RESTORATION OF UPLAND AND RIPARIAN VEGETATION COMMUNITIES IN THE SHEYENNE RIVER VALLEY

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Degraded rangelands and riparian woodlands in eastern North Dakota are increasing in frequency. Two studies were conducted to address reduced forage quantity and quality and reduced regeneration of riparian tree and shrub species. Research objectives were to (1) analyze multiple pre-seeding treatments to determine impacts on rangeland production of interseeded native species; and (2) determine if fencing, weed-barrier fabric, mowing, or herbicide treatments can increase survivability of riparian tree and shrub seedling plantings. Pre-seeding treatments with herbicide showed significantly higher production of native species than the control. High-fencing/mowing treatment and high-fencing/weed-barrier fabric/herbicide treatment in riparian tree and shrub plantings resulted in significantly higher survival than the control. These findings will be used to develop future research and management strategies.

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CHAPTER 1. GENERAL INTRODUCTION

Interseeding multiple native species is a relatively new restoration technique and management practice on tallgrass prairies in the Northern Great Plains. It is a process by which species are seeded into existing vegetation without the use of tillage, leaving the existing plant community and soil undisturbed. To increase seedling success and biomass production, competition reduction is often performed prior to seeding (Wilson and Gerry, 1995; Bakker et al., 2003). If competition reduction is not performed, newly seeded plants will not compete well against existing vegetation.

Pre-seeding treatments of herbicide application and prescribed fire, applied individually and in combination, were studied in this experiment. These treatments were applied in grazed and non-grazed test plots. Control plots, in which no pre-seeding nor interseeding treatments were applied, were used as baseline. Seed only plots in which interseeding was conducted but without pre-seeding treatments were also established. In early-August of 2012 and 2013 biomass was sampled and data analysis performed. Predictions for this study were that the combination treatment of herbicide and burning would yield the highest biomass production as it was likely to result in the greatest competition reduction. It was also predicted that the herbicide combined with burning in the grazed plots would result in the highest biomass production. These predictions were based on previous studies that showed interseeding to be the most effective when used in combination with competition reduction, and appropriately grazed rangelands having greater plant species diversity than non-grazed rangelands (Wilson and Gerry, 1995; Howe, 1999). The objective of this study was to analyze multiple pre-seeding treatments to determine impacts on biomass production. This study will also examine at the effects of grazing versus non-grazing on newly interseeded pastureland.

Land managers and restoration groups in eastern North Dakota have noticed a lack of natural tree regeneration along riparian areas, and have had mixed success in woodland restoration efforts. A recent study on riparian woodlands and shrublands of the Middle Sheyenne River found reduced canopy cover to be correlated with increased risk of invasion by perennial cool-season grasses Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromis inermis*) (Meehan, 2011). Throughout the Middle Sheyenne watershed factors have been identified that may lead to reduced seedling survival: livestock grazing, herbivory by deer or rodents, competition from other vegetation, tree seed predation, changes in environmental factors, disturbance of site conditions, or lack of disturbance.

Riparian and floodplain plant communities within the Middle Sheyenne Watershed are essential in maintaining water quality and the biological integrity of the system. Problems that have recently been acknowledged as potentially threating plant communities are the highly variable white-tailed deer population, intermittent cattle grazing, and the presence of invasive dominated plant communities along the Sheyenne Valley floodplain. To assess the impacts of these stressors on tree seedling regeneration and to analyze management strategies, tree plantings were established at two sites using species widely planted in the area.

This thesis contains two separate studies that evaluate restoration in tallgrass pastureland and woodlands as well as the influence of soil properties along the Sheyenne River. 'Chapter 2' contains a study on rangeland restoration through interseeding native species. 'Chapter 3' follows with a study on the maintenance of riparian woodlands located within the Middle Sheyenne Watershed. 'General Conclusions' then discusses the conclusions from both studies.

Literature Cited

Bakker, J.D., S.D. Wilson, J.M. Christian, X. Li, L.G. Ambrose, and J. Waddington. 2003. Contingency of Grassland Restoration on Year, Site, and Competition from Introduced Grasses. Ecological Applications. 13:137-153.

Howe, H.F. 1999. Dominance, Diversity, and Grazing in Tallgrass Restoration. Ecological Restoration. 17: 59-56.

Meehan, M.A. 2011. Riparian Ecosystems of the Middle Sheyenne River in Eastern North Dakota. Doctoral Dissertation. North Dakota State University. Fargo, ND.

Wilson, S.D., and A.K. Gerry. 1995. Strategies for Mixed-grass Prairie Restoration: Herbicide, Tilling, and Nitrogen Manipulation. Restoration Ecology 3: 290-298.

CHAPTER 2. NORTHERN TALLGRASS RANGELAND RESTORATION THROUGH INTERSEEDING MULTIPLE NATIVE SPECIES

Abstract

Degraded rangelands in southeastern North Dakota are increasing in frequency. Specific problems associated with this case of rangeland degradation are a loss of biodiversity, increasing abundance of invasive species, reduced forage quantity and quality, loss of habitat, and increased risk of erosion. In order to address these problems, and restore rangelands to a healthy prairie ecosystem, an interseeding trial was designed to analyze a variety of pre-seeding treatments including the control, burning, herbicide, seeding only, and a burn herbicide combination. 3 reps were used for each treatment in grazed and ungrazed plots. Clipping data was gathered two and three years after initial seeding in 2012 and 2013 using $0.25 m^2$ quadrats to sample 6 points/treatment/rep ultimately determining changes in production and biodiversity. Analysis of the 2012 clipping data showed significantly higher total production in the ungrazed seed, herbicide treatment than in the ungrazed seed only and ungrazed burn, seed treatments. Grazed seed, herbicide seedbed treatments showed significantly higher production than control and seed only treatments. Results will be used to provide rangeland technical assistance through media development and consultation with relevant land managers and ranchers. These efforts aim to restore and maintain biological integrity and increase sustainable production of forages.

Introduction

Interseeding multiple native species is a relatively new restoration technique and management practice on tallgrass prairies in the Northern Great Plains. It is a process by which species are seeded into existing vegetation without the use of tillage, leaving the existing plant community and soil undisturbed. To increase seedling success and biomass production, competition reduction is often performed prior to seeding (Wilson and Gerry, 1995; Bakker et al., 2003). If competition reduction is not performed, newly seeded plants will not compete well against existing vegetation.

Pre-seeding treatments of herbicide application and prescribed fire applied individually and in combination, were studied in this experiment. These treatments were applied in 2010 in grazed and non-grazed test plots. Control plots, in which no pre-seeding nor interseeding treatments were applied, were used as baseline. Seed only plots in which interseeding was conducted but without pre-seeding treatments were also established. In early-August of 2012 and 2013 biomass was sampled and data analysis performed. Predictions for this study were that the combination treatment of herbicide and burning would yield the highest biomass production as it was likely to result in the greatest competition reduction. It was also predicted that the herbicide combined with burning in the grazed plots would result in the highest biomass production. These predictions were based on previous studies that showed interseeding to be the most effective when used in combination with competition reduction, and appropriately grazed rangelands having greater plant species diversity than non-grazed rangelands (Wilson and Gerry, 1995; Howe, 1999). The objective of this study was to analyze multiple pre-seeding treatments to determine impacts on biomass production. This study will also examine the effects of grazing versus non-grazing on newly interseeded pastureland.

Literature Review

Permanent grassland pasture and range total 248 million hectares and comprise 27% of the land area in the United States. When cropland pasture (15 million hectares) and forested grazing land (51 million hectares) were added to the permanent grassland acreage, total grazing land accounted for 314 million hectares, or 34 percent of the total U.S land area and generated

$17 billion annually in revenue making them economically and environmentally important (USDA-ERS, 2011).

Tallgrass rangelands throughout the Northern Great Plains are currently invaded by two cool season perennial grasses with European and Eurasian origins, Kentucky bluegrass (*Poa pratensis*) and Smooth brome (*Bromus inermis*) (Stubbendieck, 2011; DeKeyser et al., 2009). These highly competitive species feature characteristics that give them an advantage over historically dominant warm season grasses. In the absence of herbivory or fire, both grasses increase (Grant et al., 2009) and can co-exist in the same rangeland (Murphy and Grant, 2005). Kentucky bluegrass (Wedin and Tilman 1996) and smooth brome (Vinton and Goergen 2006) have been found to disrupt ecosystem function by altering nitrogen cycling and/or carbon storage, lowering plant diversity (Pritekel et al., 2006; Vaness and Wilson 2007), and shifting seasonal forage production. These detrimental impacts affect livestock production, wildlife habitat, and ecosystem services (Hendrickson and Lund, 2010).

It is often suggested that plant diversity is positively correlated with increases in biomass production (McNaughton, 1993). This is based on the idea that there are enough differences among plants in physiology, morphology, resource requirements, and life histories so that mixtures of several species can utilize more fully limiting resources than single species (Hooper, 1998). A recent study performed by Biondini (2007) showed a consistent positive relationship between aboveground biomass and species and functional form richness. This relationship, however, was entirely driven by an increase in minimum biomass over the 5-year study.

Tilman et al. (2001) found plant diversity and niche complementarity to have progressively stronger effects on ecosystem functioning during a 7-year experiment, with 16-species plots attaining 2.7 times greater biomass than monocultures. Diversity effects were not explained by a few productive or unviable species. Rather, many higher-diversity plots outperformed the best monoculture. These results help resolve debate over biodiversity and ecosystem functioning. Results also show that even the best-chosen monocultures cannot achieve greater productivity than higher-diversity sites. It should be noted that plots were intensively maintained for the species planted.

Restoring degraded rangelands or pasture has economic and ecological benefits. One restoration method that can be used in efforts to increase biodiversity and biomass production is interseeding. This method minimizes erosion hazards, reduces disruption of plant succession, and does not require the inconvenience of complete cultivation (Schumacher, 1964). This method is preferred where there are many species in an area to be preserved and can serve to increase diversity in the planting.

There are advantages and disadvantages when using interseeding as a restoration technique. One limitation of interseeding is that competition from existing plants can cause seedling establishment to take considerably longer than when using conventional tillage (Bailey and Martin, 2007). A seed mix will develop slowly over 4-5 years when a site is interseeded. The primary benefits of interseeding include the relative ease with which many conservation species are restored, improvement in site quality, and the potential contribution to biodiversity conservation (Packard and Mutel 1997).

Interseeding alone can have limited success in promoting the growth of native plant species (Rowe, 2010). Studies by Wilson and Gerry (1995) and Bakker et al. (2003) found that native seedling establishment through interseeding was most effective when combined with some form of competition reduction. Herbicide application is one reduction method that has been used effectively prior to seeding. Spring herbicide treatments suppress early emerging cool-season invasive species resulting in competition reduction for later emerging perennial warm-season species and increased cover composition by warm-season species (DiTomaso, 2000). Glyphosate, a non-selective herbicide, was used in renovation of an over-grazed, predominantly cool-season grass pasture in Nebraska (Martin and Moomaw, 1974). Applications (2.24 Kg/ha) were made in the late spring and 6 warm-season grasses were seeded into the existing vegetation. Control of Kentucky bluegrass and Japanese brome (*Bromus japonicus*) was excellent. Since native warm-season grasses were dormant at the time of spraying, they were not affected by glyphosate. However, the cool-season grasses were actively growing and suppressed.

Historically, fire has played an important role in the maintenance of many ecosystems, particularly grasslands (Hatch et al. 1991). In rangeland, prescribed burning is often used for long-term suppression of woody species. However, burning has also been used to successfully control non-woody species such as Kentucky bluegrass. The timing of a prescribed burn is critical to successfully control this invasive species. Burns should be conducted following seed dispersal and senescence of desirable grasses and forbs and before viable seed production by the noxious weed. Prescribed burning in rangeland also can stimulate annual and perennial grass growth (DiTomaso et al. 1999; Sheley and Petroff 1999) and enhance native forb diversity (DiTomaso et. al.1999). However, it is important to note that fire may promote colonization of invasive annual grasses such as cheatgrass (*Bromus tectorum*) following burning (Young and Evans, 1978).

Studies reviewed by Daubenmire (1968) as well as studies in the Kansas Flint Hills (Anderson et al. 1970; Owensby and Smith 1979) indicate that spring burning reduces Kentucky bluegrass. Smith and Owensby (1972) concluded that actively growing Kentucky bluegrass is more susceptible to injury than the warm-season native grasses that are dormant or just beginning to grow when spring burned.

In a study conducted by Engle and Bultsma (1984), burning in a dry year in a mesic northern Mixed Prairie provided some reduction of Kentucky bluegrass on both loamy and overflow ecological sites and an increase in current year's growth on overflow sites. However, they also found that burning did not increase standing crop on loamy sites and resulted in a period of reduced vigor of green needlegrass (*Nassella viridula*). They concluded that if a primary objective of management is to control Kentucky bluegrass, mid-May burning (immediately prior to warm-season tall grass emergence) in dry years may be recommended. However, if increasing forage production is a major management objective on pastures where there is a mixture of both xeric and mesic sites, mid-May burning is not recommended in years of below average cool-season precipitation. Kurtz (2001), recommended conducting prescribed burning for 2 to 5 years followed by interseeding with an appropriate seed mix.

Grazing is a third common management tool that is already used in the tallgrass prairie. Prior to European settlement, the Great Plains had been grazed for thousands of years by large herbivores (Collins et al., 1998). Post settlement and following the introduction of domesticated livestock, overgrazing became problematic and led to negative consequences, such as loss of species diversity and increases in invasive species. However, studies have shown that moderate grazing can be beneficial to overall rangeland health (Frost and Launchbaugh, 2003). When utilizing generalists such as cattle or bison that graze on dominant species rather than keying on a select few, moderate levels of grazing tend to increase biodiversity (Howe, 1999). Grazing can reduce overall cover of dominant species providing openings for establishment of less dominant species also leading to increases in biodiversity. It is recommended that grazing be deferred from newly seeded rangeland as cattle tend to target new seedlings (Schumacher, 1964).

Studies have shown that herbicide application, prescribed fire, and grazing can be used effectively to increase success of interseeding by decreasing the cover of the existing vegetation. In some cases, combining these treatments is more effective than applying them individually. Collins et al. (1998) found that frequent burning promoted warm-season dominance but when combined with grazing, greater overall diversity was achieved. Only limited research has looked at applying these three treatments in combination to increase the success of interseeding. By determining how these treatments, when combined with interseeding, affect rangeland quality we can develop a tool for range managers to restore degraded prairies and pastureland.

Methods

The legal description of the study site is T135N, R51W, NE ¼ Section 6 (46°32'31.31"N and 97° 8'34.92"W) and is located on the Ekre Grassland Preserve in Richland County, North Dakota. The study site is 12.1 hectares (30 acres) of pastureland that had been rotationally grazed with cattle for several years prior to study commencement. In order to study the impacts of grazing, half (6.1 hectares) of the study site was fenced off to livestock use, while the other half continued to be rotationally grazed. The study area is part of the prehistoric meanderings of the Sheyenne River, an area known as the Sheyenne River Delta (Bryce et al., 1998).

The soil of the study site is primarily composed of an Aylmer-Bantry complex with 0 to 6 percent slopes. The Aylmer series is classified as a mixed, frigid Aquic Udipsammentsconsist and consists of very deep, moderately well drained, rapidly permeable soils that formed in wind worked sand on outwash plains and delta plains. The Bantry series is classified as a mixed, frigid Typic Psammaquent and consists of very deep, somewhat poorly drained, rapidly permeable soils that formed in windblown glaciofluvial deposits. These soils are on sandy delta plains and outwash plains (USDA-NRCS 2014a). The water table of the area is near the surface in the spring and following periods of heavy rainfall. The study site contains a moderate amount of micro topography. When disturbed, left exposed, or un-vegetated, blowing soil can become a hazard.

Cold winters and hot summers classify this region as having a continental climate and it has an annual mean temperature of 5.4 ^{o}C and average rainfall of 55.7cm (Manske and Barker, 1988; NDAWN, 2014). In 2012, a drought occurred in the Northern Great Plains with the study site only receiving 38.5 cm of annual precipitation. During the months of May, June, and September below normal rainfall was received. In 2013, the study site received approximately normal annual rainfall (Figure 1).

The study site is considered degraded pasture with only traces of original tallgrass prairie species restablishing. This site was once cultivated, but was probably reseeded in the 1970's. As stated, there has been minimal re-colonization of warm-season species such as big bluestem (*Andropogon gerardii*), little bluestem (*Schizacyrium scoparium*), Indian grass (*Sorghastrum nutans*), and switch grass (*Panicum virgatum*). There are also a variety of cool-season species found within the study site, including smooth brome and Kentucky bluegrass. Kentucky bluegrass is an introduced perennial grass with European origins that has been documented in the region as invading grasslands and replacing native species (Murphy and Grant, 2005; DeKeyser et al., 2009). These species were accounting for a large portion of the overall biomass production in the study site. Through a forage production analysis of every pasture on the Ekre Grassland Preserve, the study site was found to be under producing by nearly 560 Kg/ha when compared to the historic climax plant community, and was the lowest scoring pasture on the preserve (Huffington, 2011).

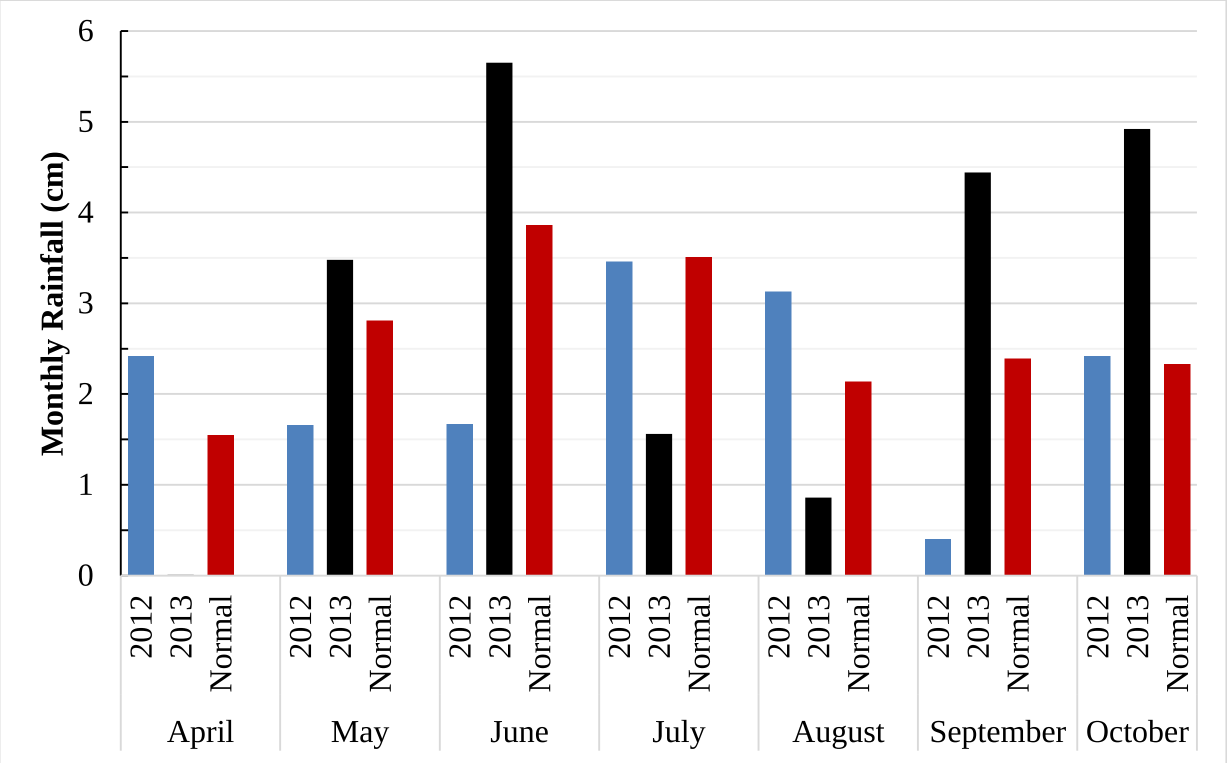


Figure 1. Monthly rainfall (cm) for Ekre NDAWN Station.

The layout for this trial was a split plot, complete block experimental design. The split plot variable for this trial was grazing with one plot being fenced off and excluded from cattle. The other plot remained actively grazed by cattle in a rotational grazing system. The between plot variables for this trial were burning, herbicide, and seeding treatments applied individually and in combination. Herbicide used for this trial was RoundUp® Concentrate Plus (The Scotts Company LLC, Worldwide Rights Reserved) and was mixed with water at a 60:1 ratio. The mixture was then applied to the appropriate plots using a boom sprayer at a rate of 23 L/ha. Spring applied strip burning resulted in primarily head fires in selected plots. The experimental design layout for this trial is shown below in Tables 1 and 2.

Table 1. Design for interseeding treatments in ungrazed plot.

Seed/Herbicide – Rep 1	Burn/Seed – Rep 2	Burn/Seed – Rep 3
Control – Rep 1	Seed/Herbicide – Rep 2	Seed/Herbicide – Rep 3
Burn/Seed/Herbicide – Rep 1	Seed – Rep 2	Control – Rep 3
Seed – Rep 1	Control – Rep 2	Seed – Rep 3
Burn/Seed – Rep 1	Burn/Seed/Herbicide – Rep 2	Burn/Seed/Herbicide – Rep 3

Table 2. Design for interseeding treatments in ungrazed plot.

Control - Rep 1	Burn/Seed/Herbicide – Rep 2	Control – Rep 3
Burn/Seed/Herbicide – Rep1	Seed – Rep 2	Burn/Seed/Herbicide – Rep3
Seed – Rep 1	Burn/Seed – Rep 2	Burn/Seed – Rep 3
Burn/Seed – Rep 1	Control – Rep 2	Seed/Herbicide – Rep 3
Seed/Herbicide – Rep 1	Seed/Herbicide – Rep 2	Seed – Rep 3

Burning and herbicide treatments were applied 3 weeks prior to interseeding to avoid effects on seed germination and seedling success. The interseeding was performed with a Truax FLEX II drill model FLXII-818, which was specifically designed for seeding prairie species. The drill seeded with 20 cm spacing and had a seeding depth ranging from 0.25 to 1.25cm deep. All blocks were seeded July 16th and 17th, 2010, with the exception of the controls. Soil moisture at the time of seeding was moist to wet with some small areas of inundation. The seed mixture for this trial was derived from the Natural Resource Conservation Service – Ecological Site Descriptions for subirrigated and sands for MLRA 56 (USDA-NRCS 2014b) which consisted of 13 different native prairie grasses and two native clovers sourced from Millborn Seeds in Brookings, SD. The seeding density and ratios were intended to restore tall grass prairie plant communities historically found at the study site (Table 3).

Table 3. Plant species and variety seeding densities.

Species	**Kg/ha**	**Species**	**Kg/ha**
Big Bluestem - Bison *(Andropogon gerardii)*	2.69	Sandbluestem *(Andropogon hallii)*	0.34
Prairie Sandreed - Goshen *(Calmolvilfa longifolia)*	1.12	Prairie Junegrass *(Koeleria macrantha)*	0.01
Switchgrass - Dakota *(Panicum virgatum)*	0.56	Porcupine grass – South Dakota native collection *(Hesperostipa spartea)*	0.11
Blue Grama – Bad River *(Bouteloua gracilis)*	0.17	Little Bluestem *(Schizachyrium scoparium)*	0.56
Canada Wildrye - Mandan *(Elymus Canadensis)*	0.56	Western Wheatgrass - Rodan *(Pascopyrum scoparium)*	0.56
Indian Grass - Tomahawk *(Sorghastrum nutans)*	0.28	Purple Prairieclover *(Dalea purpurea)*	0.28
Green Needlegrass - Lodorn *(Nassella viridula)*	0.28	While Prairieclover *(Dalea candida)*	0.28
Prairie Cordgrass – Red River Germplasm *(Spartina pectinata)*	0.17		

The grazed pasture was in a twice over rotational grazing during the duration of the study. Cattle were rotated out of the pasture on July 15, 2010 and did not reenter the seeded pasture until 2011 to help establishment of seedlings. The seeded pasture was the first pasture to be grazed starting mid-May in 2011 to reduce cool season invasive grass competition. Normal rotations were followed in 2012 and 2013. Biomass data were collected in early-August, 2012 and 2013. Clipping was performed using 0.25m^2 quadrats. Six quadrats per block were clipped. The distribution of sampling was a grid pattern of 2x3. Forbs, shrubs, and sedges were grouped individually and grasses were clipped by species.

Statistical analysis was performed on planted warm-season grass biomass by species, planted warm-season total biomass, and total plant biomass to determine treatment effects on season long production. Samples within each plot were averaged and SQRT transformed prior to analysis. Grazed and ungrazed plots were tested. Biomass data were also analyzed through a one-way ANOVA table using SAS software procedure, Version 6.1 of the SAS system for Windows (Copyright © 2013 by SAS Institute Inc., Cary, NC, USA). The Tukey's Test was used as an adjustment method to make multiple comparisons.

Results

In 2012 (2 years after interseeding), the grazed seed/herbicide treatment showed greater ($p \leq 0.05$) planted warm-season biomass production than the burn/seed treatment, seed only treatment, and control. The ungrazed burn/seed/herbicide treatment showed greater ($p \leq 0.05$) planted warm-season biomass production than the burn/seed and seed only treatments (Tables 4 and 5).

Table 4. Average biomass of planted warm-season species in the 2012 grazed plots.

Treatment	**Biomass (g/m^2)[1]**
Burn, Seed, Herbicide	51.7ab
Seed, Herbicide	89.3a
Burn, Seed	6.3b
Seed	3.6b
Control	1.0b

[1] Different letters within column indicate a significant difference ($p \leq 0.05$).

Table 5. Average biomass of planted warm-season grasses in the 2012 ungrazed plots.

Treatment	**Biomass (g/m^2)[1]**
Burn, Seed, Herbicide	93.4a
Seed, Herbicide	77.2ab
Burn, Seed	12.0b
Seed	13.4ab
Control	39.3ab

[1] Different letters within column indicate a significant difference ($p \leq 0.05$).

In 2013 (3 years after interseeding), both grazed treatments using herbicide showed greater ($p \leq 0.05$) planted warm-season biomass production than the seed only and control treatments (Table 6). Ungrazed plots showed similar trends in biomass for the seed/herbicide treatment however it was not significantly different from the other treatments (Table 7).

Table 6. Average biomass of planted warm-season species in the 2013 grazed plots.

Treatment	**Biomass (g/m^2)**[1]
Burn, Seed, Herbicide	62.3a
Seed, Herbicide	98.2a
Burn, Seed	44.6ab
Seed	6.1b
Control	2.8b

[1] Different letters within column indicate a significant difference ($p \leq 0.05$).

Table 7. Average biomass of planted warm-season species in the 2013 ungrazed plots.

Treatment	**Biomass (g/m^2)**[1]
Burn, Seed, Herbicide	133.4a
Seed, Herbicide	164.1a
Burn, Seed	16.5a
Seed	35.1a
Control	9.9a

[1] Different letters within column indicate a significant difference ($p \leq 0.05$).

In 2013, the ungrazed seed/herbicide treatment showed greater ($p \leq 0.05$) biomass production that all other treatments (Table 8). No significant difference in total biomass production was found between treatments in 2012 grazed, 2012 ungrazed, and 2013 grazed plots, respectively (Tables 9, 10, and 11).

Table 8. Average total forage biomass in the 2013 ungrazed plots.

Treatment	**Biomass (g/m^2)**[1]
Burn, Seed, Herbicide	268.4b
Seed, Herbicide	405.9a
Burn, Seed	247.8b
Seed	233.7b
Control	224.0b

[1] Different letters within column indicate a significant difference ($p \leq 0.05$).

Table 9. Average total biomass in the 2013 grazed plots.

Treatment	**Biomass (g/m^2)[1]**
Burn, Seed, Herbicide	357.1a
Seed, Herbicide	302.8a
Burn, Seed	400.4a
Seed	319.7a
Control	303.7a

[1] Different letters within column indicate a significant difference ($p \leq 0.05$).

Table 10. Average total biomass in the 2012 ungrazed plots.

Treatment	**Biomass (g/m^2)[1]**
Burn, Seed, Herbicide	243.4a
Seed, Herbicide	334.9a
Burn, Seed	190.7a
Seed	200.8a
Control	245.2a

[1] Different letters within column indicate a significant difference ($p \leq 0.05$).

Table 11. Average total biomass in the 2012 grazed plots.

Treatment	**Biomass (g/m^2)[1]**
Burn, Seed, Herbicide	323.8a
Seed, Herbicide	315.0a
Burn, Seed	375.4a
Seed	324.8a
Control	286.8a

[1] Different letters within column indicate a significant difference ($p \leq 0.05$).

Comparison of biomass between the seed, herbicide treatment and control for species groups for 2012 is shown in Table 12. Increases in warm-season graminoid biomass are seen in the seed/herbicide treatment for 2012. Increased warm-season graminoid biomass is consistent in grazed and ungrazed plots.

Table 12. Comparison of average biomass (g/m^2) for different species groups for both grazed and ungrazed for the control and seeding herbicide treatments in 2012.

Grazing	**Treatment**	**Other (sedges, rushes, forbs, and shrubs)**	**Native Cool-Season Grass**	**Native Warm-Season Grass**	**Kentucky Bluegrass**	**Smooth Brome**	**Total**
Grazed	Control	91.3	1.5	2.2	124.4	74.1	293.4
Grazed	Seed, Herbicide	104.1	4.8	89.5	86.1	35.7	320.2
Ungrazed	Control	74.6	22.6	39.3	68.4	46.6	251.5
Ungrazed	Seed, Herbicide	165.1	26.1	77.4	40.9	29.3	338.7

Comparison of biomass between the seed/herbicide treatment and control for species groups for 2013 is shown in Table 13. Increases in warm-season graminoid biomass are seen in the seed/herbicide treatment for 2013. Increased warm-season graminoid biomass is consistent in grazed and ungrazed plots.

Table 13. Comparison of average biomass (g/m^2) for different species groups for both grazed and ungrazed for the control and seeding herbicide treatments in 2013.

Grazing	**Treatments**	**Other (sedges, rushes, forbs, and shrubs)**	**Native Cool-Season Grass**	**Native Warm-Season Grass**	**Kentucky Bluegrass**	**Smooth Brome**	**Total**
Grazed	Control	58.5	2.0	3.0	122.5	118.6	304.6
Grazed	Seed, Herbicide	58.7	5.3	102.9	80.0	55.2	303.1
Ungrazed	Control	47.9	1.5	10.2	66.2	94.4	220.2
Ungrazed	Seed, Herbicide	120.6	0.2	165.0	88.9	32.1	406.8

Figure 2 shows planted warm-season biomass for 2012 and 2013 as well as annual precipitation during those years. The grazed seed, herbicide treatment had greater ($p \leq 0.05$) planted warm-season biomass than the control in 2012 and 2013. The annual rainfall for 2012 was below normal. The annual rainfall for 2013 was approximately normal.

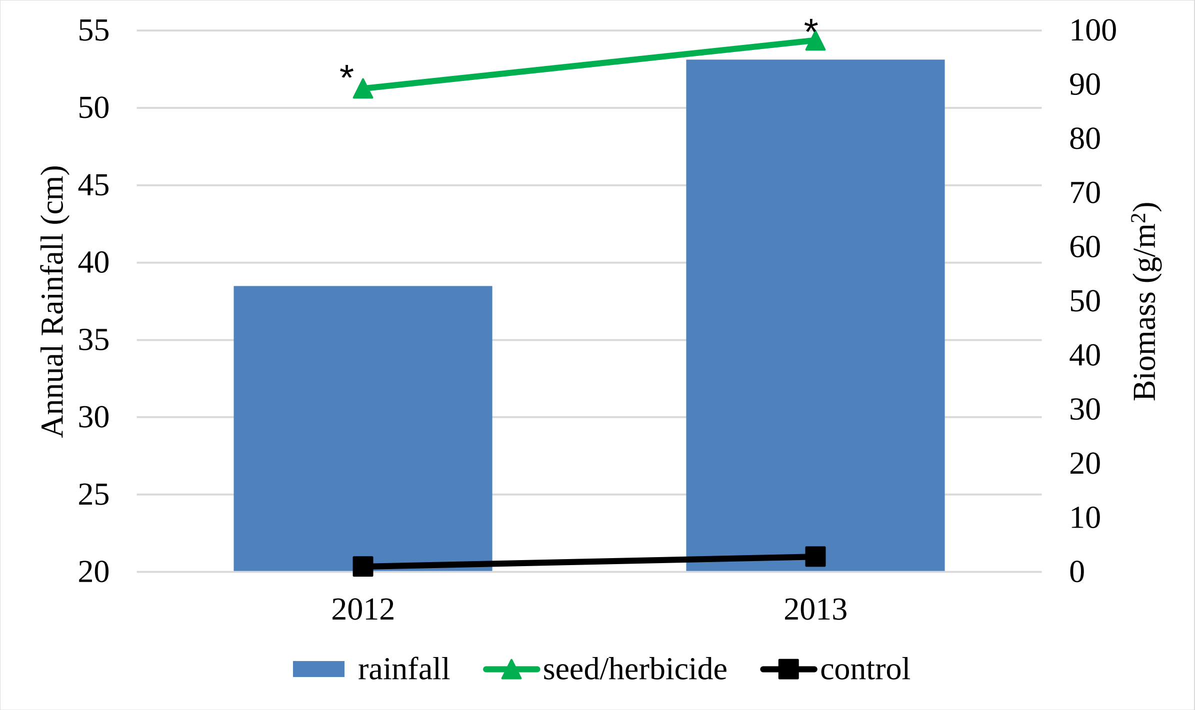


Figure 2. Planted warm-season biomass production and annual rainfall between 2012 and 2013 in grazed plots (Asterisk indicates a significant difference between the control and seed/herbicide treatment within a year).

Similar to trends in warm-season biomass, total biomass of the ungrazed seed/herbicide treatment is shown in Figure 3. In 2012 and 2013, the seed/herbicide treatment appears to have greater total biomass than the control however treatments were only significantly different in 2013.

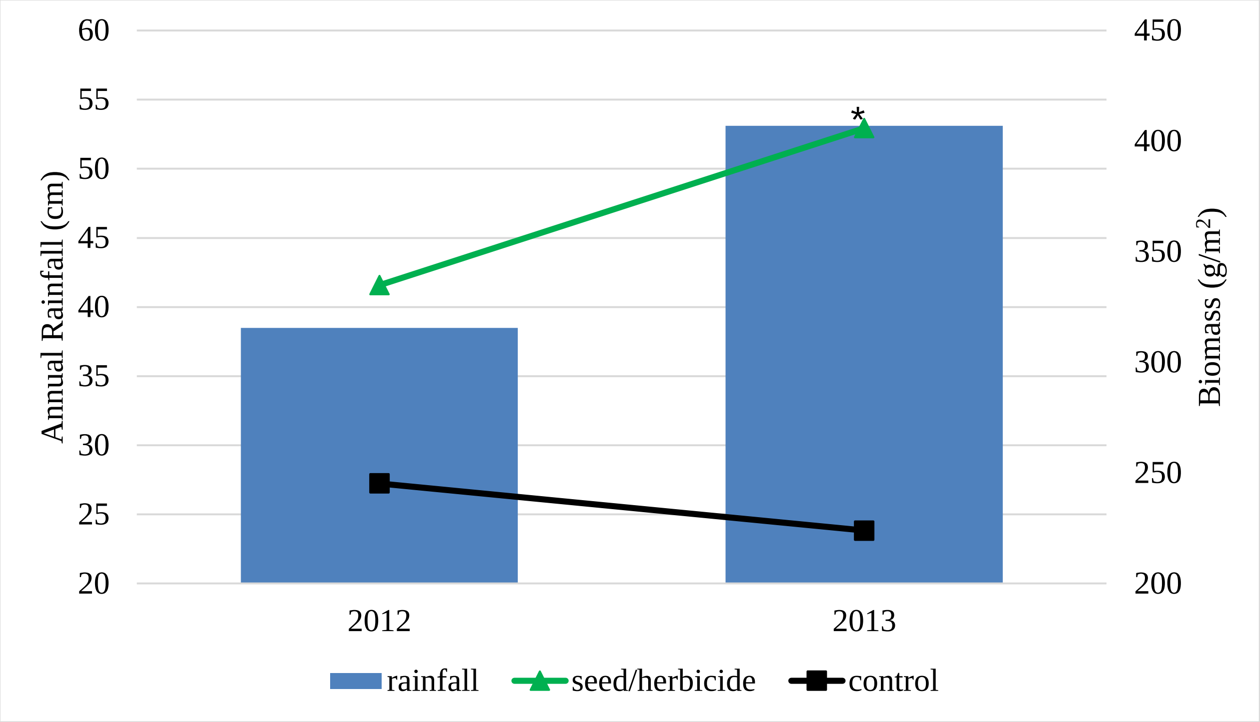


Figure 3. Total biomass production and annual rainfall between 2012 and 2013 in ungrazed plots. (Asterisk indicates a significant difference between the control and seed/herbicide treatment within a year).

Discussion

Our study found that the use of a herbicide treatment to reduce competition prior to interseeding resulted in greater warm-season and total plant biomass. These results were not surprising, however, our prediction that the burn/seed/herbicide treatment would be most successful was not borne out. Only in the 2013 grazed plots did the burn/seed/herbicide treatment yield greater warm-season plant biomass than the control and in no plots did this treatment yield greater total plant biomass. These findings show that the herbicide treatment was the most effective, and more effective when used alone rather than in combination with burning. Similar results were found by Huffington (2011) who studied seedling establishment in the first year of this trial and found herbicide treatments to be the most effective in seedling establishment, but also noted that burning had positive results. Our findings are supported by

Bakker et al. (2003), who concluded that interseeding is most effective when used in combination with some form of cover reduction.

In no plots did burning alone prior to interseeding or interseeding alone yield greater warm-season or total plant biomass than control plots. Huffington (2011) noted that a less than adequate fuel load and high soil moisture content may have decreased the effectiveness of spring burning prior to seeding and suggested that in more favorable conditions burning may have been more successful at decreasing seedling competition.

NDAWN weather data were available at the immediate study site. Annual precipitation for 2012 was 38.48 cm, far below normal precipitation levels. Annual precipitation for 2013 was 53.11 cm, approximately normal. Not only did the herbicide treatment yield greater warm-season biomass than the control but it did so over 2 years with varying conditions. Similar total biomass trends occurred in the ungrazed plots, however, total biomass in the herbicide treatment was only significantly greater in 2013.

These findings are supported by earlier evidence that plant diversity is often positively correlated with increases in biomass production (McNaughton, 1993). There are enough differences among plants in physiology, morphology, resource requirements, and life histories so that mixtures of several species can utilize more fully limiting resources than single species (Hooper, 1998; Hooper et al., 2005). The results of our study are also consistent with findings from Biondini (2007) where a consistent positive relationship was found between aboveground biomass and species and functional form richness. By taking advantage of a plant community niche that was unutilized, warm-season biomass increased though the use of interseeding in combination with pre-seeding competition reduction. This outcome is similar to findings by Tilman et al. (2001) and Tilman et al. (1996), who cited niche complementarity as having strong effects on ecosystem functioning and specifically, biomass production. The success of warm-season perennial grasses in this study supports previous findings by Biondi (2007) and Daigh (2014) found root mass and depth of rooting by warm-season perennial grasses to be important factors in the utilization of soil moisture inaccessible to other species.

Further research is needed to establish management practices to maintain increased biomass achieved from interseeding. These practices could include prescribed burning, herbicide application, or the development of a sustainable grazing system. Also, burning in consecutive years prior to interseeding can be used to reduce nitrogen in the soil and should be evaluated as a viable practice for competition reduction. Lastly, we expect our findings to only be consistent throughout the ecoregion 48b. Sand Deltas and Beach Ridges, requiring replication of this study in other ecoregions of the Northern Great Plains.

Conclusion

As found by Wilson and Gerry (1995), the plots with the greatest reduction of competition resulted in the greatest success in establishing new species. In the 2nd and 3rd year following the interseeding of native plant species, herbicide treatment prior to seeding is effective at increasing warm-season grass biomass and total biomass in years with and without moisture stress. These findings suggest that herbicide application prior to interseeding can improve seedling success and biomass production of planted species making it an effective tool in restoring rangelands and tallgrass prairie in the North Great Plains. During times of drought the benefits from interseeding a degraded rangeland include sustained forage production, making it an economical and ecologically viable tool.

Further research is needed to establish management practices to maintain increased biomass achieved from interseeding. These practices could include prescribed burning, herbicide

application, or the development of a sustainable grazing system. Also, burning in consecutive years prior to interseeding can be used to reduce nitrogen in the soil and should be evaluated as a viable practice for competition reduction. Lastly, we expect our findings to only be consistent throughout the ecoregion 48b. Sand Deltas and Beach Ridges, requiring replication of this study in other ecoregions of the Northern Great Plains.

Management Considerations

Interseeding native species is a viable tool for improving tallgrass rangeland health. When grassland managers and ranchers use this tool in combination with competition reduction, plant establishment and season-long biomass can be increased. When planning an interseeding restoration, it is essential to inventory the current plant community to determine voids in biomass by species and functional groups throughout the grazing season. Planning interseeding during favorable conditions for germination and seedling establishment is also recommended. Species to be planted should be selected from the NRCS Ecological Site Descriptions for the associated Major Land Resource Area.

Competition reduction should be conducted prior to seeding. For Kentucky bluegrass and smooth brome dominated pastures, a herbicide (RoundUp) treatment would be most effective in reducing competition and increasing production. If conditions are favorable, burning in combination with herbicide could be considered. Grazing should be deferred for at least one year following seeding. Trends in our study suggested that biomass increased when grazing was deferred for three years.

Literature Cited

Anderson, K.L., E. Smith, and C. Owensby. 1970. Burning Bluestem Range. J. Range Manage. 23:81-92.

Bailey, P., and C.O. Martin. 2007. Overview of Prairie Planting Techniques and Maintenance Requirements. EMMRP Technical Notes Collection. ERDC TN-EMMRP-ER-05. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Bakker, J.D., S.D. Wilson, J.M. Christian, X. Li, L.G. Ambrose, and J. Waddington. 2003. Contingency of Grassland Restoration on Year, Site, and Competition from Introduced Grasses. Ecological Applications. 13:137-153.

Biondini, M. 2007. Plant Diversity, Production, Stability, and Susceptibility to Invasion in Restored Northern Tall Grass Prairies (United States). Restoration Ecology 15: 77-87.

Collins, S.L. A.K. Knapp, J.M. Blair, and E.M. Steinauer. 1998. Modulation of Diversity by Grazing and Mowing in Native Tallgrass Prairie. Science 280: 745-747.

Daigh, A. L., X. Zhou, M. Helmers, C. Pederson, R. Ewing, and R. Horton. Subsurface Drainage Flow and Soil Water Dynamics of Reconstructed Prairies and Corn Rotations for Biofuel Production. Vadose Zone J. 2014. 13: 1-14

Daubenmire, R. 1968. Ecology of Fire in Grasslands. Adv. Ecol. Res. 5:209-266.

DeKeyser, S., G. Clambey, K. Krabbenhoft, and J. Ostendorf. 2009. Are Changes in Species Composition on Central North Dakota Rangelands Due to Non-use Management? Rangelands. 31: 16-19.

DiTomaso, J. M., G. B. Kyser, and M. S. Hastings. 1999. Prescribed Burning for Control of Yellow Starthistle (Centaurea solstitialis) and enhanced native plant diversity. Weed Sci. 47:233–242.

DiTomaso, J.M. 2000. Invasive Weeds in Rangeland: Species. Impacts, and Management. Weed Science 48: 255-265.

Engle, D.M., and P.M. Bultsma. 1984. Burning of Northern Mixed Prairie During Drought. Journal of Range Management. 37: 398-401.

Frost, R.A., and K.L. Launchbaugh. 2003. Presciption Grazing for Rangeland Weed Management: A New Look at an Old Tool. Rangelands 25: 43-47.

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 Restorations 27:58-65.

Hatch, D. A., J. W. Bartolome, and D. S. Hillyard. 1991. Testing a Management Strategy for Restoration of California’s Native Grasslands. Pages 343–349 in Proceedings of the Symposium on Natural Areas and Yosemite: Prospects for the Future. Denver, CO: U.S. National Park Service.

Hendrickson, J.R. and C. Lund. 2010. Plant Community and Target Species Affect Responses to Restoration Strategies. Rangeland Ecology & Management 63: 435-442.

Hooper, D. U. 1998. The Role of Complementary and Competition in Ecosystem Responses to Variation in plant diversity. Ecology 2:704–719.

Hooper, D. U., F. S. Chapin III, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, et al. 2005. Effect of Biodiversity on Ecosystem Functioning: a Consensus of Current Knowledge Ecological Monographs 75:3–35.

Howe, H.F. 1999. Dominance, Diversity, and Grazing in Tallgrass Restoration. Ecological Restoration. 17: 59-56.

Huffington, M.P. 2011. Rangeland and Pasture Improvements for Southeastern North Dakota. M.S. Thesis. North Dakota State University. Fargo, ND. 69pp.

Kurtz, C. 2001. A Practical Guide to Prairie Reconstruction. University of Iowa Press.

Manske, L.L., and W.T. Barker. 1988. Habit Usage by Prairie Grouse on the Sheyenne National Grasslands. USDA, Forest Service Rocky Mountain Forest and Range Experiment Station Research General Technical Report. RM-159. 8-20.

Martin, A.R., and R.S. Moomaw. 1974. Warm-season Grass Establishment Using Herbicides. Proc. North Cent. Weed Cont. Conf. 29:63-64.

McNaughton, S. J. 1993. Biodiversity and Function of Grazing Ecosystems. Pages 347–360 in E.D. Schulze, and H. A. Mooney, editors. Biodiversity and ecosystem function. Springer-Verlag, New York.

Murphy, R. K., and T. A. Grant. 2005. Land management History and Floristics in Mixed-grass prairie, North Dakota, USA. Natural Areas Journal 25:351- 358.

NDAWN. 2014. North Dakota Agricultural Weather Network. Available at: http://ndawn.ndsu.nodak.edu/station-info.html?station=75. Accessed 15 March 2014.

Owensby, C.E., and E.F. Smith. 1979. Fertilizing and Burning Flint Hills Bluestem. Journal of Range Management. 32:254-258.

Packard, S., and C. F. Mutel. 1997. The Tallgrass Restoration Handbook for Prairies, Savannas, and Woodlands. Washington, DC: Island Press.

Pritekel, C, A. Wittemore-Olson, N. Snow, and J. C. Moore. 2006. Impacts from Invasive Plant Species and Their Control on the Plant Community and Belowground Ecosystem at Rocky Mountain National Park, USA. Applied Soil Ecology 32:132-141.

Rowe, H.I. 2010. Tricks of the Trade: Techniques and Opinions from 38 Experts in Tallgrass Prairie Restoration. Restoration Ecology. 18: 253-262.

Schumacher, C.M. 1964. Interseeding in Nebraska. Journal of Range Management. 17: 132-137.

Sheley, R.L., and J.K. Petroff. 1999. Biology and Management of Noxious Rangeland Weeds. Weed Technology 13: 847-848.

Smith, E. F., and C W. Owensby. 1972. Effects of Fire on True Prairie Grasslands. Proc. Annual Tail Timbers Fire Ecology Conf., No. 12. p. 9-22.

Stubbendieck, J., S.L. Hatch, and N.M. Bryan. 2011. North American Wildland Plants.

Tilman, D., Wedin, D. & Knops, J. 1996 Productivity and Sustainability Influenced by Biodiversity in Grassland Ecosystems. Nature, 379, 718–720.

Tilman, D., P. B. Reich, J. Knops, D. Wedin, T. Mielke, and C. Lehman. 2001. Diversity and Productivity in a long term grassland experiment. Science 294:843–845.

USDA – Economic Research Service. 2011. Major Uses of Land in the United States.

United States Department of Agriculture, Natural Resource Conservation Service. 2014. Web Soil Survey. Available at: http://Websoilsurvey.Nrcs.Usda.Gov/App/Websoilsurvey.aspx. Accessed 11 July 2014.

United States Department of Agriculture, Natural Resource Conservation Service. 2014. Field Office Technical Guide for North Dakota. Available at: http://efotg.sc.egov.usda.gov/treemenuFS.aspx Accessed 18 November, 2014.

Vaness, B. M., and S. D. Wilson. 2007. Impact and Management of Crested Wheatgrass (*Agropyron cristatum*) in the Northern Great Plains. Canada Journal of Plant Science 87:1023-1028.

Vinton and Goergen. 2006. Plant-Soil Feedbacks Contribute to the Persistence of *Bromus inermis* in Tallgrass Prairie. Ecosystems 9: 967-976.

Wedin, D. A., and D. Tilman. 1996. Influence of Nitrogen Loading and Species Composition on the Carbon Balance of Grasslands. Science 274:1720-1723.

Wilson, S.D., and A.K. Gerry. 1995. Strategies for Mixed-grass Prairie Restoration: Herbicide, Tilling, and Nitrogen Manipulation. Restoration Ecology 3: 290-298.

Young, J. A., and R. A. Evans. 1978. Population Dynamics after Wildfires in Sagebrush Grasslands. Journal of Range Management 31: 283-289.

CHAPTER 3. MAINTENANCE OF RIPARIAN WOODLANDS LOCATED WITHIN THE MIDDLE SHEYENNE WATERSHED

Abstract

Little is known about riparian tree regeneration within the Middle Sheyenne Watershed. These plant communities are essential in maintaining water quality and the biological integrity of the system. Problems that have recently been acknowledged are the highly variable white-tail deer population, intermittent cattle grazing, and the presence of invasive dominated plant communities along the Sheyenne Valley. To assess the impacts of these stressors on woody vegetation regeneration, tree/shrub plantings were established at two sites using species native to the area. The first site was established in 2009 and is considered lowland. Treatments on the lowland site included: mowed, not mowed, high-fence, low-fence, and no fence. A completely randomized block design was used with three replications. The 12 plots in each rep were 10m x 10m and varied between low density (8 trees) and high density (36 trees). Results indicated the most effective combination of treatments was the high fence and mowing between the rows within the planting. The second site was established in 2010 and is considered to be upland. Larger plots (4) were established with treatments that included: high electric fence, low electric fence, no fence, fabric, and herbicide. Plots used at the lowland site were 50m x 50m and have no variation in density of trees. Data collected included survival and tree height at both sites. Sapling survival was surveyed at both sites for all individuals planted. High fencing was the only treatment that showed significantly higher tree sapling survival at the lowland and upland sites. The effectiveness of these treatments will be used to provide rangeland technical assistance to relevant land managers.

Introduction

Land managers and restoration groups in eastern North Dakota have noticed a lack of natural tree regeneration along riparian areas, and have had mixed success in woodland restoration efforts. A recent study on riparian woodlands and shrublands of the Middle Sheyenne River found reduced canopy cover to be correlated with increased risk of invasion by perennial cool-season grasses, Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromis inermis*) (Meehan, 2011). Throughout the Middle Sheyenne watershed factors have been identified that may lead to reduced sapling survival: livestock grazing, herbivory by deer or rodents, competition from other vegetation, tree seed predation, changes in environmental factors (soil moisture, soil nutrients, length of growing season), disturbance of site conditions, and/or lack of disturbance.

Plant communities within the Middle Sheyenne Watershed are essential in maintaining water quality and the biological integrity of the system. Problems that have recently been acknowledged as potential threats to plant communities are the highly variable white-tailed deer population, intermittent cattle grazing, and the presence of invasive dominated plant communities along the Sheyenne Valley. To assess the impacts of these stressors on tree sapling regeneration and to analyze management strategies, tree plantings were established at two sites using species widely planted in the area.

Literature Review

Riparian vegetation occupies a unique position within river basins, lying at the interface between terrestrial and aquatic ecosystems. It performs a number of important functions including nutrient buffering of groundwater from adjacent terrestrial areas (Lowrance et. al., 1984; Haycock et. al., 1993), stabilizing river bank sediments, and providing cover and habitat for wildlife (Harper et al., 1994; Large and Petts, 1994; Opperman and Merenlender, 2000).

Riparian corridors are systems of high biotic, structural, and functional diversity (Opperman and Merenlender, 2000; Gregory et al. 1991). In the western United States riparian areas have decreased and the remaining habitats have been fragmented or degraded by various human activities (National Research Council 1992; Kondolf et al. 1996). Kauffman et al. (1997) and the U.S. Department of the Interior Bureau of Land Management (1993) define a degraded riparian zone as one that lacks the capacity to provide ecosystem functions such as bank stability, maintenance of water temperatures and stream flows, and habitat features (Opperman and Merenlender, 2000).

An essential step in a successful restoration is identifying the stressors that are contributing to the decline of the system or preventing system recovery. Failure to mitigate stressors will render restoration efforts ineffective (Briggs et al. 1994; Kauffman et al. 1997). Grazing is one example of a stressor that can prevent recovery in a riparian system and many studies have shown vigorous growth of riparian vegetation following the removal of livestock (Briggs et al., 1994; Green and Kauffman, 1995; Kauffman et al., 1995). Studies have shown that grazing by livestock has resulted in the decline of riparian forests (Keller and Burnham, 1982; Platts and Wagstaff, 1984; Knapp and Matthews, 1996). Livestock can target saplings and saplings of woody riparian species when overgrazed, compact soil, and exacerbate bank erosion (Platts, 1991; Fleischner, 1994). It is estimated by Armour et al. (1994) that 50% of western riparian corridors have been degraded by livestock overgrazing. High deer population densities have also been implicated in significant changes in riparian regeneration in the eastern (Alverson et al., 1988; Tilghman, 1989) and western (Opperman and Merenlender, 2000) United States.

Opperman and Merlender (2000) suggest that deer herbivory be considered when planning a restoration project when dealing with riparian degradation and high deer densities. Preliminary fencing projects were recommended to determine if deer herbivory is limiting regeneration at a specific site.

Tree sapling mortality rates are an important limitation on riparian restoration and reforestation (Keeton, 2006). Mortality levels can be severe in the degraded conditions often encountered at restoration sites, such as moisture stress, poor soil conditions, competition with herbaceous species, and herbivory from rodents, rabbits, cattle, and deer (Stange and Shea 1998; Harmer 2001; Opperman and Merenlender 2000). Because of the many stressors on riparian tree saplings, survival rates as low as 50% are sometimes deemed acceptable (Sweeney et. al. 2002).

One tool used in riparian restoration is the planting of riparian woody species (Briggs et al. 1994; Kauffman et al. 1995). Without stress mitigation, survival rates are expected to be relatively low. Many techniques exist to mitigate stress on planted saplings including the use of weed barrier fabric, fencing, mowing, and pre-planting herbicide treatment. Fencing has been one of the most effective controls for deer damage (Opperman and Merenlender 2000). Most fencing efforts have focused on conventional nonelectrified, woven-wire designs (Ellingwood et. al. 1985; McAninch et. al. 1983). The most effective fence has been the 2.4-m vertical, woven-wire design (Caslick and Decker 1979; Craven 1983). With these findings in mind a riparian tree regeneration trial was established at lowland and upland sites along the Middle Sheyenne River. This study aimed to test the effectiveness of several treatments used in combination with fencing for increasing survivability among riparian tree and shrub plantings.

Methods

This study was conducted at two sites along the Middle Sheyenne River in eastern North Dakota, near Tolna and Pekin in southwestern Nelson County. One study site was located within a lowland riparian area (SE ¼ of Section 6 in Township 149 North, Range 59 West) and another located in upland riparian grassland (S ½ of Section 3 in Township 150 North, Range 61 West).

Soils of the upland site are comprised of an Arvilla-Sioux complex with 2 to 6 percent slopes and a Barnes-Sioux complex with 6 to 15 percent slopes. The Arvilla series is classified as a sandy, mixed, frigid Calcic Hapludoll and consists of very deep, somewhat excessively drained soils formed in moderately coarse textured glacial outwash and the underlying sand and gravel on glacial lake beaches, stream valley terraces and outwash plains. The Sioux series is classified as a sandy-skeletal, mixed, frigid Entic Hapludoll and consists of excessively drained soils formed in sand and gravel on outwash plains, terraces and eskers. The Barnes series is classified as a fine-loamy, mixed, superactive, frigid Calcic Hapludoll and consists of very deep, well drained soils that formed in loamy till.

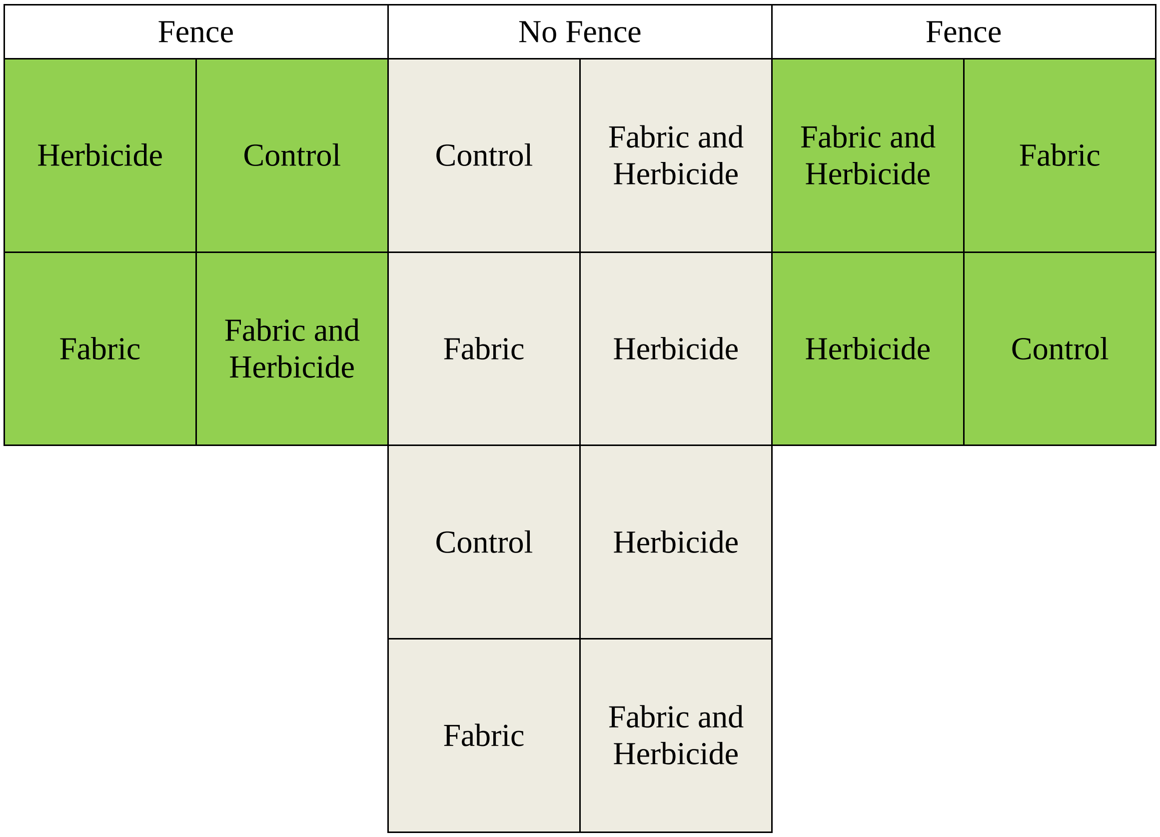
Soils of the lowland site are primarily the LaDelle series, wooded-Fluvaquents, with minor components of Fairdale, Velva, Ludden, and Rauville. Soils at the lowland site have 0 to 2 percent slopes and are frequently flooded. Below an "Oi" horizon of decomposed plant material the LaDelle series is classified as a fine-silty, mixed, superactive, frigid Cumulic Hapludoll (United States Department of Agriculture, Natural Resource Conservation Service, 2014).

The climate of the study area is characterized by variations in both temperature and precipitation. Average annual precipitation is approximately 40 cm/year near McHenry, North Dakota, of which over 80% occurs during the growing season April through October (NDAWN

2014). The study location averages 124 frost-free days annually with monthly mean, average daily temperatures ranging from -15°C in January to 20.6°C in July (NDAWN 2014).

The upland site was planted with native shrub and tree species: American plum (*Prunus Americana*), peachleaf willow (*Salix amygdaloides*), red osier dogwood (*Cornus sericea*), false indigo (*Amorpha fruticosa*), bur oak (*Quercus macrocarpa*), and cottonwood (*Populus deltoides*) (Figure 4). Weed-barrier fabric, herbicide, and fencing treatments were applied in a split plot design with two replications of each treatment (Figure 5).

Figure 4. Aerial image of upland tree restoration site south of Tolna, ND.



Fence		No Fence		Fence	
Herbicide	Control	Control	Fabric and Herbicide	Fabric and Herbicide	Fabric
Fabric	Fabric and Herbicide	Fabric	Herbicide	Herbicide	Control
		Control	Herbicide		
		Fabric	Fabric and Herbicide		

Figure 5. Treatment layout for upland riparian tree sapling planting located south of Tolna, ND.

Both fenced and non-fenced plantings were established in 50m x 50m plots with the Control (saplings planted directly into grassland sod), fabric barrier, herbicide (glyphosate) application, and a fabric herbicide combination being the treatments. Buffers of 3.7m were placed between fenced and non-fenced plots. Saplings were spaced 0.9m apart and rows were spaced 3m apart (Figure 6). A high fence plot that was 2.4m tall with 7 electric strands, and a low fence plot that was1.5m tall with 4 electric strands were used as deer and cattle exclosures. Glyphosate was applied to herbicide plots prior to planting.

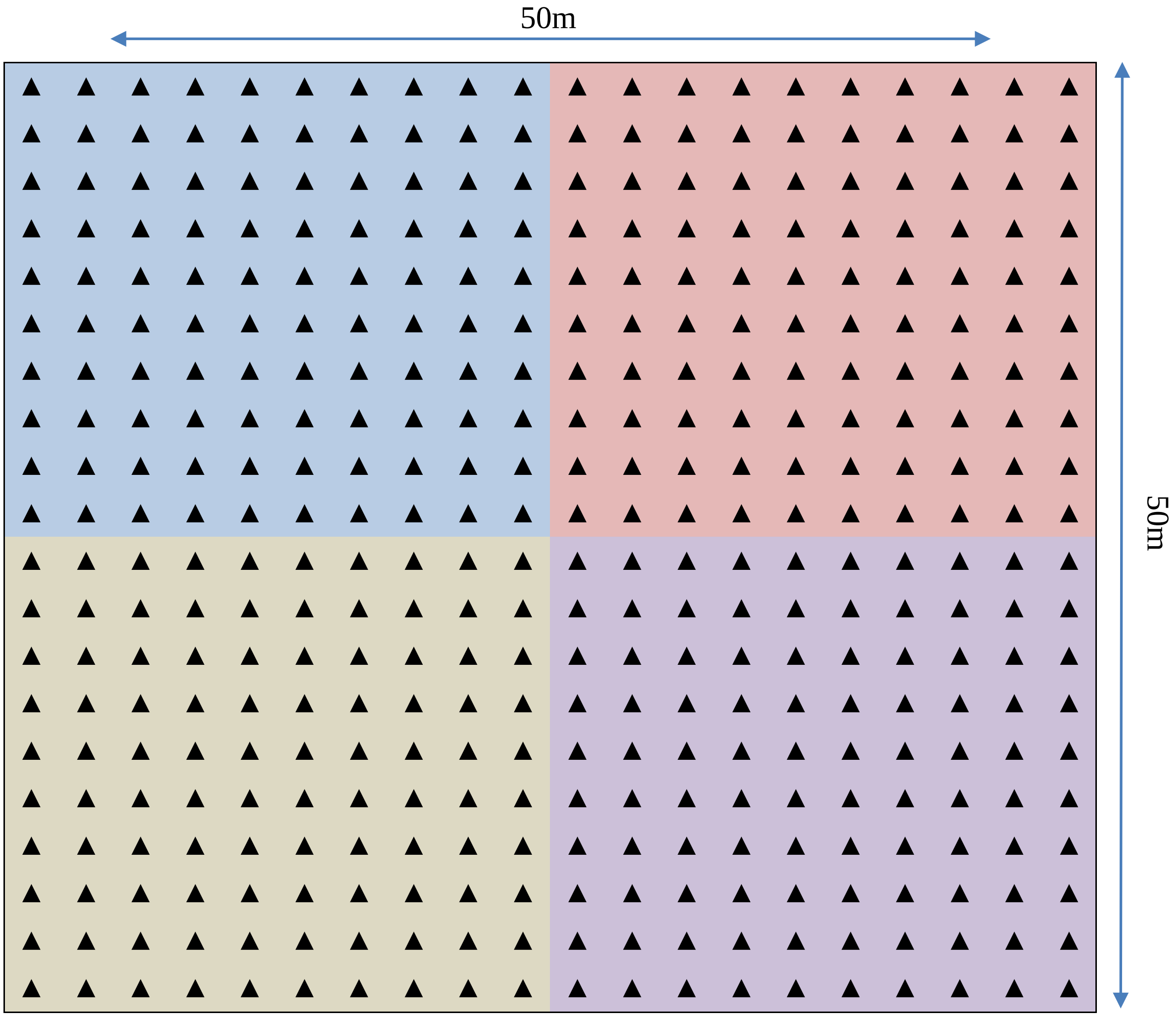


Figure 6. Tree planting plot design for upland riparian tree sapling planting located south of Tolna, ND. Tree spacing is 0.9 m, and row spacing is 3.0 m.

Saplings were planted in June of 2010. In September of 2012 and 2013 sapling survival was sampled on all trees and shrubs that were planted. Height was also recorded; however it could not be used to compare growth between species because of varying growth rates. SAS 6.4 Enterprise Guide Statistical Software was used to perform a One-Way ANOVA for each species.

The lowland site was planted with native shrub and tree species: hackberry (*Celtis occidentalis*), bur oak (*Quercus macrocarpa*), green ash (*Fraxinus pennsylvanica*), and cottonwood (*Populus deltoides*) (Figure 7). High fence deer exclosure and low fence cow exclosure, mowing between saplings, and high and low planting densities were applied in a randomized complete-block design (Figure 8). High fencing was constructed using 2.4 m plastic mesh, while low fencing was constructed with a conventional 4-strand barbed wire design. High (36 saplings) and low (8 saplings) density plantings were conducted with sapling spacing of 0.91 m in high density plots and 1.5 m in low density plots. Plot size was 10 m x 10 m (Figure 8).

Figure 7. Aerial view of lowland tree restoration site southeast of Pekin, ND.

Table 14. Layout of lowland tree restoration planting (HF = high fencing, LF = low fencing, NF = no fencing, HD = high density, LD = low density, Green = not mowed, and Blue = mowed) southeast of Pekin, ND.

Rep 1	🟦 NF LD	🟦 NF HD	🟩 NF LD	🟩 NF HD	🟩 LF LD	🟦 HF LD	🟩 HF HD	🟦 HF HD	🟦 LF LD	🟦 LF HD	🟩 LF HD	🟩 HF LD
Rep 2	🟩 HF HD	🟩 LF LD	🟦 LF LD	🟩 NF LD	🟩 NF LD	🟦 HF LD	🟩 HF LD	🟦 LF HD	🟦 NF HD	🟦 NF LD	🟩 LF HD	🟦 HF HD
Rep 3	🟩 LF HD	🟦 LF LD	🟦 NF HD	🟩 NF LD	🟦 LF HD	🟩 LF LD	🟦 HF LD	🟩 HF HD	🟦 NF HD	🟦 NF LD	🟦 HF HD	🟩 HF LD

*Dimensions of each treatment are 10 m x 10 m.

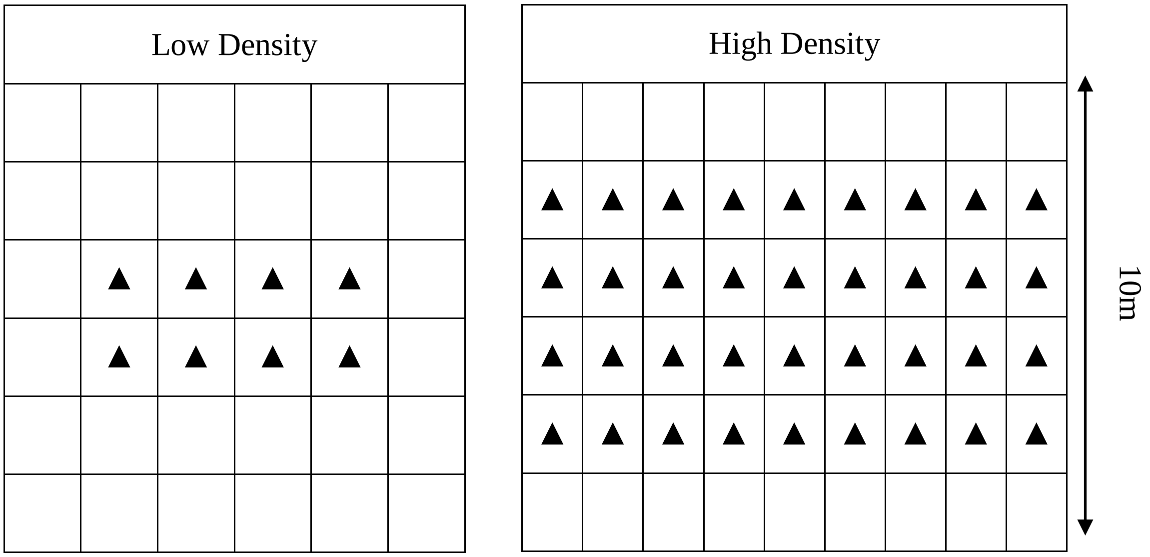


Figure 8. Lowland high and low density plot designs for tree restoration planting southeast of Pekin, ND. ▲ = Tree sapling.

Saplings were planted in June of 2009. All saplings were sourced from Lincoln-Oakes Nursery. Mowing was conducted every two weeks during the growing season and when sites were accessible. In September of 2012 and 2013 sapling survival was sampled on all trees and shrubs that were planted. Height was also recorded; however cannot be used to compare growth between species because of varying growth rates. SAS 6.4 Enterprise Guide Statistical Software was used to perform a One-Way ANOVA and Tukey’s test for each species with a 90% confidence interval. Fencing was used as the between plot factor and treatments were used as the within plot factor.

Results

At the upland site, tests of the data revealed no significant differences between treatments for any species in 2012. Figure 9 indicates shrub species (dogwood, willow, plum, and false indigo) in some treatments had higher survival rates but the variability resulted in in tests being not significant had higher survival rates in certain treatments.

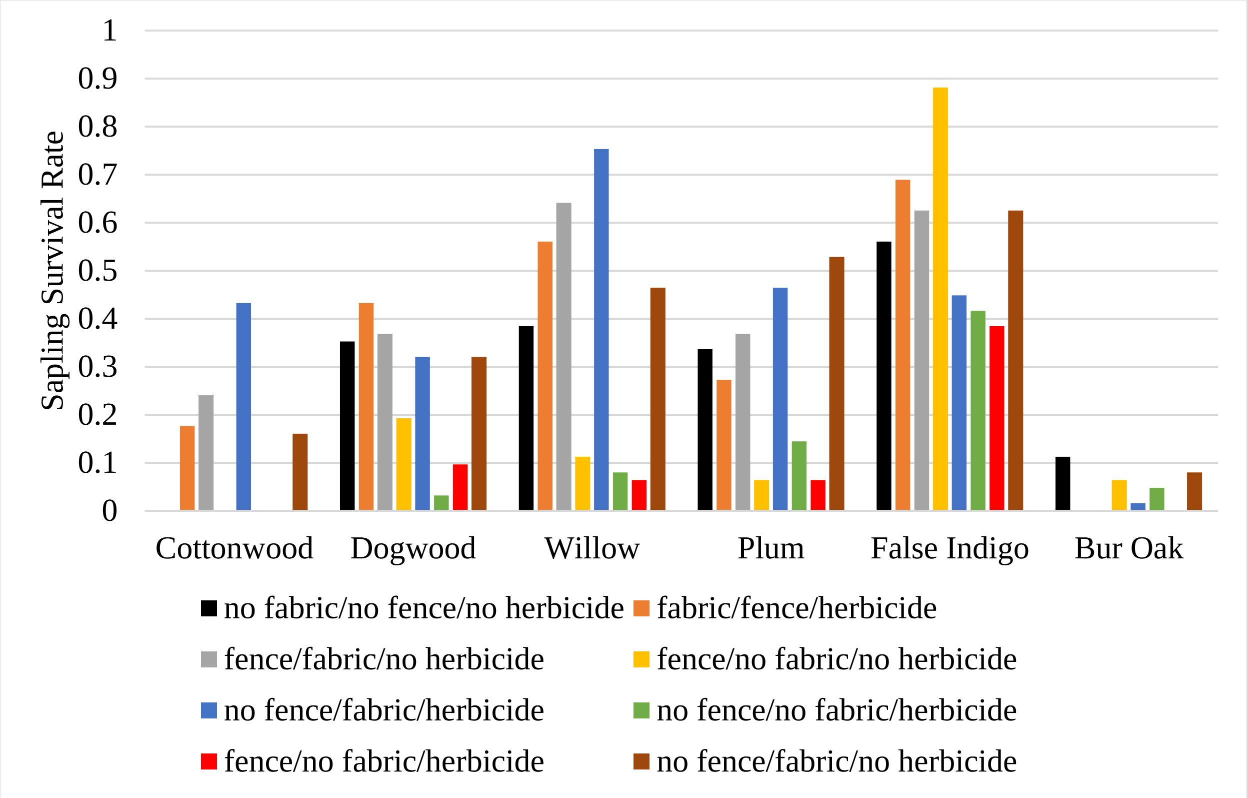


Figure 9. Upland sapling survival in 2012 at tree restoration planting south of Tolna, ND (p-value ≤ .10).

Survival rates in 2013 were similar to those seen in 2012; however lower variability yielded significant differences (p-value ≤ .10). The fabric/fence/herbicide treatment yielded significantly (p-value ≤ .10) higher survival rates than the control (no fence/fabric/no herbicide), fence/no fabric/no herbicide treatment, and the fence/fabric/no herbicide treatment within the red osier dogwood saplings (Figure 10).

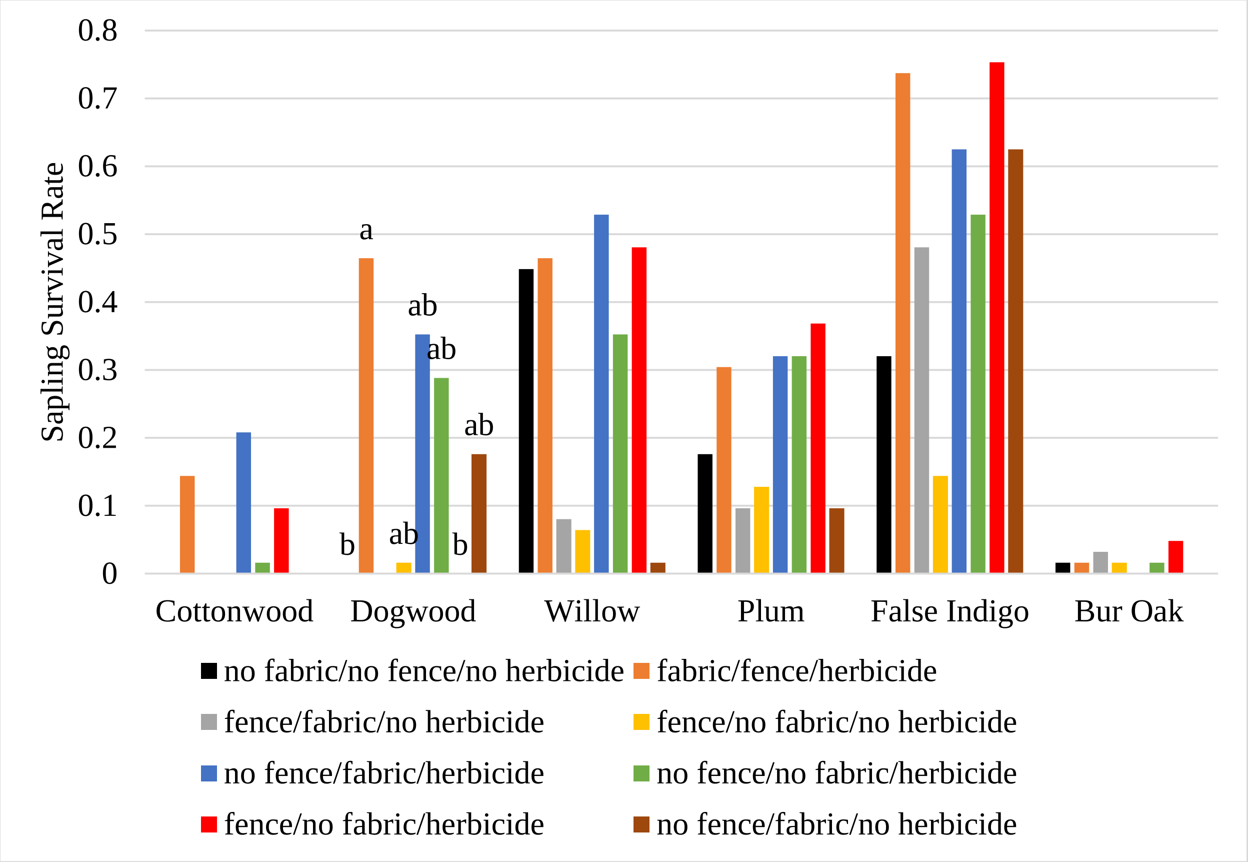


Figure 10. Upland sapling survival in 2013 at tree restoration planting south of Tolna, ND (p-value ≤ .10).

At the lowland site no significant differences between treatments were found within hackberry and cottonwood species in 2012. The high fence/mowed treatment yielded significantly higher (p-value ≤ .10) survival rates than the low fence/mowed treatment within green ash saplings. The high fence/mowed treatment also yielded significantly higher survival rates than the control, no fence/mowed treatment, low fence/not mowed treatment, and low fence/mowed treatment within bur oak saplings (Figure 11).

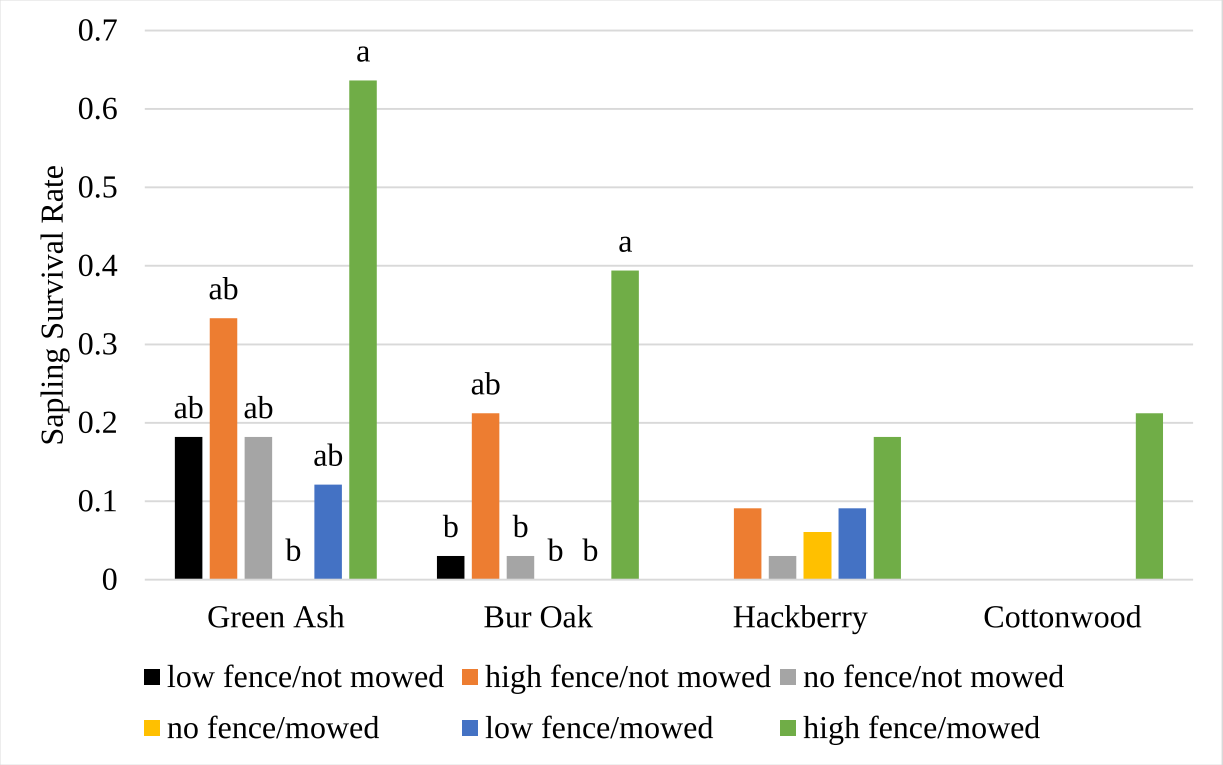


Figure 11. Lowland sapling survival in 2012 at tree restoration planting south of Tolna, ND (p-value ≤ .10).

In 2013, the high fence/mowed treatment yield significantly higher (p-value ≤ .10) sapling survival rates than the control, no fence/mowed treatment, low fence/not mowed treatment, and low fence/mowed treatment within green ash and bur oak saplings. Within hackberry saplings the high fence/mowed treatment yield significantly higher (p-value ≤ .10) sapling survival rates than all other treatments (Figure 12).

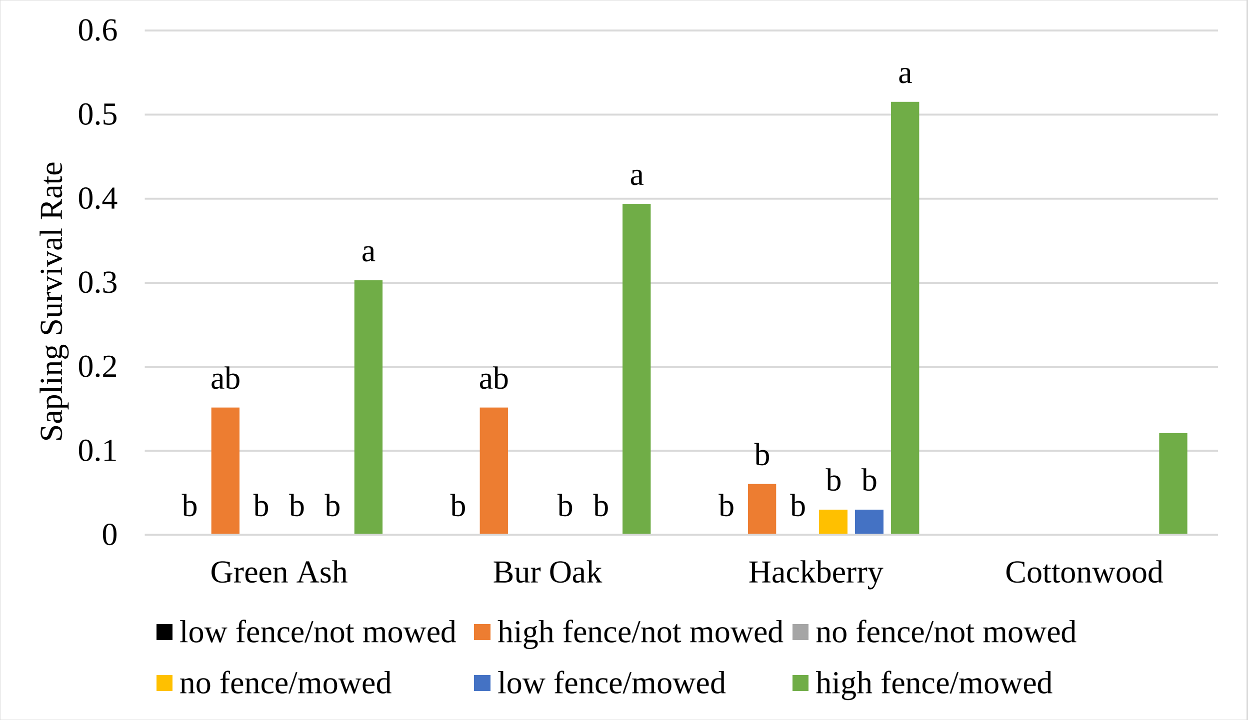


Figure 12. Lowland sapling survival in 2013 (p-value ≤ .10).

Discussion

Higher than desirable variation in sapling survival at the upland site contributed to no significant differences between treatments for within species in 2012. This trend continued in 2013, however, some treatments yielded significantly higher survival rates within red osier dogwood saplings. Sources of variation can be explained by several observations during sampling. Weed-barrier fabric, designed to reduce competition from herbaceous species, also served as corridors for several species of rodents. This was evident from girdling found primarily on saplings that had fabric applied. Fences at the upland site deterred some deer from browsing saplings; however, deer were found within the exclosures at times and deer beds were consistently found within the exclosures. The insulating effects of hollow deer hair as well as the minimal grounding surface area of hooves may moderate the shock of electric fences (Verauteren, 2006). Quite often, if a deer is partially through an electric fence before receiving a shock, it will continue through (McKillop and Sibly 1988, Curtis et al. 1994). Shrub species appeared to have greater success at establishing and maintaining higher survival rates. These species may be better suited for the abiotic conditions at the upland site such as moisture and soil characteristics.

The lowland site yielded more consistent results than the upland site. In 2012, green ash and bur oak species showed significantly higher survival rates when high fence and mowing treatments were applied. In 2013, green ash, bur oak, and hackberry species showed significantly higher survival rates when high fence and mowing treatments were applied. Plastic-mesh fencing was used at the lowland site and had greater success in excluding deer and other animals that may target saplings than the electric fence used at the upland site. Mowing between rows did not increase sapling survival unless high fencing was also applied.

Maintenance concerns regarding mowing and longevity of the mesh-fence became evident during this study. Periodic flooding occurred in 2012 and 2013 and made the site inaccessible as late as June 14th. These conditions decreased the effectiveness of mowing treatments. Flooding also caused inundation of the lowland plantings periodically. Flowing debris caused damage to the low-fence and destroyed the high mesh-fence at two points during the five-year study.

At both sites, extensive girdling of tree saplings was present. This is attributed to multiple species of rodents. There are several factors that may influence the impact of rodents on tree sapling survival rates. Dense herbaceous vegetation and weed-barrier fabric provide habitat for rabbits, mice, and voles which target tree saplings when other food is not available. Similar observations were made by Lansing (1941) in a study examining rodent damage to tree plantations in southeastern Minnesota. Lansing concluded that conditions most conducive to damage by mice at the study areas were lands with north-facing slopes or no slope, formerly cultivated, and covered with dense herbaceous vegetation. Lansing also concluded that ideal conditions for rabbit herbivory exist on formerly idle lands with thing herbaceous vegetation. Planting of tree saplings or natural establishment can also be inhibited by vegetation communities dominated by dense herbaceous vegetation. Tree saplings often compete poorly for plant available water with invasive cool-season grasses, Kentucky bluegrass and smooth brome.

Management Considerations

The upland site showed that electric fencing is not a reliable tool for excluding deer and preventing browsing of tree and shrub saplings. It is important to recognize unintended effects of management actions such as fabric installation. Although weed-barrier fabric reduces herbaceous competition, it can also serve as a corridor for rodents that target saplings. Fabric also makes saplings readily accessible to browsers. To mitigate girdling on saplings, tree tubes should be utilized in combination with fabric. The pre-seeding glyphosate treatment was shown to be ineffective in increasing sapling survival through competition reduction and is not recommended as a management strategy. Selecting the appropriate species for unique abiotic and biotic conditions at tree planting sites can influence sapling establishment and survival rates. It is also important to select sites with favorable conditions for sapling establishment.

The lowland site showed that high mesh fencing can increase the survival rates of saplings. The effectiveness of high mesh fencing is increased when combined with mowing between rows. Low barbed-wire fencing was shown to be ineffective at increasing survival rates of saplings and is not recommended to be used to exclude deer from tree plantings. Low barbed-wire (cattle exclusion only) fencing was found to effective at excluding cattle from tree saplings. This study also indicates that deer, rather than cattle, are impacting sapling survival. The riparian areas can be appropriately grazed by cattle without reducing tree sapling survival. There are a few maintenance concerns regarding tree plantings in lowland riparian areas. Plastic-mesh fencing becomes brittle after 2 years of sun exposure. This may result in holes developing and a reduction of effectiveness; however this type of fencing is easily replaced. Unique abiotic conditions in lowland riparian areas include periodic flooding and inundation of planting sites. These flood events can cause stress on saplings and often destroy mesh fencing. Additional methods to reduce browsing by deer, such as changes in harvest through hunting, should also be explored. This is a starting point to help managers determine the effects of their current land management on the regeneration of trees in the riparian woodlands.

Literature Cited

Alverson, W.S., D.M. Waller, and S.L. Solheim. 1988. Forests Too Deer: Edge Effects in Northern Wisconsin. Conservation Biology 2:348-357.

Armour, C.L., D.A. Duff, and W. Elmore. 1994. The Effects of Livestock Grazing on Western Riparian and Stream Ecosystems. Fisheries 19:9-12.

Briggs, M.K., B.A. Roundy, and W.W. Shaw. 1994. Trial and Error: Assessing the Effectiveness of Riparian Revegetation in Arizona. Restoration and Management Notes 12:160-167.

Caslick, J. W., and D. J. Decker. 1979. Economic Feasibility of a Deer-proof Fence for Apple Orchards. Wildlife Society Bulletin 7:173-175.

Curtis, P. D., M. J. Farigone, and M. E. Richmond. 1994. Preventing Deer Damage with Barrier, Electrical, and Behavioral Fencing Systems. Proceedings of the Vertebrate Pest Control Conference 16:223-227.

Craven, S. E. 1983. New Directions in Deer Damage Management in Wisconsin. Proceedings of the Eastern Wildlife Damage Control Conference 1:65-67.

Ellingwood, M. R., J. B. Mcaninch, and M. J. Farigone. 1985. Current Status of Deer Fencing in the Northeast. Proceedings of the Eastern Wildlife Damage Control Conference 2:180-185.

Fleischner, T.L. 1994. Ecological Costs of Livestock Grazing In Western North America. Conservation Biology 8:629-644.

Green, D.M., and J.B. Kauffman. 1995. Succession and Livestock Grazing In A Northeast Oregon Riparian Ecosystem. Journal of Range Management 48:307-313.

Gregory, S.V., F.J. Swanson, W. A. Mckee, and K.W. Cummins. 1991. An Ecosystem Perspective on Riparian Zones. Bioscience 41:540-551.

Harmer, R. 2001. The Effect of Plant Competition and Simulated Summer Browsing By Deer on Tree Regeneration. Journal of Applied Ecology 38:1094-1103.

Harper. D., Smith, C. Barham. P. & Ilowell, R. 1994. The Ecological Basis for the Management of the Natural River Environment. *The Ecologicul Hush for River Munugement (Ed.* By D. Tlarper and A.J.D. Ferguson), Pp. 219-238. Wiley. Chichester.

Haycock, N.E., Pinay, G. & Walker, C. 1993. Nitrogen Retention in River Corridors: European Perspective. *Amhio. 22,* 340-346.

Kauffman, J.B., R.L. Case, D. Lytjen, N. Otting, D.L. Cummings. 1995 Ecological Approaches to Riparian Restoration in Northeast Oreagon. Restoration and Management Notes 13:12-15.

Kauffman, J.B., R.L. Beschta, N. Otting, and D. Lytjen. 1997. An Ecological Perspective of Riparian and Stream Restoration in the Western United States. Fisheries 22:12-24.

Keeton, W. 2006. Evaluation of Tree Seedling Mortality and Protective Strategies in Riparian Forest Restoration. North J. Appl. For. 25 (3) 2008.

Keller, C.R., and K.P. Burnham. 1982. Riparian Fencing, Grazing, And Trout Habitat Preferences On Summit Creek, Idaho. North American Journal of Fisheries Management 2:53-59.

Knapp, R.A., and K.R. Matthews. 1996. Livestock Grazing, Golden Trout, And Streams in the Golden Trout Wilderness, California: Impacts and Management Implications. North American Journal of Fisheries Management 16:805-820.

Kondolf, G. M., R. Kattleman, M.Embury, and D.C. Erman. 1996. Status of Riparian Habitat. Pages 1009-1030 in Sierra Nevada Ecosystems Project, Final Report to Congress, Volume II. Assessment and Scientific Basis for Management Options. University Of California, Center for Waters and Wildland Resources, Davis.

Lowrance, R.R., Leonard, R.A. & Asmussen, L.E. 1985. Nutrient Budgets for Agricultural Watersheds in the Southeastern Coastal Plain. *Ecology,* 66, 287-296.

Lowland Site Aerial Imagery. 47°44'49.25"N and 98°15'2.34"W. GOOGLE EARTH. May 5, 2014. November 1, 2014.

Large, Andrew R.G. And Petts, Geoffrey E. 1994. Rehabilitation of River Margins. In: Calow, Peter and Petts, Geoffrey E., (Eds.) the River's Handbook: Hydrological and Ecological Principles. Vol. 2. Blackwell Science, Oxford, Pp. 401-418.

Mcaninch, J. B., R. Winchcombe, and M. Ellingwood. 1983. Fence Designs for Deer Control: A Review and the Results of Recent Research in Southeastern New York. Proceedings of the Eastern Wildlife Damage Control Conference 1: 101.

Mckillop, I. G., and R. M. Sibly. 1988. Animal Behaviour at Electric Fences and the Implications for Management. Mammal Review 18:91-103.

Meehan, M.A. 2011. Riparian Ecosystems of the Middle Sheyenne River in Eastern North Dakota. Doctoral Dissertation. North Dakota State University. Fargo, ND.

National Research Council. 1992. Rivers and Streams. Pages 165-261 in Committee on Restoration of Aquatic Ecosystems-Science, Technology, And Public Policy, Editors. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press, Washington, D.C.

NDAWN. 2014. North Dakota Agricultural Weather Network. Available At: Http://Ndawn/Ndsu/Nodak/Edu/. Accessed 14 July 2014.

Opperman, J.J., and A.M. Merenlender. 2000. Deer Herbivory as an Ecological Constraint to Restoration of Degraded Riparian Corridor. Restoration Ecology 8:41-47.

Platts, W.S. 1991. Livestock Grazing. Pages 389-423 In W.R. Meehan, Editor. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. Special Publication 19. American Fisheries Society, Bethesda, Maryland.

Platts, W.S., and F.J. Wagstaff. 1984. Fencing To Control Livestock Grazing on Riparian Habitats Along Streams: Is it a Viable Alternative? North American Journal of Fisheries Management 4:266-272.

Stange, E.E., and K.L. Shea. 1998. Effects of Deer Browsing, Fabric Mats, and Tree Shelters on Quercus Rubra Seedlings. Restoration Ecology 6:29-34.

Sweeney, B.W., S.J. Czapka, and T. Yerkes. 2002. Riparian Forest Restoration: Increasing Success by Reducing Plant Competition And Herbivory. Restoration Ecology 10:392-400.

Tilghhman, N. G. 1989. Impacts of White-Tailed Deer on Forest Regeneration in Northwestern Pennsylvania. Journal of Wildlife Management 53:524-532.

Upland Site Aerial Imagery. 47°47'22.45"N and 98°25'55.44"W. GOOGLE EARTH. May 5, 2014. November 1, 2014.

United States Department of Agriculture, Natural Resource Conservation Service. 2014. Web Soil Survey. Available at: http://Websoilsurvey.Nrcs.Usda.Gov/App/Websoilsurvey.aspx. Accessed 11 July 2014.

United States Department of the Interior, Bureau of Land Management (BLM). 1993. TR 1737-16, Revised 2003. Riparian Area Management 50: 139-145.

Vercauteren, K. C., M. J. Lavelle, and S. C. Hygnstrom. 2006. Fences and Deer-Damage Management: A Review of Designs and Efficacy. Wildlife Society Bulletin 34:191-200.

CHAPTER 4. GENERAL CONCLUSIONS

Interseeding native species is a viable tool for improving tallgrass rangeland health. When grassland managers and ranchers use this tool is combination with competition reduction, plant establishment and season-long biomass can be increased. When planning an interseeding restoration, it is essential to inventory the current plant community to determine voids in biomass by species and functional groups throughout the grazing season. We also suggest planning interseeding during favorable conditions for germination and seedling establishment. Species to be planted should be selected from the NRCS Ecological Site Descriptions for the associated Major Land Resource Area.

Competition reduction should be conducted prior to seeding. Our study showed that for Kentucky bluegrass and smooth brome dominated pastures, an herbicide (RoundUp) treatment would be most effective. If conditions are favorable, burning in combination with herbicide could be considered. Grazing should be deferred for at least one year following seeding. Trends in our study suggested that biomass increased when grazing was deferred for three years.

In a riparian tree regeneration trial the upland site showed that electric fencing is not a reliable tool for excluding deer and preventing browsing of tree and shrub saplings. It is important to recognize unintended effects of management actions such as fabric installation. Although weed-barrier fabric reduces herbaceous competition, it can also serve as a corridor for rodents that target saplings. Fabric also makes saplings readily accessible to browsers. To mitigate girdling on saplings, tree tubes should be utilized in combination with fabric. The pre-seeding glyphosate treatment was shown to be ineffective in increasing sapling survival through competition reduction and is not recommended as a management strategy. Selecting the appropriate species for unique abiotic and biotic conditions at tree planting sites can influence sapling establishment and survival rates. It is also important to select sites with favorable conditions for sapling establishment.

The lowland site showed that high mesh fencing can increase the survival rates of saplings. The effectiveness of high mesh fencing is increased when combined with mowing between rows. Low barbed-wire fencing (cattle exclusion only) was shown to be ineffective at increasing survival rates of saplings and is not recommended to be used to exclude deer from tree plantings. Low barbed-wire fencing was found to effective at excluding cattle from tree saplings. This study also indicates that deer, rather than cattle, are impacting sapling survival. The riparian areas can be appropriately grazed with reducing tree sapling survival. There are a few maintenance concerns regarding tree plantings in lowland riparian areas. Plastic-mesh fencing becomes brittle after 2 years of sun exposure. This may result in holes developing and a reduction of effectiveness; however this type of fencing is easily replaced. Unique abiotic conditions in lowland riparian areas include periodic flooding and inundation of planting sites. These flood events can cause stress on saplings and often destroy mesh fencing. Additional methods to reduce browsing by deer, such as changes in harvest through hunting, should also be explored. This is a starting point to help managers determine the effects of their current land management on the regeneration of trees in the riparian woodlands.