses produced. During the first year of this project, some sites scheduled for redcedar removal were identified too late in the year to make pre-treatment vegetation sampling possible and the site was photographed for reference purposes. In addition, pre-treatment sampling of sites in South Dakota planted to native grasses was not conducted as these sites consisted of bare ground. While identification of control plots to compare to treatment plots would have been desirable to monitor annual variations not caused by treatments, this was only feasible at two sites.

Permanent plots were established by marking two ends of a 50 m transect with metal tent pegs, and both locations recorded with a GPS. While monitoring was conducted for the duration of this project, specific methods, baseline conditions, and initial results were documented to allow future monitoring if desired. Monitoring plots were located in treatment areas following a stratified random design. Sites were stratified by ecological site and existing vegetation, and by different treatments, if more than one treatment combination was used at a site. Replicated plots were randomly located within each ecological site/existing vegetation condition and treatment combination.

Vegetation cover was measured using Daubenmire frames at set distances along a delineated transect. Photographs were taken of each transect. A larger plot (15X25m) was delineated and sampled for occurrence of rare plant species. Vegetation productivity was measured using double sampling procedures on sub-plots located 50 m away from the sampling transects, in order to minimize sampling effects on the vegetation response to treatments.

Quality control of vegetation sampling was assured in several ways. First, random selection for plot locations was used (computer generated points within a mapped cover type/ecological site combination). Vegetation sampling was conducted by highly skilled vegetation experts who knew the vegetation in the area (vegetation sampling personnel listed in acknowledgements section). All vegetation crews were trained by the same individual to assure uniformity in application of vegetation sampling methods. All data were carefully screened for any anomalies, and any data points that appeared spurious were double checked. All data entry was double checked to assure correct entry into digital databases.

Treatments

Treatments and their combinations were selected for each site based on the desire to move an existing plant community toward a reference plant community. The effectiveness of a specific treatment or treatment combination on an ecological site to produce a desired plant community is not well documented in the literature, although past studies of various treatments provide some guidance for selection of treatments or their combinations. Specifically, six treatments or treatment combinations were identified for this study including:

- Prescribed fire
- Prescribed grazing
- Prescribed grazing and fire
- Mechanical shrub and tree removal
- Herbicide treatment
- Prescribed fire and herbicide treatment

The following sections provide a description of each treatment and discuss its expected influence on plant communities.

Prescribed Fire

Fire is recognized as a primary disturbance process for Great Plains native grasslands (Daubenmire 1968, Vogl 1974, Wright and Bailey 1982, Higgins et al. 1989, Anderson 1990, Fuhlendorf et al. 2011). Fire is known to release nutrients to the soil, especially nitrogen, that benefit many grassland plants (Higgins et al. 1989). In addition, fire reduces the amount of old plant material which improves precipitation reaching the soil (Higgins et al. 1989, Seastedt and Ramundo 1990), soil temperatures (Hulbert 1969, Higgins et al. 1989, Seastedt and Ramundo 1990), and the structure of the plant community (Higgins et al. 1989, Collins and Gibson 1990). Fire also prevents various woody species such as redcedar from invading grasslands (Bragg and Hulbert 1976, Collins and Adams 1983, Anderson 1990, Kaul and Rolfsmeier 1993, Van Auken 2009).

The timing of fire can also affect the response of the plant community. Higgins et al. 1989 reported:

> *"Cool- and warm-season species growing together may respond differently to the same fire; seasonal timing is critical (Bragg 1982; Wright and Bailey 1982). Some plants may be actively growing and especially susceptible at the time of the fire while others will be dormant and less susceptible. Many cool-season plants will be actively growing during spring and fall fires, but most warm-season plants either will be dormant or will have not yet expended a significant amount of stored energy on new growth. In summer, cool-season plants have nearly stopped growth or are dormant. Fire at this time is usually detrimental to warm-season species (Vogl 1974). Spring burning will reduce species competition. Repeated burning on March 1 resulted in a sharp decrease in the number of Kentucky bluegrass plants in Iowa (Ehrenreich 1959). Bluegrass, a cool-season exotic, also decreased sharply by repeated burning in early March (Bailey 1978; Engle and Bultsma 1984). Most native grasses are still dormant at this time when Kentucky bluegrass, beginning to grow, becomes highly susceptible to heat injury from fire. Thus, warm-season native grasses have higher yields because of decreased competition from cool-season invaders such as Kentucky bluegrass. Native annuals are usually encouraged by burning if the fires occur at the appropriate time (Daubenmire 1968). Many annuals, as well as shortlived perennials, are opportunistic or pioneer species which require the open soil, reduced competition, and full sunlight characteristic of many post-burn sites (Vogl 1974)."*

Higgins et al. (1989) also reported:

> *"Silver-leaf scurf pea (Psoralea argophylla), lead plant (Amorpha canescens), blue false indigo (Baptista australis), pasque flower (Anemone patens), many-flowered aster (Aster falcatus), lady slipper (Cypripedium spp), white camas (Zigadenus elegans), wild lily (Lilium philadelphicum), tall gayfeather (Liatris ligulistylis), Maximilian sunflower (Helianthus maximilianii), sweet clover (Melilotus spp), purple prairie clover (Dalea purpurea), and harebell (Campanula rotundifolia) increased in abundance following spring burns."*

Anderson et al. (1970) found burning of prairies in the Flint Hills of Kansas increased big bluestem when burns were conducted mid to late spring but observed little to no effects after early spring burns. Sideoats grama (*Bouteloua curtipendula*) was not noticeably influenced by burning, while Kentucky bluegrass was nearly eliminated. Blue grama and hairy grama were favored by burning in early to mid-spring.

Gartner et al. (1978) investigated the effects of different burn seasons in western South Dakota and found that winter, late spring, and fall burns all significantly reduced field (Japanese) brome. Western wheatgrass was positively affected by winter and fall burns but declined with late spring burns. Engle and Bultsma (1984) studied spring burns during a drought in north central South Dakota and observed reduced amounts of Kentucky bluegrass and green needlegrass post-burn.

Eichhorn and Watts (1984) reported on vegetation responses to a wildfire in eastern Montana and found forbs had the greatest abundance 3-4 years after the burn and decreased after that, while burning eliminated non-sprouting woody species such as big sagebrush (*Artemisia tridentata*) and Rocky Mountain juniper (*Juniperus scopulorum*) whereas abundances of sprouting shrubs such as choke cherry (*Prunus virginiana*), snowberry (*Symphoricarpos spp*), and rose (*Rosa spp*) increased. Higgins et al. (1989) noted:

> *"Dramatic increases in sprouts of western snowberry often occur after a first fire, particularly on areas that have been idle for several years. A sequence of spring fires on the same area will eventually reduce abundance. Significant reduction requires five or more fires in 10 years or less. One or two fires followed by a series of rest years will result in an increase of aerial coverage. Hot burns in late summer to early fall have caused severe root burns on western snowberry plants."*

Ehrenreich and Aikman (1957), Knapp and Hurlbert (1986), Davis et al. (1987), and Johnson (1987) reported an increase in amounts of big bluestem following a spring burn. Similarly, little bluestem has also been reported to respond positively to spring burns (Ehrenreich and Aikman 1957, 1963). In contrast, Kentucky bluegrass has been reported to decrease following spring burns by Curtis and Partch (1948), Ehrenreich and Aikman (1963), Zedler and Loucks (1969) Richards and Landers (1973) Henderson et al. (1983), Johnson (1987), and Knops (2006). Collins and Gibson (1990) reported that spring burns will increase C_4 species while decreasing C_3 species that are actively growing during that season.

Bahm et al. (2011) studied the effects of burning as well as several herbicide treatments in efforts to restore native grasslands on South Dakota sites invaded by smooth brome and Kentucky bluegrass. Untreated control plots averaged 64% smooth brome cover and 38% Kentucky bluegrass cover after the third growing season, while plots burned in the fall of the first year had 20% smooth brome and 19% Kentucky bluegrass. DeKeyser et al. (2013) found smooth brome and Kentucky bluegrass had become the dominant species between 1984 and 2007 in North Dakota native prairies not having been burned or grazed, with only a few of the more xeric sites still maintaining a high proportion of native species. When Kentucky bluegrass increases in dominance, diversity of native species has been shown to decline (Grant et al. 2009, Miles and Knops 2009).

Towne and Kemp (2008) studied biannual burns over 14 years in the Konza Prairie in Kansas and reported

> *"species richness and diversity increased significantly with summer burning but remained stable through time with annual spring burning. After 14 yrs, species richness was 28% higher in prairie that was burned in the summer than in prairie burned in the spring. Canopy cover of big bluestem (Andropogon gerardii Vitman) and Indiangrass (Sorghastrum nutans*

[L.] Nash) increased significantly over time with both summer and spring burning, whereas heath aster (Symphyotrichum ericoides [L.] Nesom), aromatic aster (Symphyotrichum oblongifolium [Nutt.] Nesom), and sedges (Carex spp.) increased in response to only summer burning. Kentucky bluegrass (Poa pratensis L.) cover declined in both spring-burned and summer-burned watersheds."

Copeland et al. (2002) compared effects of spring and late summer burning and reported a twofold increase in subdominant species from summer burns with no change from the spring burns. Spring burns increased the amounts of flowering big bluestem 4 fold while summer burns increased this by 11 fold, but did not change the amounts of tillering by indiangrass or switchgrass (*Panicum virgatum*). Howe (1994a, 1995) studied season of burning on replicated prairie sites in Wisconsin, and found that spring fires favored summer flowering species while summer fires favored spring flowering species. Howe (1994b) recommended using a varied burning schedule as well as a varied grazing regime in prairie restoration in order to maintain the diversity of native species. A similar suggestion was made by Brudvig et al. (2008) who studied species responses to fire and grazing and reported similar results. Howe (2011) monitored responses of grasses and forbs on sites burned in May and July at 3 year intervals compared to unburned sites in Wisconsin. He reported that spring burning increased the number of native forbs present by 2 compared to unburned pastures, while July burns increased the number by 4. C_4 grasses were increased to 76% cover by spring burning compared to 52% cover on summer burn sites and 39% cover on unburned sites. Vermeir et al. (2011) studied effects of a summer burn on plant composition in a cool season plant community in the northern Great Plains. They reported that C_3 grasses increased with the exception of needle-and-thread following burning, while needle-and-thread remained unchanged. Strong et al. (2013) examined the effects of both summer and fall burning on purple threeawn (*Aristida purpurea*) and found that both summer and fall fires reduced purple threeawn, but summer fires caused a greater reduction especially when a wet spring followed the burn. Biomass of C_3 perennial grasses was not changed by either summer or fall fires.

In general, fire has been found to increase species richness in various grassland settings (Curtis and Partch 1948, Netherland 1979, Anderson and Bailey 1980, Humphrey 1984, Blankespoor 1987). However, Hulbert (1985), as reported by Collins and Gibson (1990) found that annual burns in a tallgrass prairie decreased species richness, but reported increased richness when burning intervals were 2 and 4 years apart.

In summary, fire was a key ecosystem process for grasslands of the Great Plains including the northern mixed grass prairies and northern tallgrass prairies, keeping woody plants from invading many areas, reducing buildup of litter, recycling nutrients, and influencing the composition and structure of plant communities (Higgins et al. 1989, Bragg and Steuter 1996). Season of burn affects the specific responses of plant communities. Spring burns favor warm season grasses, especially big bluestem in tallgrass prairies and blue grama in mixed grass prairies, and can set back cool season grasses including the exotic species of Kentucky bluegrass and smooth brome (Higgins et al. 1989). Summer or early fall burns have not been as extensively studied, but may have more impact on warm season grasses and may stimulate cool season grasses. Fire causes reductions in grass cover for one or more years post-burn, but then grasses return to previous levels or increase to greater amounts than occurred pre-burn. Forbs increase in amounts and richness following burning, especially after summer burns. In some studies, forbs reached maximum richness 3-4 years post-burn, and then began to decrease in numbers (Eichhorn and Watts 1984). Season of burn and location in terms of moisture and productivity gradients have an influence on the responses by specific grassland ecosystems to fire.

Prescribed Grazing

Economic Considerations

Prescribed grazing as defined by NRCS is "the controlled harvest of vegetation with grazing animals, managed with the intent to achieve a specific objective" (http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026090.pdf). Thus, prescribed grazing refers to a potentially diverse set of practices, depending upon the specific objective. For this project, prescribed grazing was used as a treatment to help move vegetation conditions toward the desired plant community. As previously discussed, the desired plant community identified for this study represents the historical conditions produced by the interaction of light grazing and frequent fire disturbance processes. This objective was discussed with the producers and their input and ideas on how to achieve this condition were incorporated into the treatments, where possible.

Various studies have indicated that while some grazing practices provide the best sustainable economic return for producers, they would not be recommended to maintain other ecosystem services such as biodiversity or overall rangeland health. Dunn et al. (2010) studied economic return associated with grazing which maintains pastures in low, good, or excellent range condition as defined by range management professionals in western South Dakota, and found the best economic returns were associated with maintaining low to good range conditions. Maintaining excellent range condition resulted in a lower economic return. Thus, South Dakota producers may be faced with the dilemma of choosing between grazing practices recommended by natural resource managers which produce excellent range conditions and may supply other values such as optimal habitat for some wildlife species, or maximizing economic return. With a high percentage of grasslands in private ownership, the economic needs of producers must be recognized and measured. West (1996) noted tradeoffs must be made between maximum production for livestock and the best possible wildlife habitat. Fuhlendorf et al. (2012) stated:

> *"Rangeland management continues to operate under the utilitarian paradigm appropriate to societal values of the 20th century and by and large has failed to provide management guidance to reverse degradation of several highly valued ecosystem services."*

Morton et al. (2010) studied attitudes of landowners in Iowa and Missouri, and noted there was strong support for grazing as a land use practice, but limited support for fire as a land management practice. While spread of redcedar was widely viewed as a concern, use of fire to control this spread was not well supported. Further, they found that landowners dependent on agricultural income did not report environmental or grassland quality factors as being important. This conundrum has been a persistent challenge to setting objectives for prescribed grazing on both public and private lands, where managing for conditions associated with light grazing regimes is unlikely to produce the maximum sustainable return in livestock production. Consequently, light grazing practices are often not considered as a management objective because of the needs or desires of agricultural producers to maximize economic returns. So in reality, this component of ecosystem diversity and its associated optimal habitat conditions for various wildlife species of concern is typically not an objective for most prescribed grazing programs. Rather, producers and many range conservationists in settings like western South Dakota may recommend prescribed grazing which maintains low to good range condition with good economic return, but that does not produce the plant communities associated with historical light grazing regimes. Further, Toombs and Roberts (2009) found a very high percentage of NRCS Environmental Quality Incentive Program funds in western states use practices which encourage uniform grazing pressure across a ranch in an effort to reduce negative effects such as degradation of riparian areas, but also to maximize grass utilization and thus economic returns to ranchers. Toombs and Roberts (2009) argue this is contrary to what prescribed grazing objectives should be, if broader conservation objectives including biodiversity are considered.

Haufler and Kernohan (2001, 2009) emphasized the importance of incentive programs for private landowners to provide a mechanism to make ecological objectives either economically advantageous to the producer or at least economically neutral. Most incentive programs today provide varying rates of matching support, requiring the producer to provide some of the costs for implementing practices. This is true for most practices identified by NRCS conservation programs, USFWS conservation programs, and state habitat improvement programs. Kemp and Michalk (2007) suggested that government subsidies may be needed to offset costs associated with managing grasslands for various ecosystem services not realized when maximizing economic return. This recommendation may be especially relevant where prescribed grazing is needed to produce a plant community representative of historical light grazing regimes. If biodiversity objectives for a landscape require the full range of native ecosystem diversity be developed on private lands, then incentive programs may be needed to offset the reduction in economic returns to the producer. Gutwein and Goldstein (2013) interviewed ranchers involved in a collaborative effort to manage for biodiversity and evaluated their interest in receiving ecosystem payments to offset grazing losses. They reported good receptivity for such payments but found there were multiple factors to consider in addressing ranch sustainability and profitability.

Ecological Considerations

Briske et al. (2008) prepared a synthesis paper on research conducted on rotational grazing as a prescribed grazing tool. They first summarized general principles concerning effects of grazing and listed the following:

- "Chronic, intensive grazing is detrimental to plant growth and survival;
- Primary productivity can be increased by lenient grazing and decreased by severe grazing;
- Forage quality is often improved by frequent grazing; and
- Species composition of plant communities can be modified in response to the frequency, intensity, and seasonality of grazing."

They concluded rotational grazing is no more effective as a grazing practice than continuous grazing and suggested:

> *"Plant production was equal or greater in continuous compared to rotational grazing in 87% (20 of 23) of the experiments. Similarly, animal production per head and per area were equal or greater in continuous compared to rotational grazing in 92% (35 of 38) and 84% (27 of 32) of the experiments, respectively… Continued advocacy for rotational grazing as a superior strategy of grazing on rangelands is founded on perception and anecdotal interpretations, rather than an objective assessment of the vast experimental evidence."*

Based on this synthesis, empirical data suggest stocking rate and timing of grazing are the two variables most important to developing a prescribed grazing plan designed to achieve specific objectives.

Stocking rate is the primary driver of the vegetation (and animal) response to prescribed grazing (Holechek et al. 2004). A basic question for specifying a prescribed grazing plan is what is meant by stocking rate? Allen et al. (2011) defined stocking rate as:

> *"The relationship between the number of animals and the total area of the land in one or more units utilized over a specified time; an animal to-land relationship over time."*

Smart et al. (2010) examined stocking rates and their relationship to various other measures including utilization rates, grazing efficiency, and harvest efficiency by cattle. They proposed that a grazing production index (GPI) should be used to assess and assign stocking rates. GPI was defined as the animal units (using an equivalent of a 454 kg cow either dry or with a calf up to 6 months of age) times days of use, divided by the weight of forage on a site. Weight of forage was defined as the peak standing crop, or "the total amount of plant material per unit of space at a given time that it is at its maximum."

Smart et al. (2010) compared GPI's they categorized as high, moderate, or light stocking rates, and found significant effects on grazing efficiencies, harvest efficiencies, and in most cases utilization. Utilization was "*the vegetation biomass that disappears from the plant community, not only due to grazing by livestock, but also to weathering, trampling, fouling, senescence, and intake or clipping by insects or wildlife,"* although controls to compare non-cattle utilization were not included in the studies examined. They reported grazing and harvest efficiencies increased with GPI, and the best cattle returns were achieved when stocking rates remained between what was considered moderate to heavy. This finding again demonstrates the economic challenges to establishing plant communities maintained by light stocking rates. Smart et al. (2010) reported utilization rates varied from 24-69%, with the average utilization rate across the six studies examined being 39% for light, 50% for moderate, and 64% for heavy stocking rates. Light utilization is usually described by range conservationists as 25-30%, a rate achieved in only one of the studies examined by Smart et al. (2010). Grazing efficiencies were lower at lighter utilization rates because other losses of forage appeared to be more constant, so grazing by cattle became a lower percentage of the total loss of forage from all causes.

The Smart et al. (2010) results reveal several challenges to developing prescribed grazing plans to meet biodiversity objectives. First, it reinforces the dilemma producer's face when striving to meet economic objectives and balancing these with other conservation objectives. Second, it reveals some of the complexities encountered when setting appropriate stocking rates. To address these challenges, Smart et al. (2010) recommended using GPI to specify the number of animals to be grazed for a set length of time divided by the amount of forage present. However, the amount of forage present is almost never known by a producer when planning a grazing regime. In addition, determining appropriate stocking rates is confounded by the annual variation in plant productivity due to different precipitation amounts. In reality, the variability in annual productivity due to precipitation may be greater than the variability caused by treatments (Gillen et al. 1998, Derner and Hart 2007, Fuhlendorf et al. 2009, Vermeir et al. 2011), making the ability to determine forage availability a moving target from year to year. Vermeire et al. (2008) found weather patterns had a greater influence on plant communities in eastern Montana than any grazing regimes studied over a 6 year period.

Grazing during the growing season reduces available forage prior to reaching peak standing crop, so peak standing crop is seldom known. Stocking rates are often based on an estimate of a site's forage production, assuming average weather conditions. This can result in stocking rates being too high from a desired utilization standpoint half of the time (when weather conditions such as precipitation are less than average), and to be lower for half of the time. During drought conditions this can result in substantially higher GPI than the grazing plan might designate. Residual effects of high stocking rates in subsequent growing seasons such as reduced productivity (Vallentine 1990), may further influence long-term grazing effects unless the stocking rate is adjusted downward to account for this actual change in GPI. All of this reveals the complex challenges encountered when developing and implementing grazing prescriptions expected to produce plant communities which are characteristic of light grazing conditions.

Quantifying heavy, moderate, or light stocking rates requires various considerations to determine what qualifies. The effects of different levels of grazing are influenced by the number and density of animals being grazed, the length of time the animals are grazed, the season of grazing, the ecological site being grazed and its historical exposure to grazing, the amount of forage available, and the frequency of grazing. Grazing may have effects on the composition and structure of the plant community, soil properties, or processes of the specific grassland ecosystems, with different effects occurring in different types of ecosystems or ecological sites. Several examples can help demonstrate these differences. The Great Plains, as discussed previously, was historically influenced by a combination of grazing and fire, with bison (*Bos bison*) and other native herbivores influencing the composition and structure of the vegetation. However, in addition to climate, grazing and fire had different influences depending upon the location, as exemplified by the potential vegetation ranging from short-grass, mixed grass, and tallgrass regions. Even greater differences in these effects have been noted in studies of other grass/shrub ecosystems where grazing by large herbivores was not a major process historically, such as in many sagebrush (*Artemesia* spp.) ecosystems. In these ecosystems, grazing has been shown to be destructive to biological soil crusts (Shinneman and Baker 2009, Shinneman et al. 2008, Ponzetti et al. 2007) often leading to invasion by cheatgrass and other exotic species. In some cases, restoration of the soil crust can take centuries (Belknap 2003). Thus, being specific to the location and type of ecological site when setting objectives for prescribed grazing, is clearly important.

Further challenges to defining stocking rates occur with specifics of use. When considering whether a site has been influenced by a light, moderate, or heavy grazing regime, it is usually assessed relative to the average levels of grazing pressure applied to a site when assessed over a reasonable time frame, such as a decade or more. So for example, a site identified as having a plant community influenced by a light grazing regime, may have experienced moderate to heavy grazing pressure from time to time but on average, the site experienced light grazing pressure. Short duration mob grazing of a tallgrass site on the Great Plains with a high utilization rate could be considered heavy grazing, especially if this occurred annually during the growing season. However, if this occurred only once in 6 years then it might be considered light grazing. In contrast, continuous grazing of a pasture by a small number of livestock that removed a small proportion of the annual forage production would be considered light grazing, but could still result in some areas within the pasture that exhibited heavier grazing conditions due to concentrated grazing of these areas with light grazing over much of the remainder of the pasture.

The effects of different stocking rates have been shown to vary in different types of grasslands. Augustine et al. (2010) and Derner and Hart (2007) found no significant grazing effects on shortgrass (blue grama) systems in Colorado. Gillen et al. (1998) found that higher stocking rates caused reductions in tallgrass species and increases in shortgrass species in Oklahoma. Switchgrass initially increased with grazing pressure but then decreased over time. Schuman et al. (1999) examined differences between heavily grazed and lightly grazed sites in western wheatgrass/blue grama plant communities in Wyoming and found peak standing crop decreased under heavy grazing as did western wheatgrass, while blue grama increased.

Short rotation, high intensity grazing by bison conducted 3 times/year in June, July, and August on replicated restored tallgrass prairies in Wisconsin caused decreases in C_4 grass species, especially little bluestem, and allowed invasion by exotic C_3 grasses (Jackson et al. 2010). Smart et al. (2012) reported western wheatgrass decreased and blue grama increased when clipped to represent 50% utilization for 3 growing seasons in a row. Spreading clipping out between growing and dormant seasons did not produce this effect. Smart et al. (2011) found plant species diversity was highest in tallgrass prairie remnants where minimal use of herbicides and light grazing was applied relative to sites with higher levels of grazing or no grazing. Stephenson et al. (2013) compared short duration grazing to deferred-rotation grazing in the Sandhills of Nebraska and reported an increase in prairie sandreed of 42% over 10 years under deferred-rotational grazing, but no other consistent differences in plant communities, plant productivity, or livestock performance were noted.

The results obtained by these studies reveal several things. First, there is a paucity of replicated studies conducted within similar grassland systems as to the effects of grazing on plant community dynamics, productivity, and other ecosystem measures. Particularly lacking are studies which consider a variety of influencing factors including combinations of stocking rate, season of use, ecological sites and their productivities, current plant community, longevity of the study in years, weather patterns, historical use of a site, and other interacting variables such as fire. Second, there are clear differences in response to grazing when evaluated relative to different grassland systems and different current plant communities. Each plant community can have species favored by specific grazing practices and others that will decrease, with some species response also being influenced by different precipitation gradients. Third, few studies have attempted to set specific objectives in terms of producing a desired plant community by using specified grazing practices. Because of this, the ability to use prescribed grazing to effectively shift plant compositions to desired conditions on specific sites remains largely an art, rather than a science.

Based on general knowledge of species sensitivities to grazing levels in northern mixed grass prairies, native cool season grasses will decrease in relative amounts with repeated moderate to heavy grazing pressure during the growing season, with some species being more sensitive than others, such as green needlegrass and Indian ricegrass. Western wheatgrass and needle-and-thread grass can tolerate moderate stocking rates, but will decline with higher stocking rates. Blue grama and buffalograss (*Bouteloua dactyloides*) will increase with moderate to heavy repeated grazing, and can eventually dominate many northern mixed grass ecological sites. Some ecological sites favor the relative dominance of these two species even in the absence of grazing. Amounts of other species are also influenced by the abiotic characteristics of different ecological sites, for example greater amounts of needle-and-thread, green needlegrass, and Indian ricegrass can be expected on loamy, clayey, and sandy ecological sites, respectively, relative to their amounts on other ecological sites.

In northern tallgrass ecosystems, tallgrass species can be expected to decrease with repeated grazing at higher stocking rates. Little bluestem is one of the first to decrease, followed by big bluestem, Indiangrass, and eventually switchgrass. Sideoats grama will be an increaser species in this system. Where northern tallgrass systems intergrade with northern mixed grass systems, other transitional effects may occur. If grazing pressure is applied during the summer, some cool season grasses such as western wheatgrass may be able to respond, but little empirical data exist to support this relationship. However, studies have documented a relationship between summer grazing and an increase in exotic cool season grasses such as Kentucky bluegrass and smooth brome, which in many instances may eventually dominate a site. These species have also been shown to increase on sites where both grazing and fire are excluded. In southern tallgrass ecosystems, the transitions with grazing are similar to those described for the northern tallgrass ecosystems but without the described interaction with northern mixed grass species.

Prescribed Grazing and Prescribed Fire

As discussed in the previous sections, historical disturbance processes in the Great Plains included both grazing and fire, and these two disturbance processes interacted to influence plant communities depending on the ecological site, and other factors such as landscape location. Fuhlendorf et al. (2012), McGranahan et al. (2012), Fuhlendorf et al. (2009a), and Vodehnal and Haufler (2008) all discuss the interactions of grazing and fire and their combined influence on the diverse ecosystems native to the Great Plains. When identifying treatments to restore native grasslands, combining these two disturbance processes becomes an important consideration. However, given the specifics discussed concerning the difficulty in applying prescribed fire and prescribed grazing individually to achieve desired restoration conditions, the interaction of the two treatments becomes even more complex. Much more research will be required to understand the interaction of these two treatments and their influence on restoring desired plant communities within the diversity of ecosystems in the Great Plains.

Mechanical Shrub and Tree Removal

Limb et al. (2010) examined herbaceous vegetation cover and composition across a gradient of redcedar invasion. They reported species richness and herbaceous canopy cover declined with increasing redcedar cover, but the decrease in species richness was consistent with species area relationships and no ecological thresholds were identified. This indicates the removal of redcedar should produce increases in species richness and cover proportional to the level of redcedar cover. Peirce and Reich (2010) found tallgrass prairies invaded by redcedar returned to plant communities similar to non-invaded sites within 3 years post removal of the redcedar. Alford et al. (2012) examined relationships of redcedar pretreatment amounts and post treatment responses by vegetation and small mammals. They reported both flora and fauna monitored in the study returned to grassland communities in the first two years post treatment regardless of the level of redcedar invasion, although they noted a very wet year occurred post treatment which may have helped with the quick recovery of the plant communities.

In general, the literature supports mechanical treatment as an effective practice for restoring grassland plant communities invaded by redcedar. In locations where prescribed fire cannot be safely or effectively applied, mechanical removal of redcedar is an option. In particular, mechanical treatment may be applied in some areas in order to produce conditions that would allow prescribed fire in the future. Mechanical treatments can be expensive, especially where heavy infestations of redcedar occur. However, they do not require a site be rested from grazing prior to treatment as is needed in most locations for prescribed fire to be used. If compensation to a landowner is required for resting a pasture to be burned, then prescribed fire can also be an expensive treatment. However, the return of functional grasslands and the increased herbaceous productivity of treated sites will often offset the costs of either treatment.

Herbicide Treatments

Hendrickson and Lund (2010) treated plant communities dominated by Kentucky bluegrass, smooth brome, or native species with various treatments. They reported burning Kentucky bluegrass in the spring followed by application of imazapic reduced the relative abundance of Kentucky bluegrass. Smooth brome was reduced by mowing and raking a site. The burning and herbicide application did reduce the overall biomass of grass the first year after treatment, but overall biomass was back to pretreatment levels by the third year post treatment. Bahm (2009) studied the responses of Kentucky bluegrass and smooth brome to application of various herbicides applied at different times of the year for pastures in South Dakota. He found both species could be reduced by the application of herbicides and the cover of native grasses increased. However, neither species were eliminated from treatment pastures, so repeated treatments would be needed to entirely remove these species from the site as well as the seedbed.

Study Site Descriptions

A total of 16 South Dakota and 10 Nebraska producers participated in this project to evaluate treatments for restoring native grasslands. A variety of treatments were used on the South Dakota sites while the range of treatments on Nebraska sites, were more limited. Tables 1 and 2 identify the general location of South Dakota and Nebraska sites, respectively, as well as the treatment practices applied and the acres treated.

Table 1. Location of study sites in South Dakota as well as the number of acres treated and the treatment practice(s) applied to restore native grasslands.

Study Site ID	County	Practice	Acres
SD1	Haakon County	Rx fire, Herbicide, Rx grazing	621
SD2	Haakon County	Rx fire, Herbicide, Rx grazing	380
SD3	Lyman County	Rx fire, Herbicide, Rx grazing	354
SD4	Hyde County	Rx fire, Herbicide, Rx grazing	185
SD5	Aurora County	Rx fire, Rx grazing	35
SD16	Sandborn County	Rx fire, Rest, Rx grazing	275
SD6	Jones County	Native grass seeding, Rx grazing	557
SD7	Bennett County	Native grass seeding, Rx grazing	171
SD8	Jerauld County	Native grass seeding, Rx grazing	16
SD9	McPherson County	Native grass seeding, Rx grazing	65
SD10	Bon Homme County	Native grass seeding, Rx grazing	31
SD11	Sanborn County	Native grass seeding, Rx grazing	25
SD12	Lyman County	Cedar removal, Rx grazing	67
SD13	Lyman County	Cedar removal, Rx grazing	150
SD14	Lyman County	Cedar removal, Rx grazing	225
SD15	Lyman County	Cedar removal, Rx grazing	88
		TOTAL:	**3245**

Table 2. Location of study sites in Nebraska as well as the number of acres treated and the treatment practice(s) applied to restore native grasslands.

Study Site ID	County	Practice	Acres
NE1	Loess Canyons	Cedar removal, Rx grazing	268
NE2	Loess Canyons	Cedar removal, Rx grazing	80
NE3	Loess Canyons	Cedar removal, Rx grazing	191
NE4	Loess Canyons	Cedar removal, Rx grazing	73
NE5	Loess Canyons	Herbicide	20
NE6	Loess Canyons	Cedar removal, Rx grazing	320
NE7	Loess Canyons	Cedar removal, Rx grazing	353
NE8	Beatrice area	Brush control, Rx fire, Rx grazing	77
NE9	Beatrice area	Cedar removal, Rx grazing	300
NE10	Beatrice area	Cedar removal, Rx grazing	240
		TOTAL:	**1922**

Precipitation Patterns

Plant community responses to treatments are strongly influenced by weather patterns following treatments. In particular, it is well documented that grassland communities are strongly influenced by the levels of precipitation, especially during the spring and summer which are the growing seasons for C_3 and C_4 species respectively. This project did not have the capability of monitoring precipitation levels at each treatment site. However, Table 3 lists the precipitation for 4 locations spread across South Dakota and Nebraska and covering the range of locations included in this project.

The precipitation data show 2010 and 2011 had precipitation levels above average during the growing season in 2010 and around averages during 2011 for all 4 regions. In 2012, precipitation levels were generally well below average for the year and the growing season, especially in the western regions represented by Elm Springs, SD and North Platte, NE. In 2013, precipitation was variable across locations and across the months, relative to the previous 3 years.

Desired Restoration Plant Communities

The identification of desired restoration conditions for native grasslands was dependent on both study site location and the ecological sites present. In all locations, the desired plant community was one that represented a light grazing regime combined with a relatively frequent fire return interval and consistent with the potential of each ecological site. In western South Dakota, this usually represented a mixed grass prairie system with dominance of native C_3 grasses and a mix of native forbs, as appropriate for each ecological site. The desired plant community on clayey sites was a western wheatgrass/green needlegrass dominated community with lesser amounts of porcupine grass, big bluestem, sideoats grama, and a diversity of native forbs including American vetch, white prairie aster, dotted blazing star, and others. On loamy sites, needle-and-thread would occur as a dominant along with western wheatgrass and to a lesser extent, green needlegrass. On sandy sites, the green needlegrass would be replaced by Indian ricegrass as a dominant species along with western wheatgrass and needle-and-thread. Thin upland sites would have similar composition as the clayey site, but annual productivity would be lower than on the clayey site.

For sites located in eastern South Dakota, a primary concern was reducing amounts of Kentucky bluegrass and smooth brome. With the higher levels of rainfall in this part of the state, the desired condition was to increase the amounts of preferred tallgrasses, specifically big bluestem, little bluestem, Indiangrass, and to a lesser extent switchgrass with a mix of native forbs. While western wheatgrass, needle-and-thread, and green needlegrass were also desirable species, the treatments targeting the exotic C_3 grasses were also expected to have a negative influence on the native C_3 grasses.

In Nebraska, the primary concern was invasion of grassland areas by redcedar. The desired restoration conditions were to increase amounts of preferred native grasses particularly big and little bluestem, Indiangrass, needle-and-thread, sand dropseed, and a mix of native forbs.

Table 3. Precipitation levels by month and annually for 4 locations in both South Dakota and Nebraska during the timeframe of the project. An annual number is not provided for 2013 as November and December were not available at the time this table was developed. Source: Weather Stations, National Climatic Data Center (www.ndcd.ncaa.gov)

	Normal (mean; 1981 to 2010) and Monthly Precipitation Levels by Year (in inches)																			
	ELM SPRINGS, SD					HURON, SD					NORTH PLATTE, NE					WESTERN, NE				
MONTH	Normal	2010	2011	2012	2013	Normal	2010	2011	2012	2013	Normal	2010	2011	2012	2013	Normal	2010	2011	2012	2013
Jan	0.4	0.2	0.7	0.2	0.5	0.5	0.7	1.6	0.7	0.3	0.3	0.0	0.0	0.1	0.3	0.7	0.0	0.6	0.0	0.4
Feb	0.6	0.5	1.1	0.4	0.1	0.6	0.9	1.5	2.1	1.1	0.5	0.5	0.0	1.4	0.6	1.0	0.0	0.3	1.9	0.6
Mar	1.2	0.8	1.1	0.1	0.5	1.5	1.8	1.4	1.0	0.8	1.1	1.9	0.0	0.6	0.4	2.1	0.0	0.5	1.3	1.6
Apr	1.8	3.0	1.7	2.0	2.0	2.3	2.4	2.6	5.4	2.9	2.3	3.4	1.9	3.9	1.2	2.6	3.1	3.1	3.7	3.2
May	3.6	4.9	6.7	1.5	4.4	3.1	3.7	3.3	1.9	5.5	3.3	2.1	2.6	1.0	1.2	4.6	4.1	7.8	1.4	7.6
Jun	2.7	2.9	3.1	1.6	1.5	3.9	7.5	3.9	3.1	3.5	3.4	7.0	3.1	0.5	2.6	4.3	5.9	2.8	4.4	2.8
Jul	1.9	1.4	2.4	0.8	4.1	2.9	6.4	3.5	0.5	1.9	3.1	5.2	3.4	0.8	4.9	3.8	1.6	1.7	1.1	1.4
Aug	1.6	1.4	2.9	0.9	1.4	2.4	1.6	2.4	1.9	1.2	2.3	2.5	1.9	1.8	2.1	3.6	2.1	4.1	0.8	2.6
Sep	1.3	2.5	1.0	0.0	0.5	2.5	3.5	0.5	0.6	1.4	1.4	1.3	1.1	0.1	1.6	3.3	4.0	1.1	1.6	2.7
Oct	1.5	0.4	0.4	0.5	4.3	1.8	0.9	1.4	1.1	5.4	1.6	0.8	2.9	0.4	1.3	2.0	0.1	1.0	2.4	3.6
Nov	0.7	0.3	0.4	0.2	-	0.9	0.1	0.4	0.2	-	0.6	0.8	0.1	0.0	-	1.4	2.1	1.8	0.0	-
Dec	0.5	0.7	0.4	0.1	-	0.5	1.4	0.2	1.1	-	0.4	0.0	0.3	0.1	-	1.1	0.1	2.0	0.8	-
Total	**17.8**	**19.0**	**22.0**	**8.2**	**-**	**22.9**	**30.9**	**22.7**	**19.7**	**-**	**20.2**	**25.4**	**17.3**	**10.7**	**-**	**30.4**	**23.1**	**26.9**	**19.2**	**-**

Results

South Dakota

SD1

Study site SD1 was located in Haakon County, South Dakota, and consisted of a 621 acre grass dominated pasture. At the initiation of the study, the site had relatively low productivity and was dominated by buffalograss and blue grama with lesser amounts of western wheatgrass and field brome. The site was a combination of clayey and thin upland ecological sites (Figure 1). Multiple treatments were applied to restore the site to the desired condition. Table 4 provides a description and time frame for treatment and vegetation monitoring conducted on site SD1. Table 5 presents the results of the vegetation sampling for SD1.

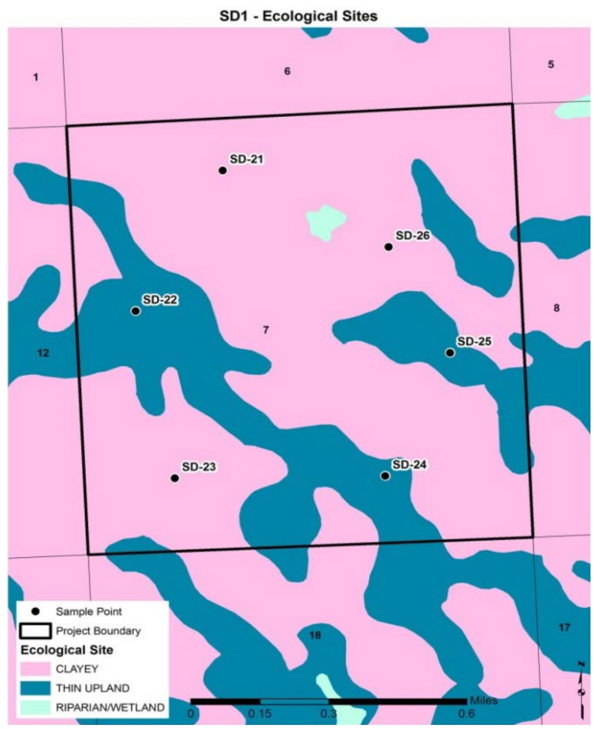

Figure 1. Ecological site map for SD1 showing locations of vegetation sample plots.

Table 4. Treatment time frame, treatment type, treatment objectives, and vegetation sampling conducted on study site SD1.

Year/Season	Treatment	Objective	Vegetation Sampling
2010 – growing season	Rx Grazing - rested	Allow build-up of fuels to support prescribed fire	Pre-treatment
2010 – late summer/early fall	Rx Fire	Remove vegetation/stimulate regrowth of natives	
2010 – late fall (prior to freeze)	Herbicide – Imazapic (2.5 oz/ac)	Control field brome and cheatgrass regrowth	
2011	Rx Grazing - rested	Protect regrowth	Post-treatment
2012	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2013	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – light to moderate	Maintain desired conditions	

Table 5. Study site SD1 - relative plant cover of species with greater than 1% cover (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	Rx FIRE and HERBICIDE and Rx GRAZING			
	Pre-Treatment	Post-Treatment		
Species	**2010**	**2011**	**2012**	**2013**
common yarrow	0.6 (0.3)	**1.8 (0.9)***	0.5 (0.4)	0.1 (0.1)
fringed sagewort	0.7 (0.4)	0.1 (0.1)	0.02 (0.02)	0.04 (0.02)
buffalograss	39.7 (3.2)	**24.2 (3.5)***++**	40.0 (12.0)	**62.1 (8.5)*+**
blue grama	4.5 (0.7)	**9.7 (2.1)**++**	**20.5 (6.0)**+**	10.8 (4.4)
field brome	13.5 (2.2)	**0.02 (0.01)***++**	**0***++**	**2.0 (1.5)***++**
needleleaf sedge	2.0 (0.4)	**0.9 (0.4)***	3.8 (1.2)	**1.5 (0.4)*++**
prairie junegrass	1.1 (0.4)	3.5 (1.7)	0.4 (0.3)	0.6 (0.5)
green needlgrass	4.0 (0.9)	4.1 (2.1)	**0 ***++**	**0.7 (0.4)**++**
western wheatgrass	30.3 (3.0)	34.4 (2.2)	32.6 (7.4)	18.4 (4.6)
prairie coneflower	1.0 (1.0)	0.2 (0.2)	0	0
scarlett globemallow	1.3 (0.3)	0.9 (0.2)	0.7 (0.2)	**0.2 (0.1)**++**
common dandelion	0	**4.1 (1.4)**++**	0	0
American vetch	0.3 (0.3)	**11.6 (2.7)**++**	0	1.3 (0.4)
sixweeks fescue	0.3 (0.2)	0.7 (0.3)	0	0
Site Measures				
Grass Productivity	933.4 (124.1)	**1422.3 (99.6)***++**	**599.0 (71.3)***	**520.8 (68.4)**++**
Total Productivity	1012.1 (119.2)	**1870.8 (58.0)***++**	**604.1 (70.1)**++**	**589.8 (75.0)**++**

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

The pre-treatment data showed both ecological sites were very similar in their plant composition both before and after treatments. The data documented the presence of higher amounts of field brome, buffalograss, and blue grama than desired and lower amounts of western wheatgrass and green needlegrass. A number of native forbs were present, but in relatively small amounts. The treatments effectively reduced the level of field brome, with significantly lower amounts of this species in all three years of post-treatment sampling. The presence of slightly more of this species in 2013 could indicate that this species was again expanding in the pasture possibly influenced by the return of grazing. Western wheatgrass and green needlegrass were quite variable in amounts in the post-treatment years, with no significant differences noted. Similarly, buffalograss and blue grama were quite variable, but certainly did not display any decreases following the treatments including the 2 years of rest from grazing. These results show that the combination of burning with a light application of imazapic herbicide effectively reduced the amount of field brome for at least 3 years post-treatment. The effects of fire and rest from grazing did not produce a noticeable shift in the plant community within the three 3 years after burning. The dry conditions of 2012 may have limited the response of the plant community to treatments, with continuing effects of the drought still evident in 2013 with reduced productivity.

SD2

Study site SD2 was located in Haakon County, South Dakota and consisted of two different grass dominated pastures. For the purpose of this study these 2 sites are referred to as the north site and the south site and represent 220 and 160 acres, respectively. At the initiation of this study, the north site was characterized by a previous seeding of mixed native grasses but also contained substantial levels of non-native species including cheatgrass, field brome, and various weeds. Only one ecological site, loamy, was present in the north site (Figure 2). The south site contained a mixture of western wheatgrass, buffalograss, field brome, smooth brome, sideoats grama, and Kentucky bluegrass at the initiation of the project. The south site was represented by primarily the clayey upland ecological site (Figure 3), with only a small portion of a loamy ecological site occurring in the southeast corner. Several small wetland ecological sites were also present. Table 6 provides a description and time frame for treatment and vegetation monitoring conducted on study site SD2 by north and south site. Table 7 presents the results of the vegetation sampling for SD2.

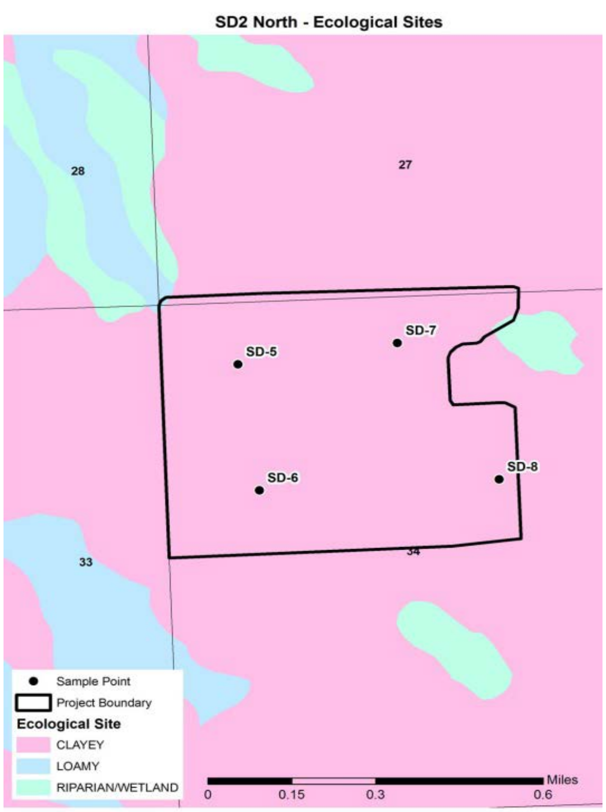

Figure 2. Ecological site map for SD2 northern pasture, showing locations of vegetation sample plots.

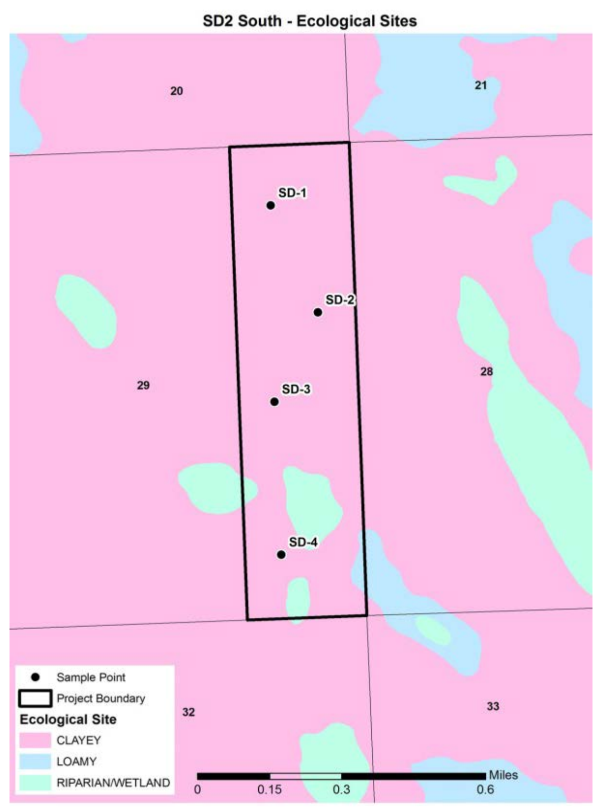

Figure 3. Ecological site map for SD2, southern pasture, showing locations of vegetation sample points.

Table 6. Treatment time frame, treatment type, treatment objectives, and vegetation sampling conducted on study site SD2 for 2 treatment areas.

Year/Season	Treatment	Objective	Vegetation Sampling
NORTH SITE - TREATMENT AREA			
2010 – growing season	Herbicide - Imazapic (5 oz./ac)	Reduce non-native grass species	Pre-treatment
2011	Rx Grazing- light to moderate	Establish desired conditions	Post-treatment
2012	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2013	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – light to moderate	Maintain desired conditions	
SOUTH SITE - TREATMENT AREA			
2010 – late summer	Rx fire	Reduce non-native grass species	Pre-treatment
2010 – fall	Herbicide – Imazapic (2.5 oz/ac)	Control field brome in following growing season	
2011	Rx Grazing - rested	Establish desired conditions	Post-treatment
2012	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2013	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – light to moderate	Maintain desired conditions	

Results for study site SD2 showed treatments were effective in reducing field brome from both sites and continued to keep levels very low for the 3 years post treatment. Both the combination of burning and herbicide, and the herbicide alone, produced significant reductions. The rate of herbicide application on the south site, which also received prescribed fire, was only approximately half the rate applied to the north site where residual vegetation was thought to require the higher application rates. Green needlegrass significantly increased on the north site, while western wheatgrass increased on both north and south sites. Kentucky bluegrass decreased on the south site while crested wheatgrass showed an increasing trend on the north site but was significant only during 2012. Smooth brome did not appear to be affected by the treatments. A mix of native and non-native forbs persisted on both sites with few significant differences noted between pre- and post-treatment conditions.

Table 7. SD-2 Relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	SOUTH PASTURE - Rx FIRE and HERBICIDE				**NORTH PASTURE - HERBICIDE**			
	Pre-Treatment	**Post-Treatment**			**Pre-Treatment**	**Post-Treatment**		
Species	**2010**	**2011**	**2012**	**2013**	**2010**	**2011**	**2012**	**2013**
common yarrow	1.9 (0.7)	2.9 (0.8)	1.0 (0.5)	**0.2 (0.1)***	0	0.2 (0.2)	0	0
crested wheatgrass	0	0	0	0	0.4 (0.4)	3.3 (3.2)	**6.7 (1.7)**+**	6.2 (3.3)
fringed sagewort	1.4 (1.3)	0	0.2 (0.1)	0.03 (0.03)	2.2 (1.0)	**0.4 (0.4)*+**	**0+**	**0.01 (0.01)+**
cudweed sagewort	3.2 (1.1)	0.9 (0.5)	**0.6 (0.4)***	1.8 (1.4)	0	0	0	0
sideots grama	0	0	0	0	18.1 (8.8)	17.9 (6.8)	24.3 (8.8)	6.1 (1.8)
buffalograss	8.4 (5.1)	5.3 (1.8)	9.9 (2.1)	**16.4 (3.9)**+**	0.4 (0.4)	2.3 (2.3)	0	0
blue grama	3.3 (0.4)	3.8 (1.3)	9.7 (2.8)	**14.8 (5.0)+**	0.3 (0.2)	0.4 (0.3)	1.8 (1.3)	0
field brome	9.9 (2.6)	**1.9 (1.3)+**	**0.2 (0.2)**+**	**1.0 (0.6)**+**	29.5 (14.1)	**8.2 (4.9)+**	**2.9 (2.5)+**	**0.5 (0.3)+**
smooth brome	0.1 (0.1)	1.7 (1.8)	1.2 (1.2)	1.7 (1.7)	7.9 (5.0)	4.5 (2.0)	8.4 (7.2)	9.6 (8.1)
needleleaf sedge	1.5 (0.9)	0	1.8 (1.4)	2.4 (1.0)	0.1 (0.1)	0.1 (0.1)	0	0
threadleaf sedge	7.6 (7.6)	4.7 (4.3)	6.9 (6.4)	7.3 (7.3)	0	0	0	0
field bindweed	0	0.3 (0.3)	0	0.2 (0.2)	10.7 (3.7)	2.8 (0.9)	3.8 (2.6)	**0.9 (0.3)*+**
prairie fleabane	0	0	0.1 (0.1)	0	0	4.4 (4.3)	0	0
needle and thread	1.4 (1.4)	1.8 (1.8)	1.6 (0.6)	0.3 (0.3)	0	0	0	0
prairie junegrass	1.7 (1.1)	1.9 (1.1)	0.7 (0.6)	0.6 (0.3)	0	0	0	0
prickly lettuce	0	0	0	0	1.6 (1.6)	0.2 (0.1)	0	0
sweetclover	0	**1.8 (1.0)***	5.6 (3.3)	0.4 (0.2)	0	0	0	0.04 (0.04)
alfalfa	0	0	0	0	7.6 (5.5)	0.4 (0.4)	0.2 (0.2)	1.0 (1.0)
green needlegrass	0.6 (0.2)	0	0	0	8.2 (2.0)	13.6 (3.1)	11.5 (3.9)	**24.2 (5.4)**+**
western wheatgrass	22.7 (5.7)	**29.7 (5.0)**+**	**50.0 (10.6)**+**	**46.7 (8.3)**+**	10.1 (4.7)	**37.1 (6.7)***+**	35.0 (16.1)	**49.1 (13.7)*+**
Kentucky bluegrass	27.4 (4.6)	29.4 (7.7)	**5.5 (2.3)**+**	0.1 (0.1)***+	0	0	2.45 (1.9)	0.1 (0.1)
prairie coneflower	1.4 (1.0)	0.4 (0.2)	1.1 (0.9)	0	0	0	0	0
scarlett globemallow	1.6 (0.6)	1.2 (0.7)	1.0 (0.6)	**0.4 (0.2)*+**	0	0	0	0
sand dropseed	2.4 (1.8)	1.5 (0.7)	1.4 (0.6)	3.0 (2.0)	0.1 (0.1)	0	0.3 (0.3)	0
white heath aster	2.1 (1.1)	0.9 (0.7)	0.4 (0.4)	0.1 (0.1)	1.0 (0.9)	0.8 (0.5)	0.2 (0.2)	1.1 (1.0)
common dandelion	0	**3.8 (0.9)**+**	0	0.3 (0.1)	0.3 (0.3)	0.4 (0.3)	0.1 (0.1)	0.2 (0.1)
American vetch	0	1.8 (1.0)	0	0.6 (0.2)	0	0.6 (0.3)	0.1 (0.1)	0.5 (0.2)
Site Measures								
Grass Productivity	1757.4 (547.4)	1216.5 (273.1)	897.0 (139.3)	1444.2 (169.5)	987.9 (198.4)	**3930.1 (562.3)**++**	**852.4 (148.2)+**	**2687.1 (351.5)***++**
Total Productivity	1871.6 (503.3)	1615.3 (133.3)	1065.2 (91.5)	1841.2 (361.1)	998.6 (197.1)	**4193.2 (567.3)**++**	**894.3 (167.4)+**	**2821.0 (390.0)***++**

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

SD3

Study site SD3 was located in Lyman County, South Dakota and consisted of a 354 acre grass-dominated pasture. The producer is an advocate of holistic range management practices which utilize intensive rotational grazing regimes so treatment objectives were developed to evaluate the effect of some of these grazing practices with other types of treatment. At the initiation of this study, the pastures selected for treatment contained a mix of grass species dominated by buffalograss, blue grama, and western wheatgrass followed by green needlegrass and field brome. The study site was represented by three upland ecological sites with clayey being the most extensive type, followed by smaller amounts of shallow clay and thin upland (Figure 4). A wet meadow dominated wetland ecological site was also present in the northern half of the study site. Four treatment areas (Figure 4) were identified with treatment area 1 representing 151 acres, treatment area 2 representing 52 acres, treatment area 3 representing 53 acres, and treatment area 4 representing 98 acres.

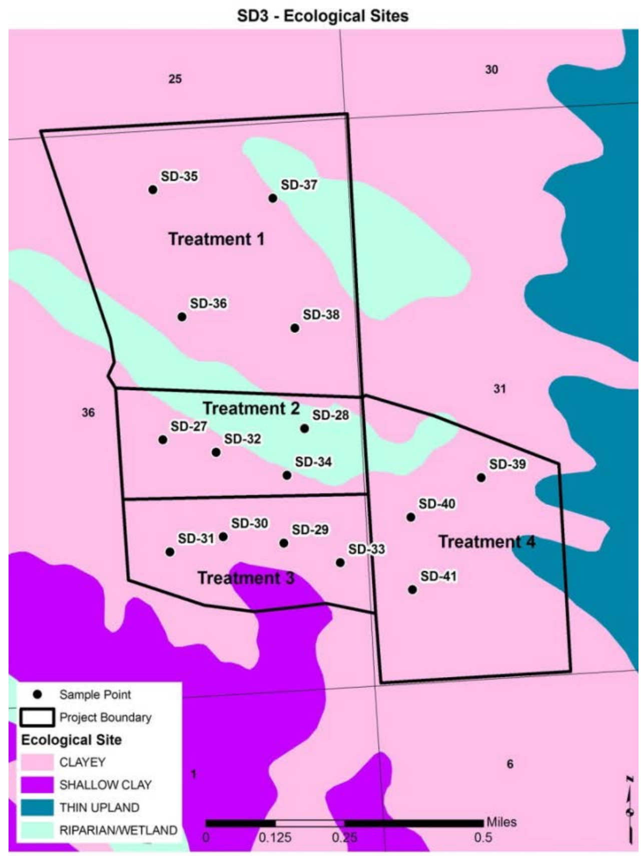

Figure 4. Ecological site map for SD3 showing locations of vegetation sample points.

Table 8 provides a description and time frame for treatment and vegetation monitoring conducted on site SD3. Table 9 presents the results of the vegetation sampling.

Table 8. Treatment time frame, treatment type, treatment objectives, and vegetation sampling conducted on study site SD3 for 4 treatment areas.

Year/Season	Treatment	Objective	Vegetation Sampling
TREATMENT AREA 1			
2010	Rx Grazing – mob (1200 yearlings @ 7 days)	Maintain grass community	Pre-treatment
2011	Rx Grazing- same	Maintain desired conditions	Post-treatment
2012	Rx Grazing – same	Maintain desired conditions	Post-treatment
2013	Rx Grazing – same	Maintain desired conditions	Post-treatment
2014 to 2021	Rx Grazing – not specified	Maintain desired conditions	
TREATMENT AREA 2			
2010 – fall	Rx Fire followed by imazapic (2.5oz/ac)	Stimulate grass production and control field brome	Pre-treatment
2011	Rx Grazing – high intensity, short duration (1800 cattle @1 day)	Establish desired conditions	Post-treatment
2012	Rx Grazing – same	Establish desired conditions	Post-treatment
2013	Rx Grazing – same	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – same	Maintain desired conditions	
TREATMENT AREA 3			
2010	Rx Fire followed by imazapic (2.5 oz/ac)	Stimulate grass production and control field brome	Pre-treatment
2011	Rx Grazing – rested	Establish desired conditions	Post-treatment
2012	Rx Grazing – moderate	Establish desired conditions	Post-treatment
2013	Rx Grazing – moderate	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – moderate	Maintain desired conditions	
TREATMENT AREA 4			
2010	Rx Grazing – high intensity rotation; 1 day spring/1 day summer	Control	Pre-treatment
2011	Rx Grazing – same	Maintain desired conditions	Post-treatment
2012	Rx Grazing – same	Maintain desired conditions	Post-treatment
2013	Rx Grazing – same	Maintain desired conditions	Post-treatment
2014 to 2021	Rx Grazing – not specified	Maintain desired conditions	

Table 9. SD3 - Treatments 1 and 2, relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	TREATMENT 1 - Rx GRAZING				**TREATMENT 2 - Rx FIRE and HERBICIDE and Rx Grazing**			
	Pre-Treatment	**Post-Treatment**			**Pre-Treatment**	**Post-Treatment**		
Species	**2010**	**2011**	**2012**	**2013**	**2010**	**2011**	**2012**	**2013**
common yarrow	4.5 (2.5)	3.0 (1.4)	0.5 (0.2)	0.01 (0.01)	1.0 (0.4)	1.8 (1.8)	**0.1 (0.1)*+**	**0 +**
buffalograss	11.3 (6.7)	**18.2 (6.1)+**	**23.8 (9.3)**+**	**20.7 (7.2)+**	30.8 (5.3)	47.6 (4.5)	51.6 (11.3)	45.6 (14.4)
blue grama	30.9 (2.1)	**7.4 (3.4)**+**	**16.7 (6.4)*+**	21.3 (4.3)	28.3 (12.5)	11.5 (3.5)	15.2 (4.8)	33.4 (8.9)
field brome	11.7 (6.4)	**20.0 (13.0)+**	**22.6 (4.0)*+**	**36.5 (7.2)**+**	2.9 (1.0)	**0.1 (0.1)*+**	**0.02 (0.02)*+**	**0.2 (0.1)*+**
needleleaf sedge	0	1.0 (0.7)	**1.9 (0.6)**+**	**0.8 (0.3)+**	0.9 (0.5)	0.8 (0.3)	1.5 (0.5)	0.1 (0.1)
western tansymustard	0.5 (0.1)	0	0	0	0	0	0	**0.1 (0.1)+**
spreading wallflower	0	0	0	0	0	0	0	0.03 (0.03)
curlycup gumweed	0.1 (0.1)	0	0	0	2.0 (1.9)	0	0	0.2 (0.2)
green needlgrass	0.5 (0.5)	3.1 (2.2)	2.0 (1.6)	**1.1 (0.7)****	1.4 (1.4)	0.6 (0.2)	0.1 (0.1)	0
western wheatgrass	37.3 (6.5)	35.2 (5.4)	29.6 (3.2)	**19.1 (5.7)**+**	28.1 (6.8)	27.0 (6.4)	30.8 (7.7)	**19.0 (6.6)***
scarlett globemallow	1.0 (0.3)	0.5 (0.2)	0.8 (0.1)	0.4 (0.2)	1.2 (0.2)	1.7 (0.8)	**0.5 (0.2)*+**	**0.3 (0.1)**+**
sand dropseed	0	0	1.5 (1.5)	0.1 (0.1)	0	0	0	0
common dandelion	0.2 (0.2)	**2.5 (0.2)***+**	0	0	1.4 (0.5)	**2.5 (0.5)***+**	**0*+**	**0.01 (0.01)*+**
field pennycress	0	0	0	0.02 (0.01)	0	0	0	0.06 (0.03)
longbract spiderwort	0	**1.2 (0.1)***+**	0	0	0	**0.7 (0.2)**+**	0	0
American vetch	0.1 (0.1)	**4.9 (1.2)**+**	0.2 (0.1)	0.01 (0.01)	0.5 (0.2)	**4.1 (0.9)**+**	0.02 (0.02)	0.5 (0.3)
Site Measures								
Grass Productivity	2777.5 (292.5)	**1503.8 (213.4)*+**	**1847.9 (104.1)**+**	**1767.6 (78.0)**+**	1365.5 (108.6)	1430.6 (150.3)	1569.1 (318.4)	1318.2 (246.9)
Total Productivity	2804.0 (273.0)	1835.7 (256.3)	**1908.2 (110.7)**+**	**1778.8 (74.8)***+**	1371.0 (105.1)	1684.0 (183.6)	1582.5 (320.7)	1351.7 (249.8)

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

Table 9. SD3 continued, Treatments 3 and 4.

	TREATMENT 3 - Rx FIRE and HERBICIDE and Rx GRAZING				TREATMENT 4 - Rx GRAZING			
	Pre-treatment	Post-treatment			Pre-treatment	Post-treatment		
Species	**2010**	**2011**	**2012**	**2013**	**2010**	**2011**	**2012**	**2013**
common yarrow	2.7 (1.5)	3.7 (1.23)	0.3 (0.2)	0.03 (0.02)	1.3 (0.9)	2.0 (1.5)	0.5 (0.3)	0 (0)
buffalograss	20.7 (6.5)	**26.54 (4.3)+**	**41.3 (8.9)*+**	24.9 (4.9)	17.6 (1.9)	13.1 (5.3)	23.1 (6.7)	23.5 (5.1)
blue grama	30.4 (10.2)	17.9 (4.8)	23.1 (5.0)	28.4 (4.7)	8.3 (0.3)	**4.9 (0.7)****	6.7 (1.9)	19.3 (6.2)
field brome	4.6 (1.7)	**0.02 (0.02)*+**	**0.1 (0.1)*+**	**0.4 (0.4)*+**	2.2 (0.5)	1.2 (0.4)	**0.7 (0.5)*****	5.4 (2.4)
needleleaf sedge	2.0 (0.5)	1.9 (1.0)	1.3 (0.2)	**0.6 (0.4)*+**	2.4 (0.6)	1.1 (0.9)	**0.4 (0.2)****	1.4 (0.6)
western tansymustard	0.1 (0.04)	0	0	1.1 (1.1)	0.3 (0.04)	0	0	**0.03 (0.03)****
spreading wallflower	0	0	0	3.5 (2.5)	0	0	0	0.2 (0.2)
curlycup gumweed	0.4 (0.4)	0	0	0.01 (0.01)	0	0.02 (0.02)	0	0 (0)
green needlgrass	2.4 (2.4)	1.5 (1.5)	0.1 (0.1)	0	24.9 (1.5)	**36.6 (1.8)***	25.0 (5.1)	**3.2 (0.7)****
western wheatgrass	35.0 (6.9)	37.8 (5.3)	32.9 (4.3)	38.9 (7.0)	37.8 (4.3)	**32.2 (4.0)****	42.7 (8.2)	43.2 (3.0)
scarlett globemallow	0.8 (0.3)	0.4 (0.1)	0.7 (0.3)	0.5 (0.2)	1.5 (0.4)	1.1 (0.5)	0.9 (0.4)	**1.8 (0.4)***
sand dropseed	0	0	0	0	1.4 (0.7)	0.3 (0.3)	0	0 (0)
common dandelion	0	**2.3 (0.3)***+**	0	0.01 (0.01)	1.3 (1.1)	2.5 (0.8)	0	0.02 (0.01)
field pennycress	0	0	0	**1.1 (0.2)**+**	0	0	0	1.2 (1.0)
longbract spiderwort	0	**0.8 (0.2)**+**	0	0.02 (0.02)	0	0.3 (0.2)	0	0.01 (0.01)
American vetch	0.2 (0.1)	**6.9 (1.4)**+**	0.1 (0.1)	0.4 (0.3)	0.1 (0.03)	**2.6 (0.5)****	0.03 (0.03)	0.04 (0.02)
Site Measures								
Grass Productivity	1301.2 (483.6)	1889.2 (230.2)	2198.7 (365.7)	1936.0 (267.1)	1077.8 (86.7)	**3024.8 (145.0)*****	1179.2 (140.2)	1613.4 (388.8)
Total Productivity	1304.6 (484.1)	2337.1 (208.6)	2205.4 (365.7)	1962.8 (267.7)	1077.8 (86.7)	**3249.6 (116.4)*****	1214.9 (161.7)	1631.2 (385.9)

,**,** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

The mob grazing treatment produced significant increases in field brome and showed a significant reduction in western wheatgrass in the 3rd year post treatment. Buffalograss response showed trends of increasing while blue grama showed trends of decreasing, but neither of these were consistently significant post treatment. The two pastures that were burned and treated with imazapic showed significant reductions in field brome for all three years post treatment. Western wheatgrass in the pasture that was burned, treated with imazapic, and rested for a year remained fairly constant. The treatment that applied high intensity short duration grazing each year of the project showed reductions in western wheatgrass in the final year, but it is unclear if this trend would continue. The pasture that was mob grazed after burning and imazapic application showed steady amounts of western wheatgrass for 2 years post treatment, but declined in the third year. As with the mob grazed pasture, it is not clear it this trend would continue. Field brome remained fairly constant in the pasture treated with high intensity short duration grazing each year of the project, as did western wheatgrass. Favorable conditions for American vetch apparently occurred in 2011, as it showed significant increases in this year across all four treatments. No other consistent trends in vegetation were noted.

SD4

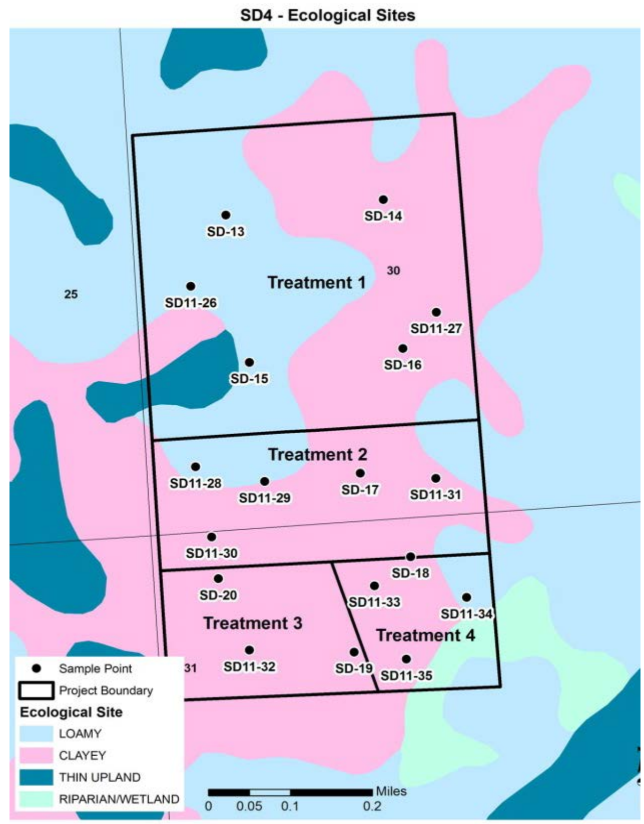

Figure 5. Ecological site map for SD4 also showing locations of vegetation sample points.

Study site SD4 was located in Hyde County, South Dakota, and represented a 185 acre grass dominated pasture. The producer expressed interest in comparing several responses to spring applied prescribed fire along with the use of glycophosphate to reduce amounts of exotic C_3 grasses (smooth brome and Kentucky bluegrass). At initiation of the study, the site was dominated by big bluestem, but also had significant amounts of Kentucky bluegrass, some alfalfa, and a small amount of crested wheatgrass (*Agropyron* cristatum). The study site was represented by mostly the clayey ecological site and the loamy ecological site, with a small inclusion of the thin upland ecological site (Figure 5). To evaluate the treatment combinations desired by the producer, the pasture was divided into 4 treatment areas as identified in Figure 5. Treatment area 1, 2, 3, and 4 represented 99, 43, 25, and 18 acres, respectively. Table 10 provides a description and time frame for treatment and vegetation monitoring conducted on site SD4. Results of the vegetation sampling are presented in Table 11-13. Because the producer decided to add additional treatments after the pre-treatment sampling was completed in 2010, two different statistical tests were used on this project site. For treatment 1, sufficient pre-treatment plots were sampled to allow for pre to post treatment analyses of each plot using paired t-tests and Wilcoxon tests. For the other three treatments, plots sampled throughout the 3 treatment pastures in 2010 were used as pre-treatment plots and were then compared to plots sampled within each of the 3 treatment plots in 2013 using an analysis of variance and Dunnett, Bonferroni, and Sidák comparisons.

As the results indicate, burning followed by spring grazing, spring grazing followed by treatment with glycophosphate, and spring grazing two years in a row all reduced the relative cover of Kentucky bluegrass. Only the treatment with only 1 year of spring grazing failed to show a significant reduction in Kentucky bluegrass. Big bluestem appeared to respond with a small increase following burning, but was only significant in 1 of 3 post treatment years. Dandelion and switchgrass were present following burning in small amounts that weren't detected in pre-treatment sampling. Other than the reduction in relative cover of Kentucky bluegrass in the herbicide treated and dual spring grazing treatments, few other consistent trends were noted in the other three treatments.

Table 10. Treatment time frame, treatment type, treatment objectives, and vegetation sampling conducted on study site SD4 for 4 treatment areas.

Year/Season	Treatment	Objective	Vegetation Sampling
TREATMENT AREA 1			
2010	Rx Grazing - rested	Allow fuel build-up to support prescribed fire	Pre-treatment
2011 - spring	Rx Fire and Rx Grazing - rested	Reduce Kentucky bluegrass	Post-treatment
2012	Rx Grazing - rested	Protect re-growth during drought conditions	Post-treatment
2013	Rx Grazing – spring - high intensity	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – spring - high intensity	Maintain desired conditions	
TREATMENT AREA 2			
2010- spring	Rx Grazing –early spring	Graze on C_3 grasses including Kentucky bluegrass	Pre-treatment
2011 – spring	Herbicide – glycophosphate	Reduce Kentucky bluegrass	Post-treatment
2011	Rx Grazing - rested	Protect regrowth	Post-treatment
2012	Rx Grazing – July	Maintain desired conditions	Post-treatment
2013	RX Grazing- July	Maintain desired conditions	Post-treatment
2014 t0 2021	Rx Grazing – moderate	Maintain desired conditions	
TREATMENT AREA 3			
2010	Rx Grazing – May	Reduce Kentucky bluegrass	Pre-treatment
2011	Rx Grazing – May	Graze on C_3 grasses in May to reduce Kentucky bluegrass	Post-treatment
2012	Rx Grazing - July	Maintain desired conditions	Post-treatment
2013	Rx Grazing- July	Maintain desired conditions	Post-treatment
2014 to 2021	Rx Grazing- July moderate	Maintain desired conditions	
TREATMENT AREA 4			
2010	Rx Grazing – May	Reduce Kentucky bluegrass	Pre-treatment
2011	Rx Grazing - July	Maintain desired conditions	Post-treatment
2012	Rx Grazing – July	Maintain desired conditions	Post-treatment
2013	Rx Grazing – July	Maintain desired conditions	Post-treatment
2014 to 2012	Rx Grazing - moderate	Maintain desired conditions	

Table 11. SD-4 (Treatments 1 and 2) Relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	TREATMENT 1 - Rx FIRE and Rx GRAZING				TREATMENT 2 - HERBICIDE and Rx GRAZING		
Species	**2010**	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**
common yarrow	0	0.1 (0.1)	0	0.5 (0.5)	0.1 (0.1)	0	0.03 (0.02)
crested wheatgrass	2.1 (0.9)	1.1 (0.8)	0.5 (0.3)	3.1 (2.0)	0.1 (0.1)	0	0.02 (0.02)
big bluestem	73.4 (4.1)	71.4 (5.1)	78.8 (4.6)	66.5 (6.9)	78.9 (4.7)	84.9 (4.0)	86.5 (2.7)
sideoats grama	0	1.0 (0.7)	0.2 (0.2)	1.1 (0.7)	2.8 (1.3)	2.4 (1.4)	0.6 (0.4)
field brome	0	0	1.0 (0.7)	0.01 (0.01)	0.2 (0.1)	2.2 (1.9)	1.0 (1.0)
smooth brome	0.5 (0.4)	1.4 (0.9)	0.5 (0.3)	4.9 (3.8)	0.1 (0.1)	0	0.02 (0.02)
lambsquarters	0	0.1 (0.1)	0.1 (0.1)	0	0	0.9 (0.7)	0.03 (0.02)
Canada thistle	0	0.6 (0.4)	0.8 (0.4)	0.2 (0.1)	0.7 (0.7)	1.7 (1.4)	1.7 (0.7)
sweetclover	0	0.1 (0.1)	0	0.01 (0.01)	2.7 (2.1)	0.02 (0.02)	0.3 (0.2)
alfalfa	3.4 (1.4)	5.8 (4.)	3.6 (3.2)	6.3 (4.2)	6.8 (4.4)	0.7 (0.3)	3.8 (1.7)
switchgrass	0	0.8 (0.4)	0.4 (0.4)	1.3 (0.6)	3.5 (2.5)	2.5 (1.3)	2.5 (1.0)
Canada bluegrass	0	0.04 (0.04)	0	0	0	0	0
Kentucky bluegrass	19.1 (5.1)	12.7 (4.0)	12.2 (4.4)	13.7 (2.8)	1.0 (0.5)	0	0.2 (0.2)
blackberry	0	0.1 (0.1)	0	0	1.1 (0.8)	0	0
curly dock	0	0.5 (0.3)	0	0.03 (0.03)	0	1.9 (1.5)	0.8 (0.5)
common dandelion	0	1.6 (0.2)	0.7 (0.2)	1.7 (0.6)	1.0 (0.4)	0.7 (0.2)	0.1 (0.1)
longbract spiderwort	0	0.1 (0.1)	0	0.01 (0.01)	0.1 (0.1)	0	1.0 (0.9)
Site Measures							
Grass Productivity	5679.5 (1115.3)	6941.3 (1278.1)	3544.2 (263.5)	1800.64(236.0)	4007.1 (315.8)	3140.5 (463.5)	2481.4 (245.8)
Total Productivity	6295.2 (758.6)	7625.3 (1318.5)	3617.6 (249.0)	1937.4 (264.3)	4616.7 (344.2)	3304.0 (457.1)	2901.8 (356.7)

Table 11. SD-4 continued; Treatments 3 and 4.

	TREATMENT 3 - Rx GRAZING			TREATMENT 4 - Rx GRAZING		
Species	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**
common yarrow	0	0.1 (0.1)	0	0.2 (0.2)	0.1 (0.1)	0.01 (0.01)
crested wheatgrass	2.2 (2.2)	0.5 (0.5)	2.7 (1.7)	1.8 (1.8)	2.6 (2.4)	9.8 (5.8)
big bluestem	61.2 (10.8)	71.7 (11.5)	49.7 (12.2)	75.5 (3.8)	56.9 (8.1)	43.9 (16.2)
sideoats grama	1.7 (0.9)	1.7 (1.7)	0	0	0.1 (0.1)	0
field brome	1.1 (1.1)	0.6 (0.6)	3.8 (3.8)	1.5 (0.7)	8.6 (1.3)	4.5 (1.3)
smooth brome	1.0 (1.0)	2.0 (2.0)	8.3 (8.3)	0.1 (0.1)	1.4 (1.4)	11.3 (5.2)
lambsquarters	0	0	0.8 (0.8)	0	0	0
Canada thistle	0	0	3.1 (3.1)	0.4 (0.4)	2.6 (1.6)	5.2 (0.5)
sweetclover	0.9 (0.6)	0	0.2 (0.2)	0	0	0.01 (0.01)
alfalfa	12.7 (4.0)	4.4 (2.2)	16.1 (12.4)	8.5 (6.8)	10.0 (8.0)	6.6 (2.5)
switchgrass	2.3 (1.7)	0.1 (0.1)	0	1.1 (0.4)	0 *	1.7 (1.7)
Canada bluegrass	0	1.6 (0.8)	6.1 (6.1)	0	0.3 (0.3)	0.7 (0.7)
Kentucky bluegrass	14.7 (8.8)	15.7 (8.4)	2.5 (1.7)	7.4 (3.7)	15.3 (9.2)	14.7 (7.1)
blackberry	0.5 (0.5)	0	0	0	0	0
curly dock	0	0	0.4 (0.4)	0.7 (0.7)	0	0.03 (0.03)
common dandelion	1.5 (0.2)	1.2 (0.4)	5.2 (2.7)	1.8 (0.8)	1.2 (0.4)	1.2 (0.7)
longbract spiderwort	0	0	0	0.2 (0.2)	0	0
Site Measures						
Grass Productivity	4496.9 (522.1)	1427.5 (535.4)	3559.8 (569.8)	2745.8 (512.0)	2142.0 (76.2)	3671.3 (558.1)
Total Productivity	5299.8 (381.6)	1656.5 (618.3)	3964.3 (434.6)	3275.2 (409.3)	2300.0 (126.0)	4278.0 (588.1)

Table 12. SD4 - Treatment 1. Relative plant cover and statistical significance between pre-treatment year and each post-treatment year.

	TREATMENT 1			
	Pre-Treatment	Post-treatment		
Species	2010	2011	2012	2013
crested wheatgrass	2.1 (0.9)	0.4 (0.2)	0.7 (0.5)	4.6 (2.7)
big bluestem	73.4 (4.1)	78.9 (3.1)	**84 (5)*+**	76.3 (4.8)
sideoats grama	0	1.6 (1)	0.2 (0.2)	0.7 (0.5)
smooth brome	0.5 (0.4)	1.5 (1.4)	0.2 (0.2)	1.3 (0.7)
Canada thistle	0	1 (0.5)	1.2 (0.5)	0.3 (0.2)
alfalfa	3.4 (1.4)	1.7 (1.1)	**0.5 (0.5)***	2 (1.4)
switchgrass	0	**1.2 (0.5)***	0	**1.9 (0.7)***
Kentucky bluegrass	19.1 (5.1)	**10.1 (2.6)*+**	**10.9 (6.2)+**	**11.6 (3.2)*+**
common dandelion	0	**1.7 (0.2)***+**	**0.9 (0.3)**+**	**1.3 (0.8)+**
Site Measures				
Grass Productivity	5679.5 (1115.3)	7947.8 (1599)	3841.9 (285.5)	**1822.7 (317.3)**+**
Total Productivity	6295.2 (758.6)	8639.2 (1586.1)	**3916.4 (250.4)***	**1965.5 (351.5)***+**

,**,** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

Table 13. SD4 – Treatments 2-4. Relative plant cover and statistical significance between pre-treatment (2010) and the final year (2013) post-treatment.

	Pre-treatment	Post-treatment		
		Treatment 2	Treatment 3	Treatment 4
Species	2010	2013	2013	2013
crested wheatgrass	2.1 (0.9)	0	2.7 (1.7)	9.8 (5.8)
big bluestem	73.4 (4.1)	86.5 (2.7)	49.6 (12.2)	43.9 (16.2)
field brome	0.7 (0.4)	1 (1)	3.8 (3.8)	4.5 (1.3)
smooth brome	0.5 (0.4)	0	8.2 (8.2)	11.3 (5.2)
Canada thistle	0	1.7 (0.7)	3.1 (3.1)	**5.2 (0.5)****
alfalfa	3.4 (1.4)	3.8 (1.7)	16.1 (12.4)	6.5 (2.5)
switchgrass	0	2.5 (1)	0	1.7 (1.7)
Canada bluegrass	0	0	6.1 (6.1)	0.7 (0.7)
Kentucky bluegrass	19.1 (5.1)	**0.2 (0.2)****	**2.5 (1.7)****	14.7 (7.1)
common dandelion	0	0.1 (0.1)	**5.2 (2.7)****	1.2 (0.7)
Site Measures				
Grass Productivity	5679.5 (1115.3)	**2481.4 (245.8)****	3559.8 (569.8)	3671.3 (558.1)
Total Productivity	6295.2 (758.6)	**2901.8 (356.7)****	**3964.2 (434.6)****	4278 (588)

**** represents significance (measured by Dunnett, Bonferroni, and Sidák comparisons) less than 0.05.

SD5

Study site SD 5 was located in Aurora County, South Dakota and consisted of a 35 acre grass dominated pasture. The site was represented by a loamy ecological site intermingled with a wetland ecological site (Figure 6). At initiation of the study, the site was heavily dominated by smooth brome, Kentucky bluegrass, and reed canarygrass. It had not received any land use for a number of years (no burning or grazing) per the landowners' objectives. The producer was interested in applying a prescribed fire treatment to encourage more native species. Table 14 provides a description and time frame for treatment and vegetation monitoring conducted on site SD5. Table 15 presents results of the vegetation sampling for SD5.

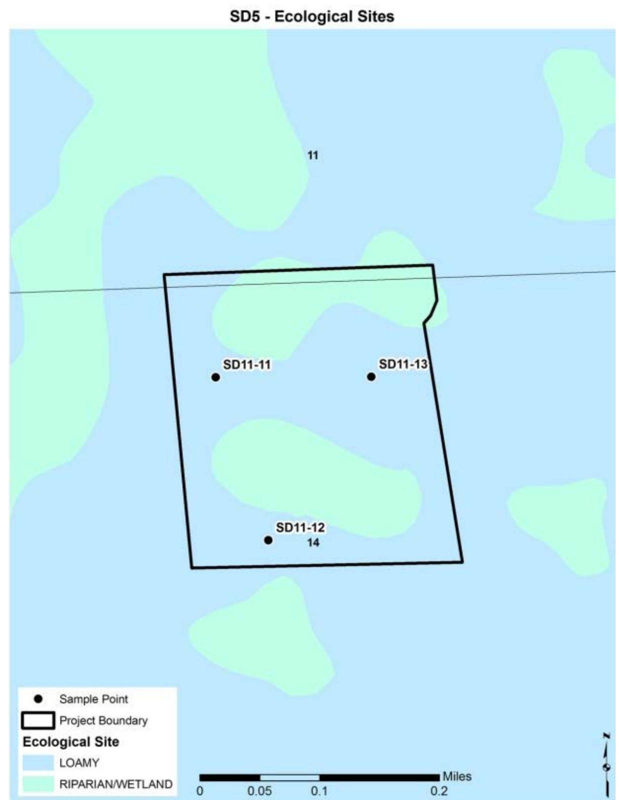

Figure 6. Ecological site map for SD5 showing location of vegetation sample plots.

Table 14. Treatment time frame, treatment type, treatment objectives, and vegetation sampling conducted on study site SD5.

Year/Season	Treatment	Objective	Vegetation Sampling
2011	Rx Grazing - rested	Producers land use objective for this site	Pre-treatment
2012 - spring	Rx Fire	Control smooth brome and Kentucky bluegrass	Post-treatment
2013	Rx Grazing – rested	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – not specified	Maintain desired conditions	

Table 15. SD-5 Relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	Rx FIRE and Rx GRAZING		
	Pre-Treatment	Post-Treatment	
Species	**2011**	**2012**	**2013**
sideoats grama	-	2.0 (1.5)	-
smooth brome	31.7 (9.5)	**47.1 (11.1)****	36.7 (4.9)
sweetclover	0.3 (0.3)	0.04 (0.04)	3.9 (3.9)
silverleaf Indian breadroot	-	2.0 (2.0)	-
reed canarygrass	11.2 (11.2)	15.3 (15.3)	2.9 (2.9)
Kentucky bluegrass	55.8 (4.7)	**24.9 (6.1)*****	53.8 (1.0)
prairie cordgrass	-	1.1 (1.1)	0.2 (0.2)
aster	0.3 (0.2)	2.2 (1.1)	1.1 (0.7)
Site Measures			
Grass Productivity	4032.7 (301.4)	**834.8 (114.3)*****	**7487.6 (291.6)*****
Total Productivity	4076.7 (305.8)	**868.1 (111.6)*****	**7642.3 (289.6)*****

,**,** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

The first year post treatment reduced the amount of Kentucky bluegrass and allowed several native forbs to increase in cover. However by the 2nd year post treatment, the site had largely returned to its pre-treatment condition. With a site this dominated by exotic grasses, a more intensive restoration program appears to be needed to increase the occurrence and dominance of native species.

SD16

Study site SD16 was located in Sandborn County, South Dakota, and represented a 275 acre grass dominated pasture. The site was characterized by rolling hills and 3 different ecological sites (Figure 7). At initiation of the study, the plant communities differed among the ecological sites, with the sandy and loamy sites being dominated by Kentucky bluegrass, while the thin upland site had porcupine grass sharing dominance with Kentucky bluegrass. The desired condition was to increase the amounts of little bluestem, porcupine grass, big bluestem, and western wheatgrass through prescribed fire. A burn was conducted in the spring of 2012. Table 16 provides a description and time frame for treatment and vegetation monitoring conducted on site SD5. Table 17 presents results of the vegetation sampling for SD5.

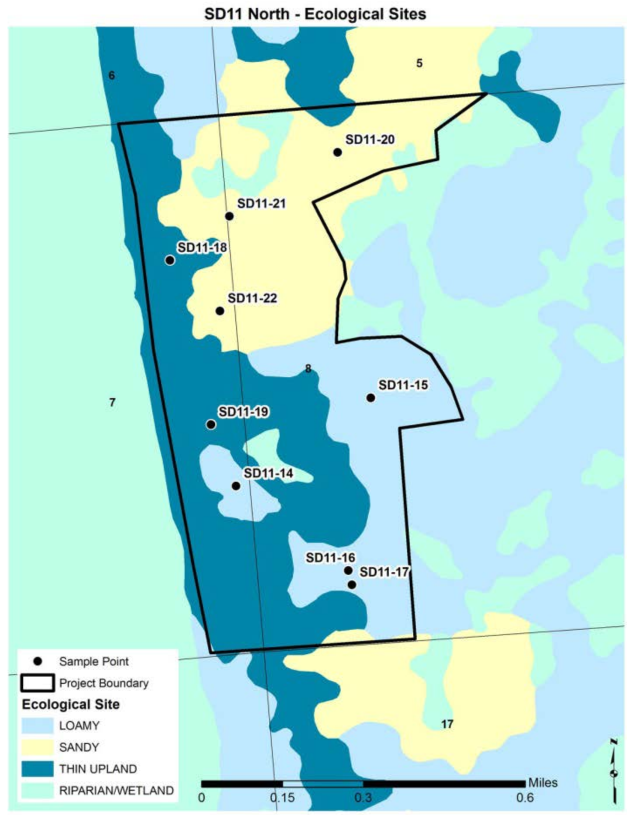

Figure 7. Ecological site map for SD16 showing locations of vegetation sample plots.

Table 16. Treatment time frame, treatment type, treatment objectives, and vegetation sampling conducted on study site SD16.

Year/Season	Treatment	Objective	Vegetation Sampling
2011	Rx Grazing - rested	Build up fuels for burning	Pre-treatment
2012 - spring	Rx Fire	Control smooth brome and Kentucky bluegrass	Post-treatment
2013	Rx Grazing – light	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – light	Maintain desired conditions	

Table 17. SD-16 Relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	Rx FIRE		
	Pre-Treatment	Post-Treatment	
Species	**2011**	**2012**	**2013**
crested wheatgrass	2.8 (1.7)	**2.1 (1.6)**++**	3.7 (2.3)
Cuman ragweed	1.4 (0.6)	2.0 (0.7)	**0.4 (0.2)***
big bluestem	0.3 (0.2)	1.6 (1.3)	0
absinthium	0.8 (0.8)	1.3 (1.3)	0.6 (0.6)
sideoats grama	0	**4.4 (2.5)+**	0
smooth brome	1.9 (1.3)	3.1 (2.6)	1.4 (0.7)
leafy spurge	2.4 (1.2)	**0.7 (0.6)*+**	1.6 (1.3)
porcupinegrass	13.5 (8.6)	5.2 (3.1)	**9.3 (7.7)+**
black medick	0.7 (0.5)	0.1 (0.1)	**0.01 (0.01)++**
sweetclover	2.5 (2.4)	2.1 (1.2)	0.5 (0.4)
green needlegrass	0.6 (0.5)	1.8 (1.3)	1.9 (1.2)
western wheatgrass	1.9 (1.4)	1.4 (0.9)	**0.2 (0.1)++**
Kentucky bluegrass	65.4 (9.4)	65.2 (8.5)	**74.3 (7.5)*++**
little bluestem	0.3 (0.3)	3.0 (2.7)	0.4 (0.4)
western snowberry	3.4 (1.3)	3.5 (0.9)	3.7 (1.5)
Site Measures			
Grass Productivity	2454.3 (146.2)	**1448.8 (224.5)***++**	1900.3 (428.7)
Total Productivity	2907.5 (238.6)	**1644.6 (234.0)***+++**	**2017.5 (400.4)**++**

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

No consistent trends were noted between pre and post treatment plant communities. The prescribed fire conducted in the spring did not produce any significant changes to the plant community occurring on any of the 3 ecological sites, and did not reduce the amounts of Kentucky bluegrass on this site.

SD6-11

Study sites SD6 through 11 were all native seeding treatments to convert former croplands back to native grasslands. Native seed selection was developed for each site based on the ecological sites present. The total number of acres targeted for restoration on these sites was 865 acres. Vegetation sampling was not conducted pre-treatment on these sites due to the lack of native vegetation. Vegetation sampling was conducted on 4 of the 6 sites in 2013 to capture a representation of the effectiveness of the various seeding efforts. Table 18 presents the results of this vegetation sampling.

Table 18. Composition of the plant community occurring on 4 seeded sites 1-2 years post-seeding in South Dakota. The dominant ecological site is also identified for each of the 4 study sites.

Species	SD6 - Clayey	SD7 - Sandy Loam	SD8 -Clayey	SD9 - Sandy
absinthium				2.17 (2.17)
alfalfa				18.54 (4.5)
bushy knotweed			1.13 (0.92)	
cheatgrass	3.45 (1.4)			
common dandelion				0.15 (0.09)
common sunflower			1.86 (1.06)	
crested wheatgrass				1.72 (1.06)
curlycup gumweed			4.54 (2.94)	
field bindweed			4 (2.25)	
field brome	22.81 (7.93)		32.25 (5.69)	5.37 (2.74)
flower of an hour			1.7 (1.7)	
green bristlegrass	51.01 (14.64)		3.51 (2.11)	
intermediate wheatgrass			1.42 (0.84)	11.77 (6.2)
Kentucky bluegrass				2.49 (0.68)
mat amaranth		15.16 (10.39)		
matted sandmat		32.1 (11.54)		
Maximilian sunflower	1.65 (1.63)			
prickly lettuce			2.68 (1.21)	
prickly Russian thistle		2.55 (1.38)		1.14 (0.82)
redroot amaranth		6.33 (3.86)		
Russian wildrye			14.05 (7.05)	1.75 (0.84)
sand dropseed		17.38 (11.75)		
sideoats grama			3.61 (3.09)	
slender wheatgrass			1.84 (1.18)	7.96 (4.33)
smooth brome			1.55 (1.5)	
stinkgrass		23.7 (4.93)		
sweetclover			17.74 (7.91)	
switchgrass			3.7 (2.88)	7.27 (3.09)
tall wheatgrass				32.85 (6.32)
upright prairie coneflower	1.59 (0.76)			
western wheatgrass	2.01 (1.03)			2.96 (1.23)
witchgrass	13.99 (11.37)			

The sampling results show a low level of establishment of any native species in the first 1-2 years post planting. Other studies have found grass seeding often takes several years to become established. Even so, these results are disappointing. At SD6 over 91% of the plant community was comprised of green bristlegrass (*Setaria viridis*), field brome, cheatgrass, or witchgrass (*Panicum capillare*). At SD7, only sand dropseed would be considered a desired native species in the plants comprising at least 1% of the sampled composition of the site. SD8 had a number of native species present, but field brome comprised nearly a third of the relative composition. SD11 had tall wheatgrass (*Thinopyrum ponticum*), an introduced species comprising nearly a third of the composition. Thus, none of the 4 sites showed promise in the first year post seeding for restoring native grasslands to these sites. It should be noted 2012 was a very dry year and possibly restricted the establishment of native seed due to very limited available soil moisture. As long as the seed remains viable, a better response may be observed in 2014 or beyond.

SD12-15

Study sites SD12 through 15 include grass dominated pastures of 4 producers which are being heavily invaded by redcedar. Treatment of these sites consisted of mechanically cutting the redcedar from areas accessible to the equipment and pushing and piling it into the nearby gullies, where equipment could not be used. The piles were then burned by the producers to further remove the redcedar remaining in the gullies. The producers agreed to use future periodic prescribed fire in the pastures to keep redcedar from reestablishing/reinvading the cleared areas. The number of acres treated with mechanical removal of redcedar totaled 530. Figures 8 and 9 show an example of this treatment. Because these treatments were set up too late in the growing season to allow pretreatment sampling, no field sampling of these sites was conducted. However, as the photographs reveal, the mechanical treatments effectively cleared redcedar from all but the most inaccessible areas.

Figure 8. Post-treatment photograph showing example of an area previously covered by redcedar.

Figure 9. Post-treatment photograph showing redcedar cut and stacked near gullies prior to burning.

Nebraska

NE1-4, 6 and 7

Study sites NE1-4, 6, and 7 are located in the Loess Canyons area of Nebraska. All sites were treated for mechanical removal of redcedar. In addition, NE2 conducted a prescribed burn the year after redcedar mechanical removal that was patchy, but did burn most of the pasture. The number of acres targeted for restoration on these sites totaled 1285 acres. The desired condition was to decrease or eliminate the redcedar and increase the amounts of big bluestem, little bluestem, western wheatgrass, needle-and-thread, sand dropseed, and other native grasses and forbs. Mechanical treatment was constrained to the less steep portions of the pasture outside the gullies. Redcedar remaining in the gullies would be targeted with future intermittent prescribed fire. Eliminating redcedar from the ridges and flatter terrain will provide the ability to establish fire breaks to allow future treatment with prescribed fire, which previously was too risky with the high fuel levels characterizing the redcedar infestation. Table 19 provides a description and time frame for treatment and vegetation monitoring conducted on these sites. Tables 20-25 present the results of the vegetation sampling.

Table 19. Treatment time frame, treatment type, treatment objectives, and vegetation sampling conducted on study site SD1.

Year/Season	Treatment	Objective	Vegetation Sampling
NE3 and 4			
2010	Mechanical cutting and piling	Remove redcedar	Pre-treatment
2011	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2012	Rx Grazing - light to moderate	Establish desired conditions	Post-treatment
2013	Rx Grazing - light to moderate	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing-light to moderate/intermittent Rx Fire	Maintain desired conditions	
NE2			
2011	Mechanical cutting/piling and Rx Fire	Remove redcedar	Pre-treatment
2012	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2013	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing-light to moderate/intermittent Rx Fire	Maintain desired conditions	
NE1, 6, and 7			
2011	Mechanical cutting and piling	Remove redcedar	Pre-treatment
2012	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2013	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing-light to moderate/intermittent Rx Fire	Maintain desired conditions	

Table 20. NE1 Relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	RED CEDAR REMOVAL		
	Pre-Treatment	Post-Treatment	
Species	**2011**	**2012**	**2013**
big bluestem	7.9 (2.4)	9.8 (2.2)	14.3 (5.3)
sideoats grama	22.1 (2.8)	32.3 (6.1)	**18.5 (2.5) *+**
blue grama	2.9 (1.5)	0.7 (0.7)	1.2 (0.7)
field brome	0.04 (0.02)	1.4 (1.0)	1.3 (0.7)
purple poppymallow	0.4 (0.4)	0.4 (0.4)	1.5 (1.2)
sun sedge	1.9 (0.7)	**0.3 (0.2)*++**	**1.0 (0.6) ++**
field bindweed	0.3 (0.3)	1.5 (1.5)	1.8 (1.8)
hogwort	0	0	3.1 (2.1)
Scribner's rosette grass	3.5 (1.5)	**0.6 (0.5) ++**	**1.1 (1.0) **++**
snow on the mountain	0.1 (0.1)	0	**2.5 (1.6) +**
needle and thread	1.4 (1.3)	0.3 (0.3)	0.8 (0.5)
eastern redcedar	3.3 (2.5)	0.1 (0.1)	0
western wheatgrass	6.6 (2.4)	7.1 (3.1)	**10.6 (2.9) ***++**
silverleaf Indian breadroot	2.2 (2.2)	0.1 (0.1)	2.3 (2.3)
Kentucky bluegrass	26.1 (7.7)	**12.4 (3.7) **++**	**2.6 (0.8) **++**
slimflower scurfpea	6.5 (1.6)	3.2 (2.0)	7.9 (3.4)
little bluestem	5.1 (3.6)	**19.7 (8.7) *++**	**14.7 (5.9) **++**
sand dropseed	1.9 (1.7)	0.7 (0.6)	1.9 (1.1)
scarlet globemallow	0	4.0 (4.0)	0
common dandelion	0.1 (0.1)	0.2 (0.2)	1.1 (1.1)
Baldwin's ironweed	1.1 (0.8)	0.2 (0.2)	0.4 (0.3)
common mullein	0	0	2.1 (1.3)
soapweed yucca	1.7 (1.7)	0.02 (0.02)	1.3 (1.3)
Site Measures			
Grass Productivity	3195.2 (277.8)	**393.8 (56.8)***++**	**1682.4 (130.7)***++**
Total Productivity	3328.3 (287.6)	**564.8 (80.7)***++**	**2540.6 (439.3)*+**

,**,** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

Table 21. NE2 relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	Pre-Treatment	Post-Treatment	
Species	**2011**	**2012**	**2013**
Cuman ragweed	4.5 (2.3)	3.9 (2.0)	**0.2 (0.1) ++**
big bluestem	3.4 (2.3)	14.0 (8.8)	3.2 (3.0)
field pussytoes	0.7(0.5)	1.5 (1.5)	0.1 (0.1)
tarragon	0.7 (0.7)	2.6 (2.6)	0
sand sagebrush	2.2 (0.8)	**0.6 (0.3) *+**	1.5 (0.9)
prairie sagewort	2.0 (1.3)	0.6 (0.6)	1.0 (0.9)
purple threeawn	1.7 (1.2)	**0.05 (0.05) +**	3.2 (2.2)
burningbush	0	0	3.7 (3.3)
sideoats grama	15.4 (3.9)	9.8 (2.4)	14.0 (3.1)
blue grama	13.1 (2.9)	**2.4 (1.2) **++**	**5.37 (0.8) **++**
hairy grama	0.6 (0.4)	5.1 (3.2)	1.0 (0.7)
field brome	5.3 (2.1)	15.5 (6.8)	**15.3 (3.5) ***++**
sun sedge	1.8 (1.1)	0	0
thymeleaf sandmat	1.9 (1.1)	**0.4 (0.4) ++**	0.4 (0.2)
tapered rosette grass	0	3.4 (3.4)	0
needle and thread	3.4 (0.9)	8.5 (4.6)	**8.4 (3.1) *+**
eastern redcedar	2.0 (1.7)	**0 ++**	**0 ++**
prairie Junegrass	2.3 (1.0)	**1.06 (0.7) +**	**0.8 (0.7) +**
flatspine stickseed	0	0	1.3 (1.0)
western wheatgrass	15.2 (4.4)	10.0 (6.9)	20.4 (6.4)
littleseed ricegrass	0.03 (0.03)	1.3 (1.3)	1.2 (1.2)
Kentucky bluegrass	5.9 (2.3)	4.1 (3.9)	**1.3 (1.3) *++**
slimflower scurfpea	1.6 (0.9)	1.3 (1.3)	0.9 (0.6)
upright prairie coneflower	1.1 (0.7)	0	0
little bluestem	3.0 (2.3)	9.9 (6.7)	7.2 (5.7)
bristlegrass	1.0 (0.7)	0.01 (0.01)	0
sand dropseed	0.6 (0.3)	2.0 (1.9)	2.5 (1.7)
Site Measures			
Grass Productivity	1840.4 (87.1)	**776.4 (258.6) **++**	**1300.7 (204.5)**++**
Total Productivity	2069.8 (72.9)	**792.8 (267.1)***++**	2355.5 (609.0)

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.
+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

Table 22. NE3 relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year. Note pretreatment in both 2010 and 2011.

	RED CEDAR REMOVAL			
	Pre-Treatment	Post-Treatment		
Species	2010	2011	2012	2013
Cuman ragweed	1.1 (1.0)	0.2 (0.2)	0.9 (0.9)	0.01 (0.01)
big bluestem	39.2 (9.7)	30.8 (7.4)	28.6 (10.8)	31.2 (9.3)
field pussytoes	1.1 (0.8)	0.8 (0.5)	1.8 (1.2)	1.3 (0.9)
tarragon	0	0	1.0 (0.7)	0
sideots grama	0	**15.2 (4.6) **++**	**10.6 (4.1) *++**	**13.8 (3.6) **++**
blue grama	1.5 (1.4)	2.2 (1.6)	4.0 (3.7)	3.1 (3.0)
field brome	5.2 (3.4)	**0.9 (0.4) ++**	3.3 (1.5)	8.3 (3.9)
sedge	2.5 (1.6)	2.1 (0.8)	2.3 (1.5)	2.8 (1.3)
needle and thread	1.8 (0.9)	**0.7 (0.3) *+**	**0.1 (0.1) *+**	**0.3 (0.2) +**
eastern red cedar	5.3 (4.3)	5.3 (3.5)	0.03 (0.02)	0.3 (0.3)
prairie junegrass	2.3 (1.7)	2.1 (1.2)	1.6 (0.8)	1.4 (1.1)
rush skeletonweed	0	0.6(0.2)	**1.4 (0.6) *++**	0
western wheatgrass	7.9 (3.9)	6.8 (3.9)	4.5 (1.7)	10.6 (4.8)
Kentucky bluegrass	10.6 (6.6)	9.5 (3.3)	6.0 (2.0)	3.1 (1.2)
slimflower scurfpea	8.6 (2.3)	6.5 (1.8)	10.09 (2.9)	6.6 (2.7)
little bluestem	4.9 (3.1)	4.4 (2.3)	**12.2 (2.8) *++**	5.8 (2.2)
sand dropseed	0	0.4 (0.3)	1.4 (0.9)	0
snowberry	0.7 (0.4)	2.4 (1.8)	2.7 (2.3)	4.2 (4.0)
ironweed	0.7 (0.7)	1.8 (1.7)	1.1 (1.1)	0
Site Measures				
Grass Productivity	-	2322.5 (332.4)	573.4 (48.0)	1385.4 (213.7)
Total Productivity	-	2649.8 (334.0)	622.0 (46.0)	1743.8 (264.0)

,**,** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

Table 23. NE-4 relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	RED CEDAR REMOVAL			
	Pre-Treatment	Post-Treatment		
Species	**2010**	**2011**	**2012**	**2013**
big bluestem	45.0 (12.9)	**33.5 (10.3)**++**	35.8 (12.2)	37.7 (13.5)
sideoats grama	0.1 (0.1)	**11.6 (5.5) *++**	**9.8 (6.8) +**	**9.6 (3.1) **++**
buffalograss	0	1.8 (1.8)	0	2.2 (2.2)
blue grama	4.1 (3.3)	9.3 (6.4)	0.4 (0.3)	0.8 (0.5)
field brome	12.0 (6.3)	3.1 (1.7)	7.5 (5.7)	6.6 (3.2)
bald brome	1.0 (1.0)	0	0	0
shortbeak sedge	0	1.2 (0.8)	3.3 (3.1)	0
fescue sedge	5.16 (3.0)	**0 +**	**0 +**	3.0 (1.8)
sun sedge	0	**2.5 (1.3) ++**	3.5 (3.2)	0
common sunflower	0	0.1 (0.1)	1.7 (1.7)	**1.4 (1.1) +**
needle and thread	2.3 (2.3)	0.6 (0.5)	3.1 (3.1)	0.01 (0.01)
eastern red cedar	2.0 (2.0)	0.1 (0.1)	0	0.1 (0.1)
rush skeletonplant	0	**0.5 (0.2) **+**	**3.2 (3.0) +**	0.3 (0.3)
sweetclover	0.1 (0.1)	**4.8 (2.1) *+**	0.1 (0.1)	5.9 (3.4)
Nuttall's sensitive-briar	1.2 (1.2)	1.8 (1.8)	0.3 (0.3)	0.1 (0.1)
green needlegrass	1.0 (1.0)	1.6 (1.6)	0	0.5 (0.5)
western wheatgrass	12.1 (4.9)	9.1 (4.4)	9.5 (6.5)	16.4 (8.1)
knotweed	1.9 (1.4)	0	0	0
Kentucky bluegrass	2.58 (1.7)	**6.0 (3.9) +**	**1.8 (1.7) ***	2.0 (1.2)
American plum	0	0	0.01 (0.01)	1.9 (1.9)
chokecherry	3.2 (2.1)	0.6 (0.6)	2.2 (2.2)	0.01 (0.01)
slimflower scurfpea	0.2 (0.2)	**1.3 (0.6) +**	**4.0 (2.2) +**	**3.7 (2.0) +**
prairie rose	-	1.2 (1.2)	0.1 (0.1)	0.6 (0.6)
little bluestem	1.5 (1.0)	1.8 (0.9)	**6.8 (2.8) *+**	2.3 (1.5)
Canada goldenrod	0	0.8 (0.6)	1.8 (1.8)	0
scarlet globemallow	0	0	1.9 (1.9)	0
Site Measures				
Grass Productivity	-	2772.9 (548.7)	309.9 (78.0)	1599.8 (197.7)
Total Productivity	-	2890.5 (564.0)	409.5 (66.2)	2127.4 (324.4)

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

Table 24. NE6 relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	RED CEDAR REMOVAL		
	Pre-Treatment	**Post-Treatment**	
Species	**2011**	**2012**	**2013**
leadplant	1.1 (0.8)	0.6 (0.4)	2.0 (1.3)
big bluestem	18.07 (3.7)	15.7 (3.2)	17.6 (4.0)
field pussytoes	8.5(4.0)	9.5 (6.2)	6.6 (3.5)
sideoats grama	20.2 (4.7)	30.0 (9.1)	21.0 (3.9)
blue grama	1.1 (0.8)	0.2 (0.1)	0.8 (0.8)
field brome	0.2 (0.1)	0.7 (0.4)	**1.5 (0.7) *+**
smooth brome	0.1 (0.1)	0	1.6 (1.5)
shortbeak sedge	0.6 (0.4)	4.2 (3.8)	2.0 (1.2)
sun sedge	3.2 (0.9)	3.8 (1.5)	5.3 (2.3)
ribseed sandmat	0	2.4 (2.2)	0
thymeleaf sandmat	0.1 (0.03)	0.01 (0.01)	**3.2 (1.5) *++**
purple lovegrass	1.4 (1.2)	0	0.2 (0.2)
needle and thread	0.5 (0.3)	0.2 (0.2)	1.8 (1.2)
eastern redcedar	15.2 (6.6)	**0.1 (0.1) *++**	**0 *++**
prairie Junegrass	0.6 (0.3)	0.1 (0.03)	2.1 (1.0)
rush skeletonplant	0.4 (0.2)	0.8 (0.6)	1.6 (1.0)
stiff goldenrod	0.1 (0.1)	0	1.3 (1.3)
soft-hair marbleseed	0.8 (0.8)	1.5 (1.5)	0.4 (0.4)
western wheatgrass	1.9 (1.3)	1.5 (0.9)	**4.1 (1.8) *++**
Kentucky bluegrass	5.3 (3.4)	**2.2 (2.1) *++**	3.1 (1.9)
slimflower scurfpea	3.3 (2.0)	2.8 (1.3)	3.2 (1.9)
fragrant sumac	2.3 (2.3)	4.3 (4.3)	2.1 (2.1)
little bluestem	9.1 (5.8)	**14.0 (6.5) *++**	6.9 (5.0)
sand dropseed	0.6 (0.3)	2.6 (1.7)	**3.5 (1.6) ***
Site Measures			
Grass Productivity	1817.5 (287.0)	**252.4 (49.9)***++**	**1058.6 (271.9)**+**
Total Productivity	1931.1 (268.8)	**335.5 (49.5)***++**	1545.7 (353.2)

,**,** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

Table 25. NE7 relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year.

	RED CEDAR REMOVAL		
	Pre-Treatment	Post-Treatment	
Species	2011	2012	2013
Cuman ragweed	1.2 (0.8)	0.2 (0.1)	1.9 (1.9)
big bluestem	1.7 (1.1)	1.0 (0.8)	2.3 (1.4)
field pussytoes	6.2 (5.4)	5.1 (4.7)	3.0 (2.7)
sideoats grama	27.7 (5.7)	26.2 (5.3)	19.7 (2.8)
blue grama	1.6 (1.6)	1.3 (1.0)	0.4 (0.2)
hairy grama	3.9 (3.9)	3.5 (3.5)	2.8 (2.8)
field brome	0.7 (0.3)	**4.0 (2.5) +**	4.1 (1.9)
shortbeak sedge	3.0 (2.7)	6.1 (4.8)	2.8 (2.2)
sun sedge	2.9 (1.0)	4.0 (1.7)	3.0 (1.0)
ribseed sandmat	-	1.7 (1.7)	-
Canadian horseweed	0.2 (0.1)	0.9 (0.5)	1.4 (0.9)
eastern redcedar	8.7 (5.1)	0.7 (0.7)	-
prairie Junegrass	0.2 (0.1)	0.1 (0.1)	4.2 (3.0)
rush skeletonplant	0.3 (0.1)	1.7 (1.0)	0.3 (0.2)
common yellow oxalis	0.03 (0.02)	0.1 (0.1)	1.0 (0.7)
western wheatgrass	7.5 (4.3)	8.6 (4.6)	**16.9 (9.2) +**
Kentucky bluegrass	7.9 (4.1)	**2.6 (2.5) *++**	**1.2 (0.5) +**
slimflower scurfpea	2.9 (1.3)	**0.3 (0.2) ++**	3.4 (1.2)
little bluestem	17.6 (11.0)	21.0 (12.9)	19.8 (11.5)
common dandelion	0.6 (0.6)	3.1 (3.1)	-
soapweed yucca	0.3 (0.3)	1.6 (1.4)	0.8 (0.8)
Site Measures			
Grass Productivity	1788.9 (406.2)	**386.3 (110.5)**++**	1681.8 (249.0)
Total Productivity	2042.3 (394.4)	**415.9 (107.8)**++**	2367.0 (387.5)

,**,** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

The results show redcedar was effectively removed from the treatment sites. Had the design used selected sampling, instead of randomly placed plots to specifically monitor the response of the plant community coinciding with areas containing redcedar, the plant community response would have been more significant. Instead, the vegetation sampling was designed to quantify the overall plant community occurring pre and post treatment on the treatment sites. With redcedar usually occurring around the edges and in scattered patches, the random placement of the plots did not often coincide with redcedar occurrence and therefore many of the vegetation sampling plots were not different between pre and post treatment conditions. The desired grasses generally showed positive trends post treatment. It was also interesting to observe a general decreasing trend in Kentucky bluegrass occurrence post treatment, although this difference was not significant within most of the individual pastures. For the NE2 site where redcedar was cut and burned and then a prescribed burn was applied to the site, both blue grama and Kentucky bluegrass showed small significant declines following the treatments. Needle-and-thread showed a slight increase by the second year post treatment, however so did field brome which was not a desired response.

NE5

Study site NE5 is also located in the Loess Canyon area of Nebraska. At the initiation of this study, this site had substantial patches of annual brome (cheatgrass) which were spot sprayed with imazapic herbicide to reduce its occurrence. Because of the relatively small area (20 acres) treated by spot spraying, vegetation sampling was not conducted on this site. The treatment resulted in a substantial reduction in annual brome and the producer was satisfied with the results.

NE8

Study site NE8 was located in the Beatrice area of Nebraska and represented a 274 acre pasture. At the initiation of the study, the pasture was experiencing substantial encroachment of shrubs and trees from the surrounding area, and had low amounts of warm season grasses. The number of acres receiving mechanical treatment totaled 77. The primary ecological sites were loamy and clayey (Figure 10). Table 26 provides a description and time frame for treatment and vegetation monitoring conducted on site NE8. Results of the vegetation sampling are listed in Table 27.

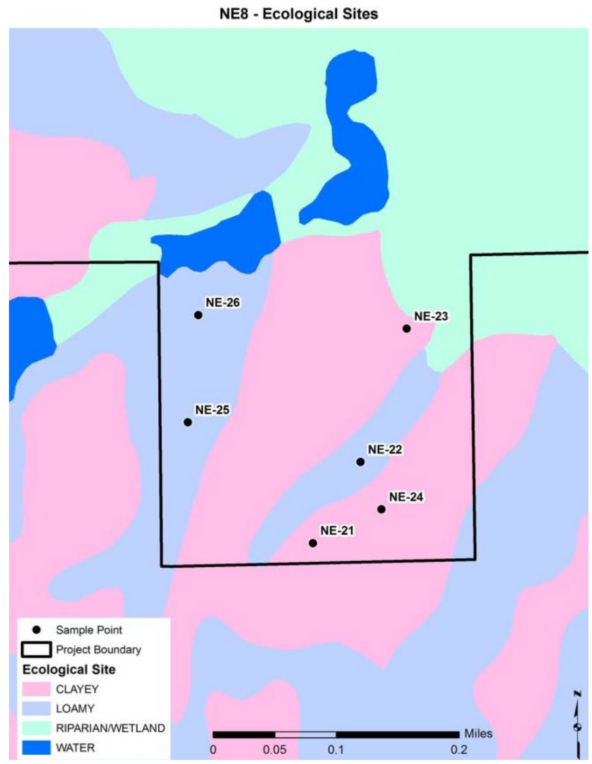

Figure 8. Ecological site map for NE8 and the location of vegetation sample plots.

The treatments reduced the amounts of redcedar, osage orange (*Maclura pomifera*), and other woody species. Responses of grasses and forbs were generally positive in the 2 years post treatment, with big bluestem showing a significant increase by the 2nd year post treatment. Responses by other species were generally not significant, although field brome showed a significant increase in the first year post-treatment. However, the treatments on this site clearly helped restore the site towards the desired native species grassland.

Table 26. Treatment time frame, treatment type, treatment objectives, and vegetation sampling conducted on study site NE8.

Year/Season	Treatment	Objective	Vegetation Sampling
2011	Rx Fire and mechanical treatment	Remove brush and trees	Pre-treatment
2012	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2013	Rx Grazing – light to moderate	Establish desired conditions	Post-treatment
2014 to 2021	Rx Grazing – light to moderate; intermittent Rx Fire	Maintain desired conditions	

Table 27. NE-8 Relative plant cover greater than 1% and statistical significance between pre-treatment year and each post-treatment year stratified by ecological site.

	SHRUB-TREE REMOVAL x BURNING x PRESCRIBED GRAZING		
	Pre-Treatment	Post-Treatment	
Species	2011	2012	2013
annual ragweed	0	1.8 (1.8)	0
leadplant	0.3 (0.3)	2.4 (2.0)	1.4 (1.0)
Cuman ragweed	1.4 (1.2)	0.1 (0.1)	**0 +**
big bluestem	18.2 (6.6)	20.1 (4.9)	**33.0 (5.2)**++**
groundplum milkvetch	0	0	1.4 (1.4)
sideoats grama	4.3 (1.8)	**11.3 (2.9)*++**	8.8 (2.4)
field brome	1.9 (1.6)	**9.9 (5.3)*++**	5.2 (3.4)
smooth brome	1.7 (1.6)	2.4 (1.6)	3.8 (2.7)
shortbeak sedge	1.2 (1.2)	1.5 (1.2)	0.7 (0.7)
heavy sedge	0	4.7 (2.4)	4.3 (2.2)
sun sedge	0	1.4 (1.0)	0
woolly sedge	0.8 (0.7)	0.02 (0.02)	0.02 (0.02)
white avens	1.0 (1.0)	0	0
honeylocust	2.0 (2.0)	1.9 (1.9)	0.03 (0.03)
beggarslice	0.6 (0.69)	0	0
eastern redcedar	7.7 (4.6)	0.3 (0.2)	0.1 (0.1)
osage orange	3.5 (3.4)	0	0
nimblewill	0.1 (0.1)	1.2 (0.8)	0
stiff goldenrod	2.1 (1.3)	1.1 (0.6)	1.3 (1.1)
nailwort	0.9 (0.9)	0	0
switchgrass	2.8 (2.0)	2.0 (1.2)	4.2 (2.3)
Canada bluegrass	2.6 (0.8)	1.3 (0.6)	2.4 (0.5)
Kentucky bluegrass	4.9 (4.9)	1.7 (1.0)	4.1 (1.2)
little bluestem	15.4 (8.0)	23.3 (10.4)	14.2 (7.2)
foxtail millet	0	0	0.6 (0.6)
Missouri goldenrod	1.9 (1.3)	1.1 (0.8)	0.6 (0.3)
Indiangrass	1.1 (0.8)	**0.1 (0.1)+**	**0.1 (0.1)+**
coralberry	0.6 (0.3)	3.9 (1.8)	3.3 (2.2)
Baldwin's ironweed	0.4 (0.4)	2.3 (2.1)	1.5 (1.1)
Carex spp.	2.1 (1.0)	1.2 (0.6)	2.0 (0.7)
Juncus spp.	5.5 (3.8)	0	0
Site Measures			
Grass Productivity	2729.8 (317.9)	**1354.5 (349.1)***++**	**1060.6 (128.4)***++**
Total Productivity	2886.0 (417.9)	**1450.0 (330.4)***++**	**1103.7 (126.2)**++**

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

NE9 and 10

Study sites NE9 and 10 were located near Beatrice, Nebraska and represented 300 and 200 acres, respectively. Substantial portions of these previously grass dominated pastures were being invaded by redcedar. Both sites were mechanically treated to remove the redcedar. NE9 was also burned in the spring. Tables 28 and 29 list the results of the vegetation sampling.

The treatments reduced the presence of redcedar on the two sites, although the random location of plots for NE10 didn't include the presence of redcedar pretreatment. For both sites, a slight trend in response by preferred grass species was noted in the two years post treatment. In addition, the treatments on NE9 presumably primarily the effects of the prescribed burn, reduces the amount of smooth brome on this site.

Table 28. NE-9 Relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year with combined ecological sites.

	RED CEDAR REMOVAL		
	Pre-Treatment	Post-Treatment	
Species	2011	2012	2013
common threeseed mercury	0.1 (0.1)	0.9 (0.6)	**0.8 (0.5)+**
harvestlice	2.8 (1.7)	1.5 (1.1)	1.4 (1.1)
annual ragweed	0	2.2 (2.1)	0
Cuman ragweed	5.3 (2.2)	5.5 (2.3)	6.9 (2.4)
big bluestem	0.6 (0.6)	**3.4 (1.5)*+**	3.6 (2.1)
field pussytoes	3.9 (2.9)	1.5 (1.1)	**4.7 (3.1)*+**
prairie threeawn	0	2.9 (2.7)	0
sideoats grama	2.6 (1.5)	2.9 (1.4)	1.5 (1)
blue grama	0.6 (0.6)	0.09 (0.09)	0.8 (0.6)
hairy grama	0.1 (0.1)	5.0 (2.7)	2.2 (1.5)
field brome	7.2 (3.2)	7.0 (2.6)	9.3 (1.3)
smooth brome	8.5 (3.6)	**0.2 (0.2)*+**	**0.1 (0.1)*+**
heavy sedge	0.5 (0.5)	0.3 (0.3)	0
thymeleaf sandmat	0	0.6 (0.6)	0
tumble windmill grass	0	0	5.4 (3.3)
Canadian horseweed	0.02 (0.02)	1.2 (1.0)	1.5 (1.1)
roughleaf dogwood	7.0 (4.4)	7.3 (2.4)	3.2 (1.7)
purple prairie clover	0.1 (0.1)	0	0.6 (0.6)
tapered rosette grass	3.3 (2.4)	**0 +**	**0 +**
Scribner's rosette grass	0.8 (0.5)	1.9 (1.2)	**3.0 (0.7)*+**
white avens	1.9 (1)	0.04 (0.04)	0
curlycup gumweed	0	0.7 (0.7)	0
eastern redcedar	1.1 (1.1)	0.1 (0.1)	0.2 (0.2)
plains muhly	0	1.1 (1.1)	0
nimblewill	0.9 (0.9)	0	2.3 (1.1)
slender yellow woodsorrel	0.01 (0.01)	0.7 (0.7)	0
thin paspalum	1.3 (0.8)	1.1 (0.4)	**0.1 (0.1)+**
switchgrass	2.4 (1.8)	0.2 (0.2)	**0.1 (0.1)+**
woolly plaintain	0.5 (0.4)	0	0.6 (0.5)

Table 28. NE-9, continued

	RED CEDAR REMOVAL		
	Pre-Treatment	Post-Treatment	
Species	**2011**	**2012**	**2013**
Canada bluegrass	2.7 (1.5)	**0.4 (0.2)+**	2.1 (1.0)
Kentucky bluegrass	4.5 (1.6)	2.6 (1.8)	10.5 (3.5)
sulphur cinquefoil	0.2 (0.1)	0	0.7 (0.5)
Missouri gooseberry	2.6 (2.6)	1.1 (1.1)	0.4 (0.4)
multiflora rose	2.0 (2.0)	2.2 (2.2)	0.8 (0.8)
little bluestem	5.8 (3.3)	5.8 (3.3)	1.7 (1.1)
yellow foxtail	2.7 (2.2)	0.7 (0.39)	0.1 (0.1)
bristly greenbrier	0.3 (0.3)	0.6 (0.6)	0
Carolina horsenettle	0.6 (0.3)	1.5 (0.7)	1.2 (0.5)
scarlet globemallow	0	0	1.1 (1.1)
prairie dropseed	0.9 (0.9)	0	0
western snowberry	0	0	1.6 (1.6)
coralberry	5.1 (2.4)	4.7 (2.2)	**7.3 (3.9)+**
spreading hedgeparsley	0.9 (0.6)	0.2 (0.2)	1.1 (1.0)
eastern poison ivy	4.1 (3.2)	1.5 (1.2)	0.9 (0.8)
field clover	0.4 (0.3)	0.9 (0.6)	1.9 (1.1)
purpletop tridens	0	**10.7 (5.0)*++**	**4.1 (1.2)**++**
American elm	1.2 (1.2)	0.2 (0.2)	0.3 (0.2)
elm hybrid	1.9 (1.9)	0	0
sedge	1.5 (0.6)	3.6 (1.8)	3.8 (0.8)
Baldwin's ironweed	3.5 (2.3)	3.4 (2.4)	3.1 (1.9)
hoary verbena	0.1 (0.1)	0.6 (0.6)	0.9 (0.8)
common mullein	0	3.2 (2.1)	0.9 (0.9)
Site Measures			
Grass Productivity	661.9 (129.1)	**259.4 (44.2)**++**	**284.1 (63.8) *++**
Total Productivity	871.7 (135.7)	572.0 (169.6)	934.8 (203.1)

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

Table 29. NE-10 Relative plant cover greater than 1% (standard error) and statistical significance between pre-treatment year and each post-treatment year with combined ecological sites.

	RED CEDAR REMOVAL		
	Pre-Treatment	Post-Treatment	
Species	2011	2012	2013
common yarrow	0.4 (0.4)	0.04 (0.04)	0.2 (0.1)
Cuman ragweed	2.2 (1.2)	3.5 (2.5)	**11.3 (5.2)*+**
big bluestem	0.4 (0.1)	**2.5 (0.9)*+**	**6.9 (2.4)**++**
field pussytoes	2.3 (1.9)	1 (0.7)	1.4 (0.8)
white sagebrush	0	0	0.6 (0.4)
sideoats grama	0.4 (0.2)	0.9 (0.4)	2.9 (1.7)
hairy grama	0	0	0.9 (0.9)
field brome	0.8 (0.4)	4.1 (4.1)	1.1 (1.1)
smooth brome	30.7 (11.9)	23.3 (12.9)	**23.9 (11.4)++**
heavy sedge	0.4 (0.4)	0.9 (0.9)	0.7 (0.7)
sedge	0.6 (0.5)	1.3 (0.8)	**1.5 (0.7)***
roughleaf dogwood	0	0	0.5 (0.5)
Scribner's rosette grass	1.4 (0.7)	**0.6 (0.3)++**	2 (1.3)
fall rosette grass	0	0.6 (0.4)	0.4 (0.4)
hairy hawkweed	0	0	1 (0.8)
dotted blazing star	0	0	0.9 (0.9)
fall panicgrass	0	2.4 (2.4)	0
switchgrass	1.7 (1.3)	1.4 (0.6)	2.9 (1)
reed canarygrass	4.9 (3.3)	0	0
timothy	0.7 (0.7)	0.03 (0.03)	0.1 (0.1)
woolly plaintain	0	0	**0.7 (0.5)+**
Canada bluegrass	12.9 (8.8)	**0 (0)++**	4.9 (2)
Kentucky bluegrass	5 (3.3)	0.1 (0.1)	1.1 (0.7)
American plum	0.6 (0.6)	1.2 (1.2)	0
prairie rose	0.3 (0.3)	0.4 (0.4)	0
tall fescue	0	0	0.8 (0.7)
meadow fescue	0	**2.5 (1.0)*+**	**1.7 (0.8)*+**
little bluestem	26.1 (8.8)	**44.5 (10)**++**	16.4 (4.7)
Indiangrass	4.1 (1.4)	7 (1.8)	7.1 (2.3)
composite dropseed	0	0	1.2 (0.9)
field clover	2.8 (2.6)	0.2 (0.2)	2.8 (2.4)
purpletop tridens	0	0	0.4 (0.3)
Site Measures			
Grass Productivity	1976.4 (668.0)	**523.8 (83.2)*++**	**911.0 (266.6)*+**
Total Productivity	2086.0 (686.4)	**542.4 (82.8)*++**	1289.3 (256.5)

*,**,*** represent significance (measured by a paired t test) less than 0.1, 0.05, and 0.01 respectively.

+,++,+++ represent significance (measured by a Wilcoxon test) less than 0.1, 0.05, and 0.01 respectively.

DISCUSSION

The overall findings from this study showed mixed results in terms of treatments used to meet the projects native grassland restoration goals. The use of imazapic to reduce the occurrence of field brome was very successful for the 2-3 years post treatment monitored in this project. The combination of prescribed fire followed by application of imazapic was particularly successful, as this combined the objective of returning fire as a disturbance process and allowing a much lower rate of imazapic application while still achieving the desired reduction in the amount of field brome. Glycophosphate applied in combination with spring grazing to a site in South Dakota reduced the amount of Kentucky bluegrass present.

Mechanical removal of redcedar worked well to restore the desired native grassland conditions on areas where equipment could operate. The use of mechanized equipment to clear vegetation is relatively expensive and limited to less steep terrain. The use of prescribed fire to remove trees and shrubs would likely be an effective treatment as well. In areas where prescribed fire is an accepted and supported practice, costs may be lower than using mechanized equipment. Where it is necessary to pay the producer to rest a pasture to build fuels to support prescribed fire, may actually make costs higher relative to mechanized treatment costs. An additional consideration is the sizes and densities of redcedar occurring on a site. As encountered in this study, mechanical treatment is frequently needed as an initial treatment to establish good fuel breaks so prescribed fire can then be used safely in the future. Because of the random placement of vegetation sample plots and the patchy nature of redcedar invasion, the benefit of redcedar removal was not as readily apparent in the vegetation response to treatments. However, even visual assessments of the treated pastures revealed the change in distribution of redcedar that the response of herbaceous vegetation that was released from the effects of redcedar where it occurred.

Prescribed fire was used as a treatment at several sites. Fire appeared to reduce levels of smooth brome at one site in Nebraska for the 2 years post-treatment. Fire combined with spring grazing reduced Kentucky bluegrass at a site in South Dakota. However, prescribed fire did not reduce Kentucky bluegrass the 2^{nd} year post-treatment at a site in Nebraska. Fire combined with spring grazing produced a slight increase in big bluestem at a site in South Dakota. A few species were noted to occur in small amounts the first year after fire at several locations, but were not significant in their occurrence and amounts. Few other changes in dominant plant species composition were noted post-treatment.

Efforts to convert cropland back to native grasslands were not effective in the first year post seeding. This may change in future years as the seedlings become better established and if weather conditions are favorable, but all of these sites exhibited species compositions with little to no overlap with the desired native plant communities. As previously noted, 2012 was a very dry year which likely had a strong impact on the effectiveness of the seeding.

For the 10 year time frame of this project, prescribed grazing as specified by state agencies was considered moderate in intensity with periodic rest of the pasture during the growing season. In general, producers agreed to a grazing plan which would limit the number of animals and the duration of grazing on a pasture in order to receive cost-share benefits for treatments. Prescribed grazing on a site in South Dakota reduced Kentucky bluegrass when applied two springs in a row as well as when combined with prescribed burning and spring application of glycophosphate. Where prescribed grazing was applied as a single treatment no changes to species composition were noted, except at study site SD3 where mob grazing contributed to significant increases in field brome and moved the site farther away from the desired plant composition.

CONCLUSIONS

This project was successful in engaging the anticipated number of producers to apply and demonstrate a variety of innovative treatments with the objective to restore or improve native grasslands. The project treated nearly 5,200 acres and involved 26 producers from a diversity of locations throughout South Dakota and Nebraska. Most of the treatments were effective in producing the desired changes with use of imazapic effectively reducing the cover of field brome and mechanical removal of redcedar effectively restoring these sites to grasslands. The use of prescribed fire showed some positive results through reductions in Kentucky bluegrass on one site, reduction in smooth brome on one site, positive through not consistently significant responses by big bluestem, and a general increase in number of species present following burning. Prescribed spring grazing helped reduce Kentucky bluegrass at one location. With one exception where mob grazing was shown to produce negative results, few other changes in plant communities following various grazing treatments produced positive trends in the 2-3 years of this study. However, given the dry year of 2012, this may have limited our ability to observe meaningful trends during the short time frame for the vegetation responses to grazing treatments.

The effort it took to engage producers to apply restoration treatments varied. Many producers were approached to participate but did not have the flexibility in their operations to apply desired treatments. Nearly all producers in South Dakota were apprehensive about applying prescribed fire. One producer (SD1) was very pleased with the results of the combined treatment using prescribed fire followed by application of imazapic. As with many of the study sites, the dry year of 2012 appeared to reduce the response of SD1's plant community in that year, with apparent residual effects carrying over into 2013. Another producer (SD3) was impressed with the plant community response to prescribed fire, especially when compared to the adjacent mob grazing treatment which he thought would produce more positive results but did not. Redcedar removal was generally well received by producers, and helped restore these sites to grass dominated plant communities. In Nebraska, use of prescribed fire has become more accepted as a treatment practice, and in one of the areas a prescribed fire cooperative had been established. This bodes well for future maintenance of these sites using prescribed fire.

The need to better define prescribed grazing and to offer compensation to producers willing to apply light grazing regimes was apparent at the conclusion of this study. A review of the literature demonstrates the economic return from grazing, especially in mixed-grass plant communities, is typically maximized at moderate to heavy grazing levels. Yet from a restoration perspective, lightly grazed plant communities rarely occur today and should be a higher priority for existing or future restoration programs. However, developing the support of producers in applying light grazing regimes would require compensating them for the reduced income they would experience as a consequence. Most conservation programs in place today work with producers to apply "prescribed grazing" objectives which typically represent moderate intensity grazing levels, often with a periodic rest during the growing season. Additional conservation practices, such as water improvements attempt to spread grazing more evenly across pastures to promote an even distribution. These practices assume that moderate grazing levels and the homogenous distribution of grazing are the appropriate application of "prescribed grazing" from a grassland restoration perspective in northern mixed grass and northern tallgrass prairies but this is erroneous. While these practices may produce various other conservation benefits which are not to be minimized, native grasslands need conservation programs targeting restoration of plant communities representing the light grazing regime conditions. To make this objective acceptable to producers, will require the ability to directly compensate them for the loss of income resulting from their participation in such programs.

With each year, more and more individuals, organizations, and researchers are raising awareness of the concern for the future of native grasslands in the Great Plains. They frequently point to the enormous need for much more extensive and effective restoration programs and practices in native grasslands, especially in the northern mixed-grass and northern and southern tallgrass prairies. This project demonstrates some of the challenges encountered when engaging producers in restoration projects as well as the challenges in achieving the desired response in plant communities. However, the results show great promise in the ability of many treatments to produce positive outcomes. To be most effective for many species of wildlife, grassland restoration is especially needed in large blocks, something this project could not effectively address. New ways of encouraging producer participation and engagement in efforts to build projects representing large blocks of restored grasslands are needed. Conservation programs which provide incentives, in addition to fully compensating producers for their voluntary reduction in grazing levels, are needed to achieve plant community objectives consistent with light grazing regimes. Failure to transition existing programs to this new paradigm will likely result in the continued decline of a number of grassland wildlife species and possibly lead to additional listings under the endangered species act, which in turn may greatly complicate the future engagement of producers in conservation programs.

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LITERATURE CITED

Alford, A. L., E. C. Hellgren, R. Limb, and D. M. Engle. 1012. Experimental tree removal in tallgrass prairie: variable responses of flora and fauna along a woody cover gradient. Ecological Applications 22:947-958.

Allen, V. G., C. Batello, E.J. Berretta, J. Hodgson, M. Kothmann, X. Li, J. McIvor, J. Milne, C. Morris, A. Peeters, and M. Sanderson. 2011. An international terminology for grazing lands and grazing animals. Grass and Forage Science 66: 2-28.

Anderson, H. G., and A. W. Bailey. 1980. Effects of annual burning on grassland in the aspen parkland of east-central Alberta. Canadian Journal of Botany 58:985-996.

Anderson, K. L., E. F. Smith, and C. E. Owensby. 1970. Burning bluestem range. Journal of Range Management 23:81-92.

Anderson, R. C. 1990. The historic role of fire in the North American grassland. Pages 8-18 in: S. L. Collins and l. L. Wallace, editors. Fire in North American tallgrass prairies. University of Oklahoma Press, Norman.

Arenz, C. L., and A. Joern. 1996. Prairie legacies- invertebrates. Pages 91-110 in: F. B. Samson and F. L. Knopf, editors. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Washington, D.C.

Augustine, D. J., J. D. Derner, and D. G. Milchunas. 2010. Prescribed fire, grazing, and herbaceous plant production in shortgrass steppe. Rangeland Ecology and Management 63:317-323.

Belknap, J. 2003. The world at your feet: desert soil crusts. Frontiers in Ecology and the Environment 1:181-189.

Bahm, M. A. 2009. Conversion of exotic cool-season grasslands to restored native plant communities using herbicide treatments. Ph.D. dissertation, South Dakota State University, Brookings.

Bahm, M. A., T. G. Barnes, and K. C. Jensen. 2011. Herbicide and fire effects on smooth brome (Bromus inermis) and Kentucky bluegrass (Poa pratensis) in invaded prairie remnants. Invasive Plant Science and Management 4(2):189.

Bailey, A. W. 1978. Effects of fire on the mixed prairie vegetation. Proceedings of the Prairie Prescribed Burning Symposium and Workshop, U.S. Forest Service, Bureau of Land Management, and U.S. Fish and Wildlife Service, Jamestown, ND.

Blankespoor, G. W. 1987. The effects of prescribed burning on a tall-grass prairie remnant in eastern South Dakota. Prairie Naturalist 19:177-188.

Bragg, T. B. 1982. Seasonal variations in fuel and fuel consumption by fires in a bluestem prairie. Ecology 63:7-11.

Bragg, T. B., and L. C. Hulbert. 1976. Woody plant invasion of unburned Kansas bluestem prairie. Journal of Range Management 29:19-23.

Bragg, T. B., and A. A. Steuter. 1996. Prairie ecology: the mixed prairie. Pages 53-66 in: F. B. Samson and F. L. Knopf, editors. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Washington, D.C.

Brand, M. D. and H. Goetz. 1986. Vegetation of exclosures in southwestern North Dakota. Journal of Range Management 39:434-437.

Branson, F., and J. E. Weaver. 1953. Quantitative study of degeneration of mixed prairie. Botanical Gazette 114: 397-416.

Brudvig, L. R., C. M. Mabry, J. R. Miller, and T. A. Walker. 2008. Evaluation of central North American prairie management based on species diversity, life form, and individual species metrics. Conservation Biology 21:864-874.

Collins, S. L., and D. E. Adams. 1983. Succession in grasslands: Thirty-two years of change in a central Oklahoma tallgrass prairie. Vegetatio 51:181-190.

Collins, S. L., and D. J. Gibson. 1990. Effects of fire on community structure in tallgrass and mixed-grass prairie. Pages 81-98 in: S. L. Collins and l. L. Wallace, editors. Fire in North American tallgrass prairies. University of Oklahoma Press, Norman.

Copeland, C. E., W. Sluis, and H. F. Howe. 2002. Fire season and dominance in an Illinois tallgrass prairie restoration. Restoration Ecology 10:315-323.

Cully, A. C., J. F. Cully, Jr., and R. D. Hiebert. 2003. Invasion of exotic plant species in tallgrass prairie fragments. Conservation Biology 17:990-998.

Curtis, J. T., and M. L. Partch. 1948. Effect of fire on the competition between bluegrass and certain prairie plants. American Midland Naturalist 39:437-443.

Daubenmire, R. 1968. Ecology of fire in grasslands. Pages 209-266 in: J. B. Cragg, editor, Advances in ecological research, volume 5, Academic Press, New York.

Davis, M. A., K. L. Lemon, and A. M. Dybvig. 1987. The effect of burning and insect herbivory on seed production of two prairie forbs. Prairie Naturalist 19:93-100.

DeKeyser, E. S., M. Meeham, G. Clambey, and K. Krabbenhoft. 2013. Cool season invasive grasses in northern Great Plains natural areas. Natural Areas Journal 33:81-90.

Derner, J. D., and R. H. Hart. 2007. Livestock and vegetation responses to rotational grazing in shortgrass steppe. Western North American Naturalist 67:359-367.

Dunn,B. H., A. J. Smart, R. N. Gates, P. S. Johnson, M. K. Beutler, M. A. Diersen, and L. L. Janssen. 2010. Long-term production and profitability from grazing cattle in the northern mixed grass prairie. Rangeland Ecology & Management, 63(2):233-242.

Ehrenreich, J. H. 1959. Effect of burning and clipping on growth of native prairie in Iowa. Journal of Range Management 12:133-137.

Ehrenreich, J. H., and J. M. Aikman. 1957. Effect of burning on seedstalk production of native prairie grasses. Proceedings of the Iowa Academy of Sciences 64:205-212.

Ehrenreich, J. H., and J. M. Aikman. 1963. An ecological study of the effect of certain management practices on native prairie in Iowa. Ecological Monographs 33:113-130.

Eichhorn, L. C., and C. R. Watts. 1984. Plant succession on burns in the river breaks of central Montana. Proceedings of the Montana Academy of Science 43:21-34.

Engle, D. M., and P. M. Bultsma. 1984. Burning of northern mixed prairie during drought. Journal of Range Management 37:398-401.

Fuhlendorf, S. D., D. M. Engel, J. Kerby, and R. Hamilton. 2009a. Pyric herbivory: Rewilding landscapes through the recoupling of fire and grazing. Conservation Biology 23:588-598.

Fuhlendorf, S. D., D. M. Engel, C. M. O'Meilia, J. R. Weir, and D. C. Cummings. 2009b. Does herbicide weed control increase livestock production on non-equilibrium rangeland? Agriculture, ecosystems, and environment 132:1-6.

Fuhlendorf, S. D., D. M. Engel, D. Elmore, R. F. Limb, and T. G. Bidwell. 2012. Conservation of pattern and process: developing an alternative paradigm of rangeland management. Rangeland Ecology and Management 65:579-589.

Gutwein, M., and J. H. Goldstein, 2013. Integrating conservation and financial objectives on private rangelands in northern Colorado: rancher and practitioner perceptions. Rangeland Ecology & Management 66:330-338.

Henderson, R. A., D. L. Lovell, and E. A. Howell. 1983. The flowering responses of 7 grasses to seasonal timing of prescribed burns in remnant Wisconsin prairie. Proceedings of the North American Prairie Conference 8:7-10.

Hulbert, L. C. 1969. Fire and litter effects in undisturbed bluestem prairie in Kansas. Ecology 50:874-877.

Gartner, F. R., J. R. Lindsey, and E. M. White. 1986. Vegetation responses to spring burning in western South Dakota. Proceedings of the North American Prairie Conference 9:143-146.

Gillen, R. L., F. T. McCollum III, K. W. Tate, and M. E. Hodges. 1998. Tallgrass prairie response to grazing system and stocking rate. Journal of Range Management 51:139-146.

Grant, T.A., B. Flanders-Wanner, T.L. Shaffer, R.K. Murphy, and G.A. Knutsen. 2009. An emerging crisis across Northern Prairie refuges: prevalence of invasive plants and a plan for adaptive management. Ecological Restoration 27:58-65.

Haufler, J. B., and B. J. Kernohan. 2001. Ecological principles for land management across mixed ownerships: private land considerations. Pages 73-94 in: V. H. Dale, and R. A. Haeuber, editors. Applying ecological principles to land management. Springer, New York, NY.

Haufler, J. B., and B. J. Kernohan. 2009. Landscape considerations for conservation planning on private lands. Pages 153-176 in: J. J. Millspaugh, and F. R. Thompson, III, editors. Models for planning wildlife conservation in large landscapes. Academic Press, Amsterdam, Netherlands.

Hendrickson, J. R., and C. Lund. 2010. Plant community and target species affect responses to restoration strategies. Rangeland Ecology and Management 63:435-444.

Higgins, K., F., A. D. Kruse, and J. L. Piehl. 1989. Effects of fire in the Northern

Great Plains. U.S. Fish and Wildlife Service and Cooperative Extension Service, South Dakota State University, Brookings, South Dakota. Extension Circular 761. Jamestown, ND: Northern Prairie Wildlife Research Center. (http://www.npwrc.usgs.gov/resource/habitat/fire/index.htm)

Holechek, J. L., R. D. Pieper, and C. H. Herbel. 2004. Range management: principles and practices. 5th ed. USA: Pearson Prentice Hall, Upper Saddle River, New Jersey.

Howe H. F. 1994a. Response of early- and late-flowering plants to fire season in experimental prairies. Ecological Applications 4: 121–133.

Howe H. F. 1994b. Managing species diversity in tallgrass prairie: assumptions and implications. Conservation Biology 8: 691–704.

Howe H. F. 1995. Succession and fire season in experimental prairie plantings. Ecology 76: 1917–1925.

Howe, H. F. 2011. Fire season and prairie forb richness in a 21-y experiment. Ecoscience 18:317-328.

Hulbert, L. C. 1985. History and use of Konza Prairie Research Natural Area. The Prairie Scout 5:63-93.

Humphrey, L. D. 1984. Patterns and mechanisms of plant succession after fire on *Artemisia*-grass sites in southwestern Idaho. Vegetatio 57:91-101.

Jackson, R. D., L. K. Paine, and J. E. Woodis. 2010. Persistence of native C4 grasses under high-intensity, short-duration summer bison grazing in the eastern tallgrass prairie. Restoration Ecology 18:65-73.

Johnson, L. A. 1987. The effect of fires at different times of the year on vegetative and sexual reproduction of grasses, and on establishments of seedlings. M.S. thesis, Iowa State University, Ames.

Kaul, R. B., and S. B. Rolfsmeier. 1993. Native vegetation of Nebraska. Map. University of Nebraska Conservation and Survey Division. Lincoln.

Knops, J.M.H. 2006. Fire does not alter vegetation in infertile prairie. Oecologia150:477-483.

Kemp, D. R., and D. L. Milchalk. 2007. Towards sustainable grassland and livestock management. Journal of Agricultural Science 145:543–564.

Knapp, A. K., and L. C. Hurlbert. 1986. Production, density and height of flowering stalks of three grasses in annually burned and unburned eastern Kansas tallgrass prairie: A four year record. Southwestern Naturalist 31: 235-241.

Knopf, F. L. 1996. Prairie legacies- birds. Pages 135-148 in: F. B. Samson and F. L. Knopf, editors. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Washington, D.C.

Koper, N., K. E. Mozel, and D. C. Henderson. 2010. Recent declines in northern tall-grass prairies and effects of patch structure on community persistence. Biological Conservation 143:220-229.

Kuchler, A. W. 1985. Potential national vegetation. National atlas of the United States of America. Map. U.S.D.I. Geological Survey, Washington, D.C.

McGranahan, D. A., D. M. Engle, S. D. Fuhlendorf, S. J. Winter, J. R. Miller, and D. M. Debinski. 2012. Spatial heterogeneity across five rangelands managed with pyric-herbivory. Journal of Applied Ecology 49:903-910.

Limb, R., D. M. Engle, A. L. Alford, and E. C. Hellgren. 2010. Tallgrass prairie plant community dynamics along a canopy cover gradient of eastern redcedar (*Juniperus virginiana* L.). Rangeland Ecology and Management 63:638-644.

Miles, E.K., and J.M.H. Knops. 2009. Shifting dominance from native C4 to non-native C3 grasses: relationships to community diversity. Oikos 118:1844-1853.

Morton, L. W., E. Regen, D. M. Engle, J. R. Miller, and R. N. Harr. 2010. Perceptions of landowners concerning conservation, grazing, fire, and eastern redcedar management in tallgrass prairie. Rangeland Ecology and Management 63:645-654.

Netherland, L. 1979. The effect of disturbances in tallgrass prairie sites on an index of diversity and equitability. Southwestern Naturalist 24:267-274.

Noss, R. F., 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological Report 28, U.S.D.I. National Biological Service, Washington, D.C.

Ode, D. J., et al. The seasonal contribution of C3 and C4 plant species to primary production in a mixed prairie. Ecology 61:1304-1311.

Pierce, A. M., and P. B. Reich. 2010. The effects of eastern red cedar (*Juniperus virginiana*) invasion and removal on a dry bluff prairie ecosystem. Biological Invasions 12:241-252.

Ponzetti, J. M., B. Mccune, and D. A. Pyke. 2007. Biotic soil crusts in relation to topography, cheatgrass and fire in the Columbia Basin, Washington. Bryologist 110:706-722.

Richards, M. S., and R. Q. Landers. 1973. Responses of species in Kalsow Prairie, Iowa to an April fire. Proceedings of the Iowa Academy of Sciences 80:159-161.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. Bioscience 44:418-421.

Samson, F. B., and F. L. Knopf. 1996. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Washington, D.C.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 2004. Great Plains ecosystems: past, present, and future. Wildlife Society Bulletin 32:6-15.

Sauer, J. R., J. E. Hines, J. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2011. The North American Breeding Bird Survey, results and analysis 1966 - 2009. Version 3.23.2011. USGS Patuxent Wildlife Research Center, Laurel, MD.

Seasted, T. R., and R. A. Ramundo. 1990. The influence of fire on belowground processes of tallgrass prairie. Pages 99-117 in: S. L. Collins and l. L. Wallace, editors. Fire in North American tallgrass prairies. University of Oklahoma Press, Norman.

Shinneman, D. J., and W. L. Baker. 2009. Environmental and climatic variables as possible drivers as post-fire cover of cheatgrass (*Bromus tectorum*) in seeded and unseeded semi-arid ecosystems. International Journal of Wildland Fire 18:191-202.

Shinneman, D. J., W. L. Baker, and P. Lyon. 2008. Ecological restoration needs derived from reference conditions for a semi-arid landscape in western Colorado, USA. Journal of Arid Environments 72:207-227.

Sinkins, P. A., and R. Otfinowski. 2012. Invasion or retreat? The fate of exotic invaders on the northern prairies 40 years, after cattle grazing. Plant Ecology 213:1251-1262.

Smart, A. J., J. D. Derner, J. R. Hendrickson, R. L. Gillen, B. H. Dunn, E. M. Mousel, P. S. Johnson, R. N. Gates, K. K. Sedivec, K. R. Harmoney, J. D. Volesky, and K. C. Olson. 2010. Effects of grazing pressure on efficiency of grazing on North American Great Plains rangelands. Rangeland Ecology and Management 63:397-406.

Smart, A. J., R. N. Gates, P. S. Johnson, and R. Schafer. 2012. Summer and winter defoliation impacts on mixed-grass rangeland. Rangeland Ecology and Management 65:506-515.

Smart, A. J., M. J. Nelson, P. J. Bauman, and G. E. Larson. 2011. Effects of herbicides and grazing on floristic quality of native tallgrass pastures in eastern South Dakota and southwestern Minnesota. Great Plains Research 21181-189.

Stephenson, M. B., W. H. Schact, J. D. Volesky, K. M. Eskridge, E. M. Mousel, and D. Bauer. 2013. Grazing method effect on topographical vegetation characteristics and livestock performance in the Nebraska Sandhills. Rangeland Ecology and Management 66:561-569.

Strong, D. J., L. T. Vermeire, and A. C. Ganguli. 2013. Fire and nitrogen effects on purple threeawn (Aristida purpurea) abundance in northern mixed-grass prairie old fields. Rangeland Ecology and Management 66:553-560.

Toombs, T. P., and M. P. Roberts. 2009. Are Natural Resources Conservation Service range management investments working at cross-purposes with wildlife habitat goals on western United States rangelands? Rangeland Ecology and Management 65:351-355.

Towne, E. G., and K. E. Kemp. 2008. Long-term response patterns of tallgrass prairie to frequent summer burning. Rangeland Ecology and Management 61:509-520.

USDA Natural Resources Conservation Service. 2006. Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. USDA Agricultural Handbook 296, Washington, D.C. (ftp://ftp-fc.sc.egov.usda.gov/NSSC/Ag_Handbook_296/Handbook_296_low.pdf)

Vallentine, J. F. 1990. Grazing management. Academic Press, San Diego, CA.

Van Auken, O. W. 2009. Causes and consequences of woody plant encroachment into western North American grasslands. Journal of Environmental Management 90:2931-2942.

Vermeire, L. T., J. L. Crowder, and D. B. Wester. 2011. Plant community and soil environment response to summer fire in the northern Great Plains. Rangeland Ecology and Management 64:37-46.

Vermeire, L. T., R. K. Heitschniidt, and M. R. Haferkamp. 2008. Vegetation response to seven grazing treatments in the northern Great Plains. Agriculture Ecosystems and Environment 125:111-119.

Vogl, R. J. 1974. Effects of fires on grasslands. Pages 139-194 in: T. T. Kozolowski and C. E. Ahlgren, editors, Fire and ecosystems, Academic Press, New York.

Vodehnal, W., and J. B. Haufler. 2008. Grassland conservation plan for prairie grouse. North American Grouse Partnership. Fruita, CO.

West, N. E. 1996. Strategies for maintenance and repair of biotic community diversity on rangelands. Pages 326-346 in: R. C. Szaro and D. W. Johnston, editors. Biodiversity in managed landscapes. Oxford University Press, New York, NY.

Whisenant, S. G. 1990. Postfire population dynamics of *Bromus japonicas*. American Midland Naturalist 123:301-308.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, Inc. New York, NY.

Zedler, J., and O. L. Loucks. 1969. Differential burning of *Poa pratensis* fields and *Andropogon scoparius* prairies in central Wisconsin. American Midland Naturalist 81:341-352.

Restoring Native Grasslands in Northern Mixed-grass and Northern Tallgrass Ecosystems

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Restoration Need

The Great Plains biome has long been known for its vast landscapes of rolling grasslands. Today, the native grasslands remaining in this region are considered among the ecosystems at greatest risk in the United States. This is primarily due to their direct conversion to croplands and other agricultural uses, as well as the indirect effects of changes to historical ecosystem processes and dynamics and the spread of invasive and exotic plant species. The resulting cumulative changes in native ecosystem diversity have been dramatic, and the corresponding impacts to biodiversity are of increasing concern to wildlife professionals, among others. For example, as a group, grassland birds in North America are declining faster than any other grouping of birds. Due to these concerns, both the South Dakota and Nebraska Wildlife Action Plans set goals for restoring native grassland diversity in order to maintain 26 species of greatest conservation need associated with grasslands in South Dakota and 34 species associated with grasslands in Nebraska. In addition, The Grassland Conservation Plan for Prairie Grouse endorsed by the Association of Fish and Wildlife Agencies in 2008 set grassland restoration goals across the Great Plains.

Grasslands in South Dakota and Nebraska primarily occur within the northern mixed-grass prairie and northern tallgrass prairie. Western wheatgrass (*Pascopyrum smithii)* occurs throughout the northern mixed-grass prairie along with needleandthread (*Hesperostipa comate*), green needlegrass (*Nassella viridula*), and porcupine grass (*Hesperostipa spartea*) as additional cool season or C_3 species, and blue grama (*Bouteloua gracilis*) as an associated warm season or C_4 species. Many remaining grassland areas within the northern mixed-grass prairie have been invaded by Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*). The northern tallgrass prairie, in contrast, is primarily dominated by C_4 grass species including big and little bluestem, sand bluestem (*A. hallii*), blue grama, hairy grama (*B. hirsute*), sideoats grama (*B. curtipendula*), prairie sandreed (*Calamovilfa longifolia*) and sand dropseed (*Sporobolus cryptandrus*), with lesser amounts of the C_3 grass species, needleandthread. Historically, fire was a frequent disturbance to both of these grassland types, as was grazing by large herbivores.

Restoration Methods

To evaluate and demonstrate possible grassland restoration treatments, both individually and in combination, a Conservation Innovation Grant (NRCS #69-3A75-11-185) project was initiated to apply innovative treatments to selected pastures of 26 producers in South Dakota and Nebraska. The goal was to restore over 4,000 acres of native grasslands to the compositions and structures common to these sites historically, but that are less common or lacking today. Vegetation sampling was conducted for 1 year pretreatment for 1-3 years post treatment depending on the site to monitor the effectiveness of transitioning a site towards the desired conditions. In addition, existing literature was reviewed to summarize documented responses of plant communities to similar treatments used in this project. The full results of the vegetation sampling and literature review including citations are available in the project final report (www.emri.org). Specifically, selected treatments or innovative combinations of these treatments used in this project included:

- Prescribed fire
- Prescribed grazing
- Mechanical tree/brush removal
- Herbicide treatments

Treatment Recommendations

Prescribed Fire

Fire is recognized as a primary disturbance process for native grasslands of the Great Plains. Fire provides benefits to the grassland by releasing nutrients to the soil, reducing the amount of old plant material and allowing precipitation to reach the soil, and preventing woody species such as eastern redcedar (*Juniperus virginianus*) from invading grasslands. In northern tallgrass ecosystems the timing of prescribed fire has been found to influence the response by plant communities. Spring burning favors a response by C_4 grass species, especially big bluestem and little bluestem. Summer burning has been found to increase the diversity of forbs occurring on the site for one or more years after the burn. Spring burning, especially early spring, has been found to decrease amounts of Kentucky bluegrass and smooth brome.

In northern mixed-grass ecosystems, burning in the early spring has been found to decrease amounts of Kentucky bluegrass in some sites, but has not shown any effect on the species composition in others. Summer burning increases overall plant diversity including forbs for one or more years post burn. Prescribed fire also reduces the invasion by many woody species such as redcedar. Some shrubs resprout after a burn and require repeated burns over multiple years to significantly reduce them from the plant community. In some cases a hot summer burn may damage the roots and reduce these species with a single fire event. Several studies found overall productivity decreased following summer burns, particularly the first year, but then returned to equivalent or higher levels in subsequent years.

Grass resprouts after prescribed fire in a South Dakota pasture.

Prescribed fire is an important treatment to use in maintaining and restoring native grasslands in the northern mixed-grass and tallgrass ecosystems. Prescribed fire has been found to produce important benefits even when used only to maintain desired existing plant communities. It can also be used to shift species compositions of plant communities, especially in northern tallgrass ecosystems where targeted seasonal application can reestablish warm season grasses. In this project, spring burning applied to pastures containing Kentucky bluegrass was found to reduce the relative cover of this species in a northern mixed grass and in a northern tallgrass plant community. Spring burning was also found to reduce the relative cover of smooth brome on a northern tallgrass site. Spring burning of a site that was nearly completely dominated by Kentucky bluegrass and smooth brome remained dominated by these species 2 years post-treatment indicating in sites with low amounts of native vegetation, additional treatment or combinations of treatments may be required.

Prescribed Grazing

Prescribed grazing is difficult to characterize as, by definition, it is a treatment designed to meet whatever grazing goals are specified for a site. In this project, we specified the treatment goal to be restoration of native grassland communities and especially to restore species compositions and structures representative of plant communities produced by light grazing regimes, as these are plant communities lacking in many areas. Relative to this goal, there is a paucity of information on plant community responses to light grazing treatments in northern mixed-grass and tallgrass ecosystems. Responses of various grass species to varying levels of grazing have been reported in the literature. For northern mixed-grass ecosystems, species that are known to decrease with moderate or heavy grazing regimes include green needlegrass, Indian ricegrass (*Achnatherum hymenoides*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and other species of needlegrass. Western wheatgrass and needleandthread are of intermediate sensitivity to grazing, being able to maintain their compositions up to moderate grazing levels, but declining with persistent heavier grazing levels. Blue grama and buffalo grass (*Bouteloua dactyloides*) are increasers with sustained moderate to heavy grazing pressure. Invasive species such as field (Japanese) brome (*Bromus japonicus*) and cheatgrass (*B. tectorum*) have also been found to increase following heavy grazing pressure. In the northern tallgrass ecosystems, species that decrease with sustained grazing pressure include big and little bluestem and Indiangrass (*Sorghastrum nutans*), while switchgrass (*Panicum virgatum*) is intermediate in sensitivity. Sideoats grama is an increaser with sustained heavier grazing pressure. For all of the above situations, the underlying ecological site and precipitation levels will interact with grazing pressure to influence which species will be present.

Grazing in a South Dakota pasture.

Implementation of a prescribed grazing treatment to benefit decreaser species is often difficult because of economic constraints for the producer and the relatively long time required to transition back to lighter grazing regime plant communities. In northern mixed-grass ecosystems, moderate to heavy grazing regimes have been reported to produce the best economic returns to producers. To apply light grazing regimes, producers must either be compensated for the reduced income associated with the reduced level of grazing, or be willing to accept some economic loss. Providing additional ecosystem services associated with these plant communities may provide additional revenue sources and may be a mechanism to engage producers in restoring plant communities associated with light grazing regimes.

Light grazing is generally considered conditions produced by sustaining <35% utilization of the annual productivity of grasses. No studies conducted in northern mixed-grass or tallgrass grasslands were found that monitored plant community responses to long term application of this level of grazing. A challenge in applying any grazing prescription is in determining how much utilization has occurred in any growing season. A generally applied practice is to base stocking rates of livestock on the anticipated production of grasses in a pasture, using ecological sites (esis.sc.egov.usda.gov) to predict average grass productivity. However, annual differences in precipitation results in highly variable grass production from year to year, so in many years, utilization rates may substantially exceed desired rates. Often drought conditions will have residual effects extending into subsequent years and can lead to much higher utilization rates than originally targeted. Utilization can be measured in any year by comparing to conditions within exclosures where grazing is excluded. However this can be difficult to accurately assess, particularly with season-long grazing, but has been effectively used to measure grazing utilization. The actual grazing system applied (season-long grazing, rotational grazing, etc.) has been reported to be less of a factor than a combination of the total stocking rate applied, and the application of adequate rest for pastures.

Prescribed grazing is an essential treatment in restoring native grasslands. However, developing and monitoring specific prescriptions as well as finding ways to adequately engage (and compensate) producers for reduced grazing levels has the challenges discussed above. Expanding markets for new ecosystem services offer mechanisms to help address this in the future. For the present, program guidelines should be considered which allow for at least full compensation for any revenues lost through adjustments to grazing regimes, and optimally would allow for additional incentives for producers.

Mechanized equipment removing shrubs and trees invading native grassland in Nebraska.

Seasonal application of prescribed grazing has been shown to produce shifts in compositions of plant communities. Early spring grazing has been found to help reduce amounts of Kentucky bluegrass and produce responses by warm season grasses in northern tallgrass ecosystems. In this project, Kentucky bluegrass was found to be reduced in a northern tallgrass pasture treated with two years of early spring grazing. A mob grazing trial in a northern mixed-grass pasture was found to increase levels of field brome, and showed trends of reducing cover of several desired species. More replicated grazing trials are needed which factor in specific grazing prescriptions, ecological sites, existing plant communities, timing of grazing, level of grazing, and annual weather patterns in order to understand the relationships among these factors and treatment outcomes. Until these are conducted, much of the responses of grassland communities in northern mixed-grass and tallgrass ecosystems will remain anecdotal.

Mechanical brush control

As mentioned previously, an important role of fire in Great Plains grasslands was keeping various woody species from invading sites. In particular, eastern redcedar has invaded many grassland areas in northern tallgrass ecosystems and to a lesser extent the northern mixed-grass ecosystems. Where excessive coverage and densities of redcedar make use of prescribed fire difficult, mechanical brush control can be an effective treatment. While this treatment is limited to less steep terrain for the equipment to operate, it can be effective in removing redcedar and in creating fire breaks along ridgelines and other areas where the terrain may be more favorable. Where flatter terrain is intermixed with steep and rocky gullies and draws, an effective technique is to push or stack cut redcedar into adjacent gullies and draws to

Mechanical tree cutting, stacking and piling to facilitate additional burning of remaining redcedar in gullies and draws.

allow a follow-up prescribed fire to remove the remaining redcedar. Where mechanical brush control is applied, it is recommended to follow with a prescribed fire within a few years. This will kill off the younger redcedar seedlings likely to sprout from remaining seed and will reduce or eliminate the need for future mechanical treatment of the site.

Herbicide Treatments

Herbicides were evaluated for two primary uses. One was to control annual invasive grasses including field brome and cheatgrass; imazapic was used for this purpose, often combined with prescribed fire. The second was glyphosphate applied at specific times to target actively growing Kentucky bluegrass or smooth brome and encourage expansion of big and little bluestem or other tall warm season grasses.

Imazapic was applied at two different rates. On several sites, prescribed fire was used in late summer/early fall after allowing sufficient fuels to establish and carry a fire. Once the site had received some fall moisture but before a hard freeze, 2-3 oz/ac of imazapic was applied. This is a very light application of this herbicide, but combined with prescribed fire that reduced the vegetation present, it worked very well in controlling field brome and cheatgrass for the first 1-3 years post-treatment. On another site, 5-6 oz/ac of imazapic was applied in the fall after the site was grazed during the summer. The heavier rate of application was used to address the larger amounts of vegetation present on the site. This level of application also provided good control of field brome and cheatgrass for the first 1-3 years post-treatment. These treatments, especially the combination of prescribed fire with a light application of imazapic, displayed good potential for controlling undesirable invasive annual grasses. No consistent significant changes to other vegetation were noted, however an experimental design which separated out the individual effects of the treatments compared with controls was not conducted in these demonstration sites.

Glyphosphate application in early spring followed by early spring grazing the next year reduced Kentucky bluegrass on a treatment site, but did not produce a significant response by big or little bluestem post-treatment although substantial amounts of these species were present. Other studies have also found that application of glyphosphate while Kentucky bluegrass is actively growing can help reduce the dominance of this species. Replicated experiments across different sites and with differing existing plant communities are needed to better understand the effectiveness of this treatment in controlling species such as Kentucky bluegrass and smooth brome.

Conclusions

Restoration of native grasslands in the northern mixed-grass and northern tallgrass ecosystems of the Great Plains should be a high priority conservation action. In particular, historically occurring grassland communities resulting from a light grazing and a relatively frequent fire regime are especially needed. These are the native grassland conditions most under-represented in the landscape today, when compared to historical conditions, and as demonstrated by the population declines of numerous grassland associated species.

Programs to provide focused funding and technical assistance are needed to achieve these goals for grassland restoration. As discussed, various practices are available to transition existing grasslands and agricultural lands to these underrepresented and desired plant communities. In particular, prescribed fire, mechanical brush control, selective use of herbicides, and prescribed grazing are practices for returning fire to grassland ecosystems, controlling undesirable invasive species and tame grasses, controlling spread of redcedar, and maintaining light grazing regimes on appropriate sites. While more information is needed to understand the complexities of

South Dakota native northern mixed-grass ecosystem.

treatment responses as influenced by ecological site, existing plant communities, weather patterns, as well as the timing, intensities, and rates of application, enough information exists to move aggressively forward with restoration efforts. Using an adaptive management framework is also recommended so that we can continue to add to our knowledge of how effective different treatments and their combinations can be to transition existing conditions towards the plant communities needed to meet restoration goals.