THE EFFECTS OF HERBIVORY AND VEGETATION COMPETITION ON SEEDLING SURVIVAL AND GROWTH IN THE MIDDLE SHEYENNE RIVER WATERSHED, NORTH DAKOTA

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MASTER OF SCIENCE

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ABSTRACT

There is a concern about the lack of regeneration of riparian hardwood forest communities in the Middle Sheyenne Watershed of northeastern North Dakota. Natural resource managers and landowners are unsure if herbivory by ungulates or other factors are responsible for a lack of tree seedling regeneration and survival. We focused our research on the role of ungulates and competitive vegetation in seedling survival and growth in demonstration tree planting sites. Landowners utilized exclosures from ungulate browsing and/or grazing, and different forms of vegetation control. The riparian study showed the combination of deer with cattle significantly affected survival of seedlings after three years at $p<0.012$, and that vegetation competition played less of a role in seedling survival. The upland study found that tree and shrub species in general did not respond significantly in terms of overall growth with treatments such as fabric and glyphosate herbicide to control vegetation competition.

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CHAPTER 1. GENERAL INTRODUCTION

There is a concern amongst resource managers about the lack of survival of tree seedlings in the Middle Sheyenne River Watershed. Tree plantings in riparian areas were experiencing higher than expected mortality, and included plantings that completely failed in some cases (personal communication David Nowatzki, ND Forest Service). There appears to be a lack of natural regeneration of young trees less than 2.5 cm diameter at breast height (dbh). The lack of survival of naturally occurring seedlings could pose a problem to the regeneration of riparian forests because the recruitment of younger classes of trees would be hindered. The lack of regeneration over time can result in the lack of different age classes in the forest stand.

There are several suspected reasons as to why tree plantings have not succeeded. White-tailed deer (*Odocoileus virginianus* Zimmermann) are suspected as playing a role in reduced seedling survival. A deer's diet is comprised of 50% woody browse from trees and shrubs (Smith et al. 2007). Herbivory by browsing deer can play a significant role in reduced survival and growth of tree seedlings (White 2012, Bradshaw and Waller 2016). Long term data suggests that deer can affect regeneration and composition of forests on a regional scale over time in Wisconsin (Bradshaw and Waller 2016).

Areas along the Sheyenne River are grazed by cattle (*Bos taurus*), often all summer long. Landowners wanted to know if cattle grazing impacted seedling growth and survival in their forested areas. Grazing by cattle had no significant effect on seedling survival of oak (*Quercus*) in California between grazed and ungrazed plots in spring and summer seasons (Hall et al. 1992). The authors recognized that there was a "high potential for deer browsing" that could not be excluded from the cattle grazing treatment. They suggested that wildlife may have contributed to seedling survival losses in grazed woodlands (Hall et al. 1992). However, grazing of cattle in wooded draws of South Dakota has been shown to negatively affect seedling growth, with increases in growth seen after cattle were excluded (Beottcher and Johnston 2005).

There are several ways to protect areas from browsing and grazing by large ungulates like cattle and deer. Methods employed include different types of fencing, repellants, and tree tube shelters (Curtis et al. 1994, Vercauteren et al. 2006, Stange 2008). Some of these methods are much more expensive than others. Different fences have different costs associated with them as well as different levels of effectiveness, maintenance, and lifespan (Vercauteren et al. 2010).

Competition from grasses such as smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.) may be affecting seedling establishment in North Dakota's cool season pastures. Some studies indicate that herbicide would be an effective pre-planting site treatment (Baer and Groninger 2004), however, other studies indicate that herbicide played no difference in seedling survival (Dubois et al. 2000, McLeod et al. 2000). Landscape fabric is recommended for increasing growth rates and retaining soil moisture (North Dakota Forest Service 2003, Stange 2003). Fabric, however, can have unintended consequences on growth by increasing white-tailed deer browse incidence on seedlings, making seedlings easier to locate again the contrast of the fabric rather than being partially hidden by vegetation (Stange and Shea 1998). Grass cover has been found to compete with tree seedlings for moisture (Ball et al. 2002). It is unknown whether or not mowing may be one treatment used in riparian areas where chemical and fabric application are not practical.

This thesis contains two studies involving tree seedling survival in the Middle Sheyenne Watershed. In late spring of 2009, we monitored a newly planted reforestation demonstration site on private property south of Pekin, ND. This planting was located in a riparian area along the

Sheyenne River. By fall of 2009, it was evident that the high mesh fencing was having some effect on seedling survival between the high fence and no fence plots.

The following year in 2010, the Red River Riparian Project inquired about setting up demonstration site in an old pasture under new ownership and not grazed with livestock. This presented the opportunity to observe deer herbivory without the presence of livestock, and included the treatments of electric fence, herbicide, and landscape fabric. The landowner who allowed us to monitor his afforestation project was looking to support as many deer as possible on the grassland. The site was being afforested to provide for recreational deer hunting opportunities. The white-tailed deer population was abundant during the time of both of these studies, with deer densities around 23.5 deer per km^2 (North Dakota Game and Fish 2010). Forested acres, whether in riparian areas or on the uplands, offer critical habitat for white-tailed deer in northeastern North Dakota (Sternhagen 2016).

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CHAPTER 2. THE EFFECTS OF VEGETATION COMPETITION AND HERBIVORY BY LARGE UNGULATES ON SEEDLING SURVIVAL IN A RIPARIAN REAFFORESTATION SITE ON THE MIDDLE SHEYENNE RIVER

Abstract

There has been a concern about the lack of regeneration of riparian hardwood forest communities in the Middle Sheyenne Watershed of northeastern North Dakota. Natural resource managers and landowners were unsure if herbivory by ungulates was responsible for afforestation failures. We tested herbivory by exclusion of white-tailed deer (*Odocoileus virginianus* Zimmermann) and/or cattle (*Bos taurus*) from plots of planted seedlings in a Randomized Complete Block Design. A mowing/clipping treatment was used to control competition by invasive grasses. White-tailed deer combined with cattle grazing showed a significant negative impact to seedling survival in this study. At the conclusion of three years, the high fence treatment (excluded white-tailed deer and cattle) showed significant differences in survival of seedlings compared to the unfenced plots at $p \leq 0.012$. The mowing treatment was significantly positive towards the survival of hackberry (*Celtis occidentalis* L.) compared to unmowed plots, however, a significant interaction between treatments had taken place.

Introduction

The lack of success in natural regeneration of riparian forests has gained increasing attention of resource managers in the U.S. in the past two decades (Allen et al. 2001). In North Dakota, restorationists have had concerns for bottomland hardwood forests because of the lack of natural regeneration and low success in afforestation practices (Craig Brumbaugh, personal communication). Watershed restoration programs, such as the Red River Riparian Project in Grafton, ND, allocate funds to tree plantings in riparian areas in an effort to improve water quality (Red River Riparian Project 2009). Afforestation practices in North Dakota are commonly cost shared by programs such as EPA 319 and NRCS EQIP (NRCS 2011, NDDOH 2016).

Riparian areas are important land areas used for grazing cattle in northeastern North Dakota. Some area farmers along the Middle Sheyenne River graze cattle all season long in riparian area pastures (Elmer Bakke, personal communication). The practice of excluding cattle from riparian areas is seldom used. Rotational grazing to allow controlled utilization of riparian areas has been underutilized in this area. Cattle generally are allowed to graze these cool season pastures without regular rotation away from the riparian zone (personal observation). Cattle operators in the area are often farmers who rely primarily on cash crops, and supplement their operations with livestock.

Land managers, state agencies, and local farmers in the Middle Sheyenne River watershed expressed concern over the lack of tree regeneration along the Middle Sheyenne River. Project managers from the Red River Riparian Project and the North Dakota Forest Service approached NDSU in winter of 2009 to investigate failed seedling plantings on private land by observing a landowner's new riparian reforestation site. Included in their concerns were the effects of cattle, deer, and competition from grasses on tree regeneration (Craig Brumbaugh, personal communication).

Given the above information, we sought to determine whether or not the common practice of grazing cattle in riparian areas was impacting seedling survival. Deer browsing was another factor we wanted to study due to deer being prevalent in riparian areas where restoration tree plantings often occur. The effects of deer and cattle would be tested using different fencing regimes. We also wanted to investigate if controlling competitive grasses using a mowing treatment would have any significant effect on seedling survival.

Literature Review

Riparian areas can be sensitive to cattle grazing. Cattle sometimes show heavy use of riparian areas and can over-utilize these areas easily (Platts and Nelson 1985). When cattle are given the choice of terrain, they prefer grazing upland areas of the pasture when summer temperatures are cooler and upland vegetation is still palatable (Marlow 1986). In late summer and early fall, riparian areas are utilized more than uplands, primarily due to better availability of palatable forage and the need to escape from weather conditions (Marlow 1986, Parsons et. al 2003).

Grazing cattle in riparian areas can have negative effects on soil properties and water quality. Increased soil erosion caused by improper grazing duration can lead to sediment loading into streams if cattle along a river are allowed to graze for too long (Marlow 1985). Grazing by cattle has caused soil compaction in the top layers (down to 20 cm) of floodplain soils of Russia (Utkaeva et al. 2009). Hoof action resulted in soil compaction, reduced porosity, and reduced infiltration in grazed silvopastures in the Pacific Northwest (Sharrow 2007).

Grazing livestock in woodland pastures can affect tree regeneration, seedling growth, and the composition of a forest community (Dufour-Dror 2007, Uytvanck and Maes 2008). Grazed woodlands showed a reduction in seedling density and saplings in Tabor oak (*Quercus ithaburensis* Decne.) compared to exclusion fenced sites in Israel (Dufour-Dror 2007). Recommendations from this study included fencing of young seedlings to exclude cattle, using deferred grazing period of two years to allow additional growth of seedlings, and the reduction of livestock stocking rates. Grazing around young English oak (*Quercus robur* L.) and European ash (*Fraxinus excelsior* L.) seedlings significantly impacted seedling growth rather than survival during the first three years of the study (Uytvanck and Maes 2008).

The exclusion of cattle grazing wooded areas in the Northern Great Plains has yielded positive results. A study in Stanley, SD along the confluence of the Cheyenne and Missouri Rivers demonstrated substantial results in growth of the wooded draw community comprised of green ash (*Fraxinus pennsylvanica* Marshall*)*, hackberry (*Celtis occidentalis* L.), American elm (*Ulmus americana* L.), cottonwood (*Populus deltoides* W. Bartram *ex* Marshall), and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) after cattle were removed from those areas for six years (Beottcher and Johnson 2005). The study found that basal area increased by 82%, tree density by 40%, and expansion of trees upslope by 16% (Beottcher and Johnson 2005). One limitation of the study is the absence of statistical analysis of data, and whether or not these results are significant.

Cattle prefer to graze grasses much of the time, with 61% or more of their diet comprised of grasses (Holechek 1982, Gallina 1993). The remaining portion of their diet is comprised of browse that includes forbs, shrubs, and sometime trees. Seasonal variations in forage availability and nutritional value affected the choice of vegetation preferences of cattle in a study in Mexico (Gallina 1993). Forbs averaged more utilization than shrubs and trees combined (Gallina 1993). During the dry season, cattle increased their use of trees as browse, which included *Quercus, Arbutus*, and *Phoradendron* species (Gallina 1993). Due to a short season of forb palatability in a southeastern Oregon study (Holechek), shrubs were about 23% of cattle diets. Shrub species browsed included common snowberry (*Symphoricarpos albus* (L.) S.F. Blake), ninebark (*Physocarpus malvaceus* (Greene) Kuntze), and spiraea (*Spiraea betulifolia* lucida (Douglas *ex* Greene) C.L. Hitchc.).

Despite studies reflecting positive change in tree growth with the exclusion of grazing (Boettcher and Johnston 2005, Dufour-Dror 2007), the discontinuation of grazing in woodland pastures can affect forest species composition by possibly shifting the community to favorable conditions for other species. A study in Northern Ireland demonstrated how the exclusion of grazing promoted the potential succession of other tree species over that of durmast oak (*Quercus petraea* (Mattuschka) Liebl.) (Cooper and McCann 2010). Given the resulting establishment of *Fraxinus spp*. and *Ilex spp.* when grazing was excluded, it was predicted that without future grazing practices, the forest community could shift away from the traditional oak dominance and towards *Fraxinus* and other species (Cooper and McCann 2010).

The lack of natural regeneration of *Quercus spp.* in the presence of grazing has been studied. Factors not pertaining to livestock, such as herbivory by wildlife, are affecting survival significantly (Hall et al. 1992, Griffin 1976). Hall et al. (1992) found that grazing intensities by livestock had no significant effect on survival of *Quercus douglasii* Hook. & Arn., nor was there a significant difference in grazed and ungrazed plots on seedling survival. In the United Kingdom, grazed pastures have been studied in efforts to increase oak (*Quercus*) recruitment due to a lack of regeneration of the species (Linhart and Whelan 1980). Natural regeneration of oak was significantly absent in a sheep grazing exclusion study in a *Quercus\Fraxinus\Alnus* woodland in Northern Wales (Linhart and Whelan 1980). Neither the area fenced in 1960 to exclude sheep, nor the unfenced plots revealed any meaningful recruitment of oak, despite the site including mature oaks. Where sheep were excluded since 1960, ash and sycamore recruited in significant numbers. Where sheep were not excluded, hawthorn and ash were recruited, though in lesser numbers. Based on these studies, it appears that the exclusion of grazing was not a factor significant enough by itself to increase oak regeneration.

Researchers and resource professionals discuss the lack of natural regeneration of tree species (Griffin 1976, Allen et al. 2001, Stanturf et al. 2001, White 2012). These studies point to agents (that do not include recent grazing of cattle) as reasons for poor regeneration and establishment of afforested sites. White-tailed deer and small mammal herbivory have affected afforestation efforts in restoration projects in the Lower Mississippi Alluvial Valley (Stanturf et al. 2001). Agents affecting regeneration and/or restoration of oaks and other tree species include site conditions, drought, lack of natural disturbance such as fire, and invasive species. Wildlife predation on acorns and seedlings by rodents and deer such as white- tailed deer *(Odocoileus virginianus* Zimmermann*)* often play a role in regeneration of oaks. Bur oaks produce large acorn crops generally every two to three years, with smaller or absent crops in between major crops (Burns and Honkala 1990), and high acorn predation would limit the number of available acorns for germination. In a study in California (1976), Griffin found that deer, mice, voles, and rabbits were important herbivores responsible for browsing seedlings in a reservation rested from grazing for 37 years. Despite rested range conditions, he noted that the reservation displayed "rare" occurrence of valley oak (*Quercus lobata* Nee) seedlings reaching sapling stage. Deer and other animals were discussed as a likely reason for low recruitment to sapling size (Griffin 1976).

Recent literature involving the analysis of long term data point to white-tailed deer as having significant effects on seedling recruitment and survival (White 2012, Bradshaw and Waller 2016). In the study of a Minnesota old growth forest, comparisons of data collected seventeen years apart revealed two decades of over-browsing by white-tailed deer led to recruitment failure of size classes over 2.5 cm dbh in unprotected plots (White 2012). Similarly, Bradshaw and Waller (2016) found that deer herbivory significant depressed sampling recruitment for several age classes in northern Wisconsin. Several more significant findings were derived from their analysis of U.S. Forest Service Forest Inventory and Analysis (FIA) conducted from 1983-2013. They found deer populations were having a significant widespread effect in northern Wisconsin forests over a thirty year period on eight of ten tree species studies. The analysis of long term data provide evidence that deer can affect regeneration and composition of forests on a regional scale over time (Bradshaw and Waller 2016).

White-tailed deer utilize riparian bottomland forests for food, cover and travel. A study in north central Missouri demonstrated how radio collared white-tailed deer showed a preference to flat, low-lying areas that have bottomland forest characteristics versus upland areas (Zwank et al. 1979). The bottomland forest provided the deer with connected sections of high quality browse and desired cover. Riparian areas had the greatest deer densities compared to upland habitats (98 deer in bottomlands vs. 5 deer on uplands).

White-tailed deer browse on shrubs and trees as a mainstay in their diets (Hunt and Mangus 1954, Kohn and Mooty 1971, Gallina 1993, Smith et al. 2007). One study in North Dakota found deer browse on trees and shrubs in nearly 50 percent of their annual diet on average (Smith et al.2007). White-tailed deer prefer the twig tips of woody plants and eat the leaves once twig tips are unavailable (Ginnett and Cooper 2002).

Deer have the ability to digest woody browse species and other plants containing tannins. Tannins are found in 79 percent of deciduous woody plants, 17 percent of annual plants, and 14 percent of herbaceous perennials (Beck and Reed 2001). Tannins are neutralized by unique proteins in the deer's saliva, and therefore are unable to reduce protein digestion in the rumen of this ungulate (Robbins et al. 1987). As a result, deer are able to utilize a great number of different forbs, shrubs and young trees in the spring, summer, and fall (Fullbright and Ortega 2006). Deer utilize forbs in as much as half of their diet, starting in spring and ending in late August in North Dakota (Smith et al. 2007). Deer are found to have very little grass in their diets

(Gallina 1993, Smith et al. 2007). Deer can negatively influence changes in a plant community by over-browsing. Forest plant communities utilized by high deer densities experienced increased grass cover and decreased species diversity floristic quality (Urbanek et al. 2012). Over-browsing of understory forbs can create bare ground where grasses may invade (Rooney and Waller 2003).

Riparian areas of the Middle Sheyenne River contain a diverse number plant species (Meehan 2011). Ecological site description work by Meehan (2011) detailed over 150 species of forbs, grasses, shrubs, and trees in a survey of riparian sites. Her work included sites in the McVille, Pekin, and Tolna, N.D. areas. Given these diverse food choices, research is needed to find out if deer browsing is affecting seedling survivability in riparian sites where regeneration of seedlings is not taking place.

The pressure of invasive and exotic plant species in forested areas is also a concern for natural resource managers. Grass cover was found to compete with tree seedlings for the consumption of below-ground resources in the spring due to thermal inhibition, and reduced the availability of resources to support tree seedling growth in the early summer (Ball et. al 2002). Smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.) are commongrasses found in riparian areas along the Sheyenne River (Meehan 2011). Though the establishment of these exotic grass species occurs over time, it is not known to what degree the competition of grass species effect regeneration of tree species.

Seedling mortality in afforestation plantings is a widespread concern in many areas of the country. The protection of tree seedlings using tree shelters (Stange and Shea 1998, Keeton 2008) or fencing has been studied (Opperman and Merenlender 2000). Green ash seedlings utilized by deer can show high mortality (74.1%) if not protected in the first year with tree shelters (Keeton 2008). In a couple of these studies (Stange and Shea 1998, Keeton 2008), however, there are sometimes implications that may have influenced survivability measurements. For example, other mammals, such as voles, are shown to have utilized seedlings for food during the same time as deer, sometimes even having utilized the seedling roots below ground.

Past and present land uses have been noted as being important by restorationists in determining the degree to which reforestation of an area can be accomplished (Groninger 2005). There is a need for research into tree regeneration in association with different land uses of riparian areas. The agents that affect the survivability of seedling plantings in bottomlands and riparian areas of this portion of the country are not yet known. It is hypothesized that deer, cattle, and competition from grasses may be playing a role in the failure of seedlings to survive, possibly causing the bottomland forest area not to regenerate on its own (Craig Brumbaugh personal communication). In review of literature for this study, no studies of tree regeneration had yet tested the combination of deer browsing, cattle grazing, and competitive invasive grasses, except in a recent study in Nebraska bur oak savannas (Granger et al. 2017). This particular study found that deer and cattle as an ungulate group has significant impact on the survival of bur oak seedlings in year one of the study. It should be noted this study did not use fencing to test the effects of herbivory of ungulates, but rather used small box cages 60 cm x 60 cm assembled by using portions of cattle panels.

Methods

The study site was located approximately 4 kilometers (2.5 miles) south east of Pekin, ND (T149N R59W S6, or 47°44’48.26” N, 98°14’59.67” W) in the Sheyenne River Valley. The once wooded riparian area (Figure 1) at this location lacked natural tree regeneration for decades (Elmer Bakke personal communication). Pre-examination of the site revealed few seedlings with a thick cover of invasive grass species such as smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.). Mature bur oak (*Quercus macrocarpa* Michx.) and box elder (*Acer negundo* L.) trees were found scattered throughout the riparian area.

The research site was located within 50 meters of the river, and had similar growing conditions for all three blocks. Deer were present in the study area year round, and the site had been grazed by cattle annually for decades (Elmer Bakke personal communication). The current operator grazed twenty head of cattle in the pasture in either August or September of each year. The pasture was approximately 48.5 hectares comprised of solely riparian corridor.

Figure 1. Aerial photos of the Sheyenne River Channel in 1968 (top) and 2010 (bottom) near Pekin, N.D. in the Middle Sheyenne Watershed. (Picture used with permission from Reede 1972). Bottom: Photo taken in summer of 2010 (USDA Farm Service Agency, accessed via Google Earth 5/10/2010). In both photos (a) denotes the location where the riparian woodland restoration study site was later planted in 2009, and (b) denotes the Harrisburg Channel.

The study location averages 120 to 140 frost free days (USDA-NRCS 2010). The mean annual precipitation, during the past 15 year period starting in 1995, was 51cm (20.09 inches) (NDAWN 2012). In the summer of 2009, below average rainfall was received at the study site. Precipitation data is provided from the McHenry, N.D. weather station located approximately 43.5 km SW of research site (Table 1.)

The amount of precipitation received in the spring months of each growing season was unpredictable. The first growing season (2009) experienced above normal amounts of precipitation in the months of April, August and September, and below normal precipitation in May, June, and July (Table 1). At the end of the first growing season, only 88 percent of normal precipitation had been received. In contrast, in the second growing season (2010) experienced an above normal amount of precipitation in the months of April, May, June, and September. Below normal amounts of precipitation were received July and August of that year. The third growing season (2011) experienced above average precipitation for all months except May, which was over 1.5 cm below normal precipitation.

Table 1. Growing season precipitation data from NDAWN weather station at McHenry, N.D. Normal conditions are 1995 to the end of first summer after planting in 2009.

Precipitation data from McHenry, ND April to September 2009				
Month	**Total Precip.(cm)**	**Normal(cm)**	**Departure from Normal**	**% of Normal**
April	4.50	3.02	1.47	149
May	4.88	6.55	-1.68	74
June	2.95	9.19	-6.25	32
July	3.25	8.66	-5.41	38
August	8.18	7.26	0.91	113
September	11.28	5.18	2.18	218
Total	35.03	39.88	-8.78	88
April to September 2010				
Month	**Total Precip.(cm)**	**Normal (cm)**	**Departure from Normal**	**% of Normal**
April	3.56	3.02	0.53	118
May	7.77	6.55	1.22	119
June	11.63	9.19	2.44	127
July	5.31	8.66	-3.35	61
August	4.37	7.26	-2.90	60
September	11.02	5.18	5.84	213
Total	43.66	39.88	3.78	109
April to September 2011				
Month	**Total Precip.(cm)**	**Normal (cm)**	**Departure from Normal**	**% of Normal**
April	3.58	3.02	0.56	118
May	4.06	6.55	-2.49	62
June	15.04	9.19	5.84	164
July	14.20	8.66	5.54	164
September	5.61	5.18	0.43	108
Total	52.35	39.88	12.47	131

The study site is located in a glacial meltwater valley along the Middle Sheyenne River Channel. During the late Wisconsonian glaciation, the Sheyenne River Channel formed when glacial Lake Souris overflowed. Meltwaters flowed southeast approximately 112 km. The combining of the Lake Souris overflow and other glacial meltwater sources created a wide river channel 914 m across and 30.5 m in depth (Reede 1972). The meltwaters eventually discharged into Lake Agassiz in southeastern North Dakota (Colton et al. 1963). The Harrisburg channel is located nearby the study site (Figure 1, b). This channel was created from the meltwaters of the slowly retreating Leeds Lobe, as well as the Viking and Kloten moraines (Reede 1972).

The site is comprised of LaDelle series soils formed from an alluvium parent material (USDA-NRCS 2010). The LaDelle series belongs to the following taxonomic class: Fine-silty, mixed, super active, frigid Cumulic Hapludolls. The LaDelle silty clay loam (G566B) is found in wooded river channels of zero to six percent slope. This soil type is found on the rises of flood plains that are frequently flooded, and contains some decomposed plant litter in the top 2.5 cm of soil. It is a moderately well drained soil, with a high available water capacity. LaDelle silty clay loam is also found where the channel levels at zero to two percent slope (G564A) located next to the study site (USDA-NRCS 2010).

Three blocks in a randomized complete block design contained randomly assigned treatments in twelve subplots (Figure 2). All three blocks were on the north side of the river. Mowing treatments and grazing/browsing treatments were assigned randomly within each block. Each block was mowed in all plots initially to reduce height of vegetative cover prior to planting of the plots.

Each plot measured 10m x 10m, therefore each block totaled 120 m in length and 10 m in width. Four-strand barbed wire fencing was applied to subplots that were assigned a low-fence treatment (Figure 3). High-fence treatment included the same four strands of barbed wire with 2.4 m (8ft) tall plastic webbed fencing. This additional fence was secured at the top with zip-ties along a fifth strand of wire, while staples were added at ground level. No-fence subplots were inserted according to the randomized order.

Block 1										
No Fence	No Fence	No Fence	Low Fence	High Fence	High Fence	High Fence	Low Fence	Low Fence	Low Fence	High Fence
Mow	Mow	No Mow	No Mow	Mow	No Mow	Mow	Mow	Mow	No Mow	No Mow
8	36	8	8	8	36	36	8	36	36	8
		No Fence								
		No Mow								
		36								

Block 2											
High Fence	Low Fence	Low Fence	No Fence	No Fence	High Fence	High Fence	Low Fence	No Fence	No Fence	Low Fence	High Fence
No Mow	No Mow	Mow	No Mow	No Mow	Mow	No	Mow	Mow	Mow	No Mow	Mow
36	8	8	36	8	8	8	36	36	8	36	36

Block 3											
Low Fence	Low Fence	No Fence	No Fence	Low Fence	Low Fence	High Fence	High Fence	No Fence	No Fence	High Fence	High Fence
No Mow	Mow	Mow	No Mow	Mow	No Mow	Mow	No Mow	No Mow	Mow	Mow	No Mow
36	8	36	8	36	8	8	36	36	8	36	8

Figure 2. Randomized Complete Block Design showing fence treatment, mow treatment, and seedling density per plot at the Pekin, ND site.

Figure 3. Photo showing fencing regime at the Middle Sheyenne Watershed riparian forest restoration study site near Pekin, ND. The letter (a) denotes a high fence, (b) denotes a low fence.

Seedling planting began the first week in June 2009 after the waters of the 100 year record flood of the Sheyenne River receded. Seedlings were planted one meter apart (Figure 4). Species planted included bur oak, green ash, hackberry, and cottonwood. Seedling stock was provided by the Big Sioux Nursery, Watertown, S.D., and was planted as bare root seedlings. Height varied from 40 to 80 cm.

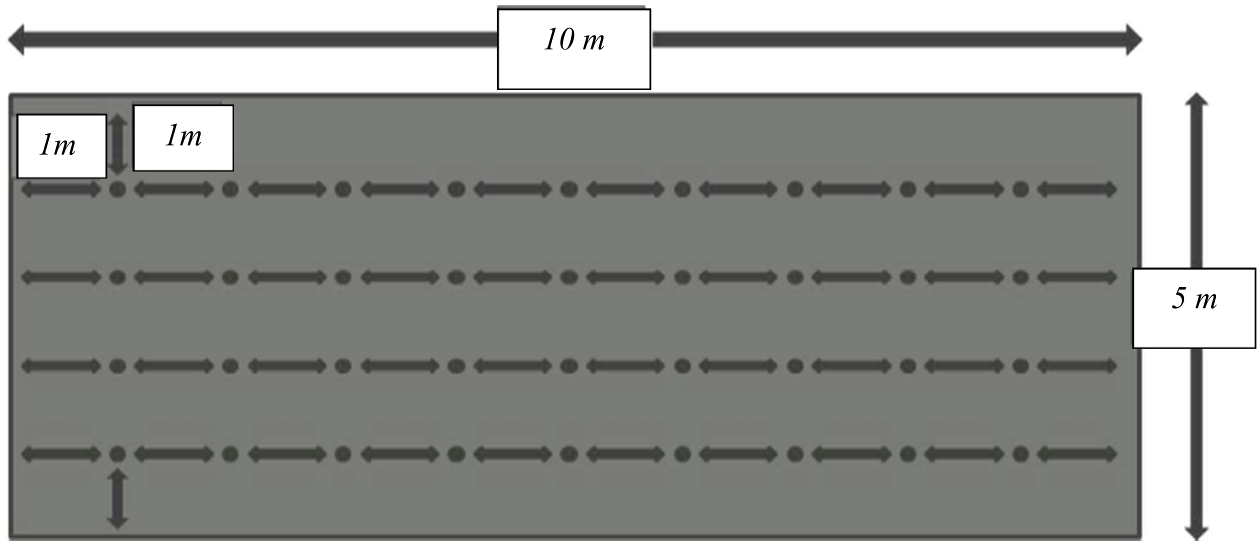

Figure 4. Subplot design for high density seedling plantings at the Pekin, ND riparian restoration site. Each dot denotes one seedling; 36 seedlings per subplot.

The timing of mowing treatments was based on vegetative growth, where grass was not allowed to reach beyond approximately 0.5 m in height. Mowing took place across all mowing assigned subplots in June, July, and September. Each time the mowing treatment was completed, a hand shears were used to clip remaining grass from around each seedling within the subplot. Plastic flags were placed near seedlings to help to avoid accidental mowing over seedlings.

Cattle were released into the pasture around August 15th, 2009 which included the study area and additional grazing along both sides of the river. The timing of the cattle utilizing the study area was determined by the land manager and his rotational grazing needs given weather conditions. As mentioned previously, the cattle operator released his twenty head of cattle in either August or September each year to graze the rest of the season.

Data was collected mid-August of each field season. The species name, height, and survival were recorded. Evidence of browse was also recorded. Seedlings that had not yet broken bud by that time were considered to be dead, unless other indicators of life could be found, such as a slight green color on bark towards the base of the tree. The typical browse signs recorded showed either complete leaf removal where only the petiole remained, or a ragged bite or tear mark. Browse intensity, or the degree of use, was not recorded. Data was collected in June and August of 2009 and 2010, as well as June and September of 2011. The June collection allowed for the inventory of survival before cattle would be released into the area. The August or September inventory allowed for the survey of survival and browsing after cattle were released.

A two-way ANOVA Randomized Complete Block Design (RCBD) was run with a general linear model (ProcGLM) to compare survival percentages across the fencing and mowing treatments in the high density plots, which contained 36 seedlings. Analysis of data was completed using SAS Enterprise Guide 7.1 of the SAS System for Windows (Copyright © 2000-2017 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). Treatments were analyzed on a plot basis, and therefore the sample size is n=18. Tukey's test for multiple comparisons used at $\alpha = 0.05$. Descriptive statistics and graphical representations were constructed using Microsoft Excel 2010.

Results

Fencing Treatments

Fencing treatment survival rates are summarized in Table 2 for season 1 (2009), season 2 (2010) and season 3 (2011). Seedling survival for all species decreased each season for all levels of fencing.

Table 2. Fencing Treatment Effect on Seedling Survival

Year	High Fence	Low Fence	No Fence	Average Survival
2009	75% a	63% a	59% a	65%
2010	47% a	33% a	27% a	36%
2011	32% a	13% ab	6.5% b	17%

*Letters that are different within a year are significantly different at p = 0.05

Season 1: The high fence treatment had an overall seedling survival of 75% and the no fence treatment showed only a 59% survival of seedlings (Table 2). The low fence treatment showed 63% survival at the end of the first growing season. Average survival across all treatments was 65%. Differences in fence treatments were not significant in Season 1 at p = 0.05 (Table 3).

Table 3. Analysis of Variance (ANOVA) of Treatments on Seedling Survival in 2009

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.024	0.01	1.53	0.26
Mow	1	0.00018	0.0002	0.02	0.88
Block	2	0.048	0.02	3.08	0.09
Fence*Mow	2	0.001	0.0007	0.09	0.92

Bur oak, green ash, and hackberry did not show any significant differences in survival when analyzed as individual species across treatments at *a*=0.05. Cottonwood showed a significant difference in the fence treatment (Table 4) with $p \leq 0.001$ in the High Fence versus No Fence treatments (Table 5). High Fence versus Low Fence also showed significant differences in survival for cottonwood (Table 5).

Table 4. Analysis of Variance (ANOVA) of Cottonwood Survival in 2009 at the Pekin, N.D. Site

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.605	0.30	14.7	0.001
Mow	1	0.007	0.007	0.32	0.59
Block	2	0.320	0.16	7.68	0.01
Fence*Mow	2	0.013	0.007	0.32	0.74

Table 5. Standard Deviation and Average Survival of Cottonwood in 2009 at the Pekin, N.D. Site

Treatment Levels	Average Survival	Standard Deviation	Significance *
High Fence	70%	0.14	a
Low Fence	59%	0.20	b
No Fence	49%	0.22	b

*Treatments labeled with different letters are significantly different at $p \leq 0.05$.

Season 2: The high fence treatment yielded a 47% survival of seedlings survival and the no fence treatment resulted in 27% seedling survival. Survival of seedlings in the low fence was 33% at the end of the second growing season. Differences in seedling survival were not significant between fence treatments at $a = 0.05$ in Season 2 (Table 6). Cottonwood had a mean survival of only 12% by the end of 2010 averaged across all treatments. There was 26%, survival in the high fence, 4% survival in the low fence, and 6% survival in the no fence plots for Cottonwood in 2010. Cottonwood had shown a difference in survival between high fence and no fence at $p \leq 0.07$, however, this result is above our level of significance ($p \leq 0.05$) (Table 7).

Table 6. Analysis of Variance (ANOVA) for All Species and Treatments in 2010

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.125	0.063	2.71	0.12
Mow	1	0.003	0.003	0.15	0.71
Block	2	0.076	0.038	1.65	0.24
Fence*Mow	2	0.028	0.014	0.61	0.56

Table 7. Analysis of Variance (ANOVA) for Cottonwood Survival in 2010

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.35	0.177	3.63	0.07
Mow	1	0.01	0.011	0.23	0.64
Block	2	0.16	0.081	1.68	0.23
Fence*Mow	2	0.06	0.028	0.59	0.57

Bur oak showed no significant differences in survival between treatments in 2010. Green ash showed no significant differences in survival across treatments in 2010 at *a*=0.05 (Table 8). Hackberry showed no significant differences in survival across treatments in 2010 (Table 9).

Table 8. Analysis of Variance (ANOVA) for Green Ash Survival in 2010

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.21	0.10	3.32	0.08
Mow	1	0.003	0.003	0.09	0.77
Block	2	0.24	0.12	3.92	0.06
Fence*Mow	2	0.03	0.017	0.54	0.60

Table 9. Analysis of Variance (ANOVA) for Hackberry Survival in 2010

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.03	0.01	0.71	0.52
Mow	1	0.07	0.07	3.94	0.08
Block	2	0.003	0.001	0.10	0.91
Fence*Mow	2	0.02	0.009	0.46	0.65

Season 3: Differences in seedling survival were significant at $p \leq 0.012$ (Table 10) between the high fence treatment and the no fence treatment in the fall of 2011. The high fence treatment and low fence treatments were not significant at $p \leq 0.05$, but rather at $p \leq 0.052$, just above our level of significance. Differences between low fence and no fence were not significant on survival. The high fence treatment yielded 32% survival of seedlings survival and the no fence treatment resulted in 13% seedling survival. The low fence treatment had a 6.5% survival at the end of the third growing season (Table 11).

Table 10. Analysis of Variance (ANOVA) For All Species and Treatments in 2011

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.22	0.11	7.07	0.01
Mow	1	0.01	0.01	0.90	0.37
Block	2	0.10	0.05	3.21	0.08
Fence*Mow	2	0.08	0.04	2.43	0.14

Table 11. Standard Deviation and Average Survival of All Species in Fenced Plots in 2011 at the Pekin, N.D. Site

Treatment Levels	Average Survival	Standard Deviation	Significance *
High Fence	32%	0.24	a
Low Fence	13%	0.09	ab
No Fence	6.5%	0.08	b

*Treatments labeled with different letters are significantly different at p = 0.05

Bur oak did not show significant differences between the fence and mow treatments (Table 12).

Table 12. Analysis of Variance (ANOVA) for Bur Oak in 2011 at the Pekin, N.D. Site

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.24	0.12	3.89	0.06
Mow	1	0.01	0.01	0.45	0.52
Block	2	0.08	0.04	1.29	0.32
Fence*Mow	2	0.09	0.05	1.51	0.27

Cottonwood did not have significant differences in survival between the fence and mow treatments (Table 13).

Table 13. Analysis of Variance (ANOVA) for Cottonwood in 2011 at the Pekin, N.D. Site

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.05	0.03	1.00	0.40
Mow	1	0.03	0.03	1.00	0.34
Block	2	0.05	0.03	1.00	0.40
Fence*Mow	2	0.05	0.03	1.00	0.40

Green ash did not show significant differences between the fence and mow treatments (Table 14).

Table 14. Analysis of Variance (ANOVA) for Green Ash in 2011 at Pekin, N.D. Site

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.30	0.15	3.10	0.09
Mow	1	0.0007	0.0007	0.02	0.90
Block	2	0.25	0.12	2.59	0.12
Fence*Mow	2	0.16	0.08	1.63	0.24

Hackberry showed a significant difference in the fence treatment ($p < 0.001$) and mow treatment in ($p < 0.03$) Season 3 (Table 15). There was also a significant interaction between the fence and mow treatments for hackberry.

Table 15. Analysis of Variance (ANOVA) for Hackberry in 2011 at Pekin, N.D. Site

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	p value
Fence	2	0.24	0.12	14.29	0.001
Mow	1	0.05	0.05	6.24	0.03
Block	2	0.04	0.02	2.56	0.13
Fence*Mow	2	0.15	0.07	9.17	0.006

*Treatments labeled with different letters are significantly different at $p = 0.05$

There were significant differences between high fence and low fence at $p = 0.008$, and high fence and no fence at $p = 0.001$ for hackberry (Table 16 and 17).

Table 16. Standard Deviation and Average Survival of Hackberry in 2011 at Pekin, N.D. Site

Treatment Levels	Average Survival	Standard Deviation	Significance
High Fence	34%	0.16	a
Low Fence	14%	0.16	b
No Fence	7%	0.11	b

*Treatments labeled with different letters are significantly different at $p = 0.05$

Table 17. Standard Deviation and Average Survival of Hackberry in Treatment Combinations in 2011 at the Pekin, N.D. Site

Treatment Levels	Average Survival	Standard Deviation	Significance *
High Fence			
Mow	43%	0.20	A
No Mow	25%	0.06	ABC
Average High Fence	34%		
Low Fence			
Mow	28%	0.06	AB
No Mow	0%	0.00	C
Average Low Fence	14%		
No Fence			
Mow	0%	0.00	C
No Mow	14%	0.12	BC
Average No Fence	7%		

*Treatments labeled with different letters are significantly different at p = 0.05

Mowing Treatments

The differences in mowing treatments of mowed or non-mowed plots were not statistically significant at α=0.05 in either season 1, 2 or 3 (Figure 5).

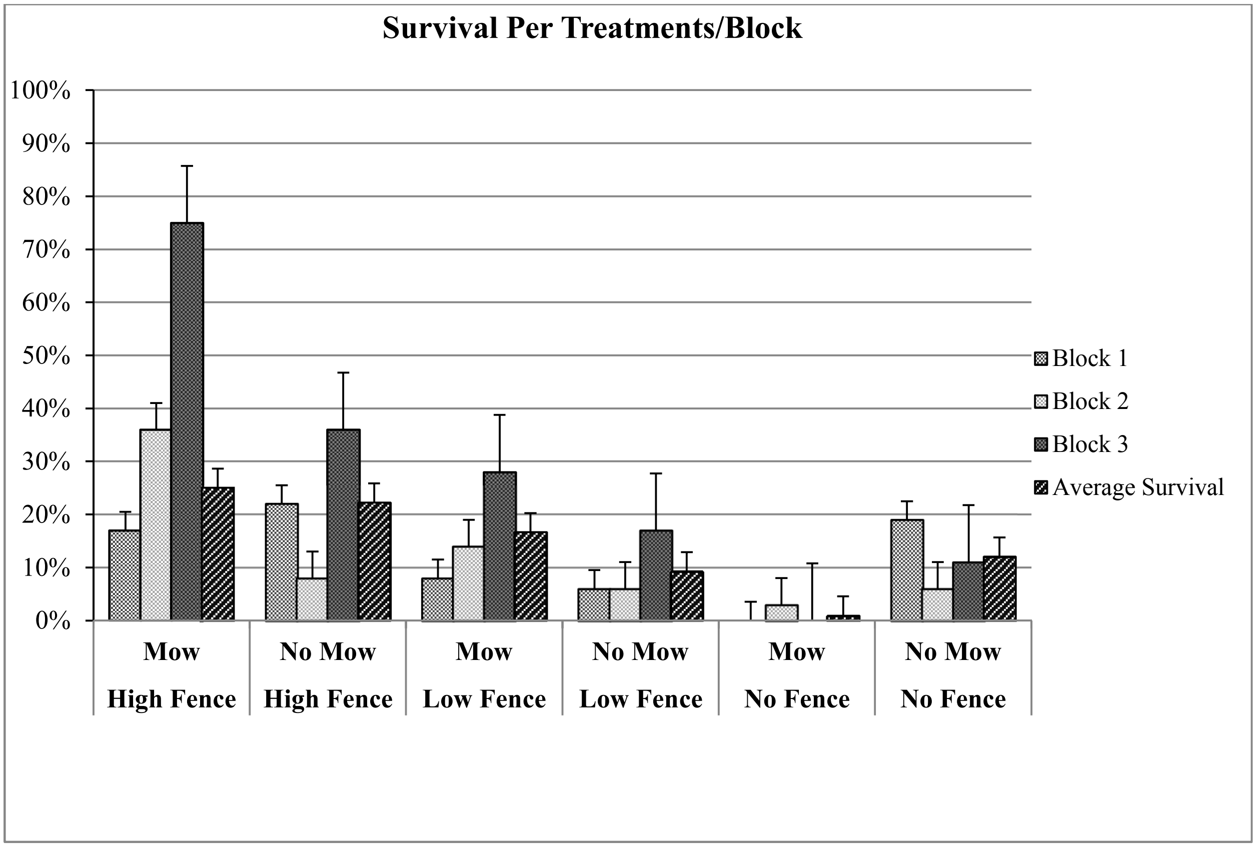

Figure 5. Seedling survival per treatment and block combination of the mowing and no mowing treatments at the Middle Sheyenne Watershed riparian reforestation study site near Pekin, N.D.

Seedlings were inspected for signs of browse in each treatment. Visual summary data showed deer browsed many of the seedlings in the low fence and no fence treatment throughout the summer (Figure 6). Deer demonstrated some preference to cottonwood and green ash seedlings in June 2009 (Figure 7). In 2010 and 2011, deer browsed the no fence and low fence plots to a similar degree as was observed in 2009.

Figure 6. Two fawns enter a low fence/mowed plot at the riparian reforestation study site near Pekin, N.D.

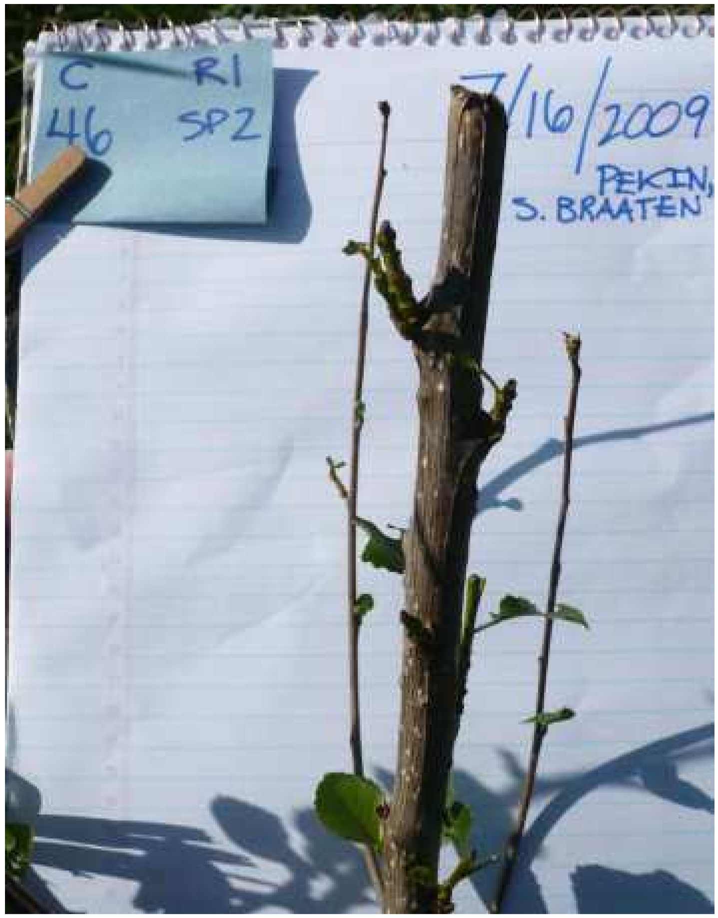

Figure 7. Cottonwood seedling showed leaf removal typical of deer browse at the riparian reforestation study site near Pekin, N.D. (Top of stick cut at nursery).

Seedlings in several plots were also noticeably damaged by rodents. The characteristics of rodent damaged observed included small areas of bark removal and gnawed sections 7 to 10 cm from the base of the seedling, or seedlings chewed in half. Only 3% of seedlings were affected by rodent damage on the main stems in 2009. In 2010, 30% of seedlings were damaged by rodents. A large number the seedlings that showed signs of rodent damage were already dead at the time of the survey in 2010. The survey in 2011 did not reveal more than a handful additional instances of rodent damage compared to the year prior. It is unknown if the rodent damage occurred while the seedling was alive. It is not known which species of rodent or rodents were responsible for the damages. Beavers also affected survival of tree seedlings in our study. Several trees in a high fenced plot were chewed down by beavers during 2010 after the fence was damaged by a minor flood that year.

Discussion

This three year study demonstrated how the effects of herbivory by large ungulates reduced the survival of seedlings planted in a riparian reforestation site in the Northern Great Plains. Our results cannot determine the effects of cattle alone on seedling survival, but rather show significant results of cattle and deer as a herbivory group. Because the combination of white-tailed deer and cattle exclusion has received little research as a herbivory group, published data to compare with our results was very limited, however, a recently published study conducted on a bur oak savanna in Nebraska (Granger et al. 2017) concurs with our finding of deer and cattle together can play a role in reduced survival of seedlings. In this study, they found that deer and cattle were the leading cause of mortality with one year old oak seedlings without exclosures, despite other factors attributing to mortality (Granger et al. 2017). Despite the lack of evidence in our study that bur oak analyzed by themselves were significantly affected by deer and cattle as a herbivory group in any of the three years, with year three ($p<0.06$), the high fence vs. no fence treatment supports that deer and cattle are an important ungulate group impacting seedling survival by year three for the overall mix of riparian species including bur oak, green ash, cottonwood, and hackberry.

In the first season, cottonwood showed a significant difference in survival between high fence that excluded all ungulate herbivory and the low fence treatment that excluded cattle, but allowed deer access. Because deer utilized the seedlings in the low fence treatment without the involvement of cattle, the significant difference between low fence and high fence showed that deer by themselves impacted survival of cottonwood by August of the first season. This finding is not surprising because based on browse data collected in 2009, deer had demonstrated some preference for cottonwood as soon as buds broke that first summer.

Our results can be compared to findings of other studies involving seedling survival and herbivory prevention treatments used in riparian areas (Stange and Shea 1998, Opperman and Merenlender 2000, and Keeton 2008). Green ash (*Fraxinus pennsylvanica* Marshall) seedlings not protected from deer herbivory in a forested floodplain/hardwood swamp planting in Vermont (Keeton 2008) showed increased seedling mortality versus those areas that were protected by tree shelters after 3 years. In Minnesota, northern red oak (*Quercus rubra* L.*)* protected from deer herbivory using tree shelters resulted in the reduction of seedling mortality from 34.6% to 3.2% in an old abandoned agricultural field (Stange and Shea 1998). While these studies show the increased survival using protective measures against deer herbivory, our study did not find significant results in seasons 2 or 3 for cottonwood. This was surprising, however, the lack of significance can be partially explained by looking at the damages caused by the floods of 2010 and 2011. In the spring of 2010, an increase of mortality of cottonwood seedlings due to beaver in the high fenced plots in our study compromised our findings. Beaver hauled off many seedlings from the high fence plots that had fence loosened and lifted by flooding. In 2011, high floodwaters and natural demolition of the fence by the swollen Sheyenne River opened plots to the beavers, further compromising our results. In addition, by 2010 we started to see more rodent damage in plots, with not all plots receiving the same amounts of rodent damage.

The use of exclosures in riparian areas to pinpoint herbivory by deer (in this case the low fence) did not yield significant results like that of another study (Opperman and Merenlender 2000). Herbivory by black-tailed deer (*Odocoileus hemionus columbianus*) severely limited the regeneration of the tree species narrowleaf willow (*Salix exigua* Nutt.), red willow *(S. laevigata* Bebb), arroyo willow (*S. lasiolepsis* Benth.), white alder (*Alnus rhombifolia* Nutt.), and Oregon ash (*Fraxinus latifolia* Benth.) in areas not protected by deer exclosure fencing in a degraded riparian habitat in Mendocino County, California (Opperman and Merenlender 2000). While our results do not definitively determine deer as significantly impacting seedling survival for bur oak, green ash, or hackberry, there is still an importance of protecting seedlings from herbivory in this area. White-tailed deer in the Pekin, N.D. area were playing a role, however, not by themselves. Deer are a part of a larger herbivory group having an impact, and exclusion by one form or another is an appropriate measure.

Our study introduced the possibility of using a tall mesh/5 strand wire fence exclosure to protect seedlings from the possible herbivory by deer and cattle in a prairie stream environment, though the treatment proved not to be without its own limitations. Literature at this time does not reflect the use of such a fencing combination in a riparian exclosure study. The mesh fence by itself was successful at excluding white-tailed deer at an upland site at Camp Grafton North, ND (Murdoff 2010). We added plastic mesh fence as a component to our riparian study based on the success in that study. In general, we had overall less success with the fence of any kind because it proved to be difficult to maintain in a flood plain. Plastic mesh fence and a five strand wire fence in our study was severely damaged in the 2011 Sheyenne River flood (Figure 8). Damage to one block of the experiment resulted in the complete reinstallation of all fencing materials around the tree plots. A large amount of flood debris became lodged against fence posts, tangled in barbed wire, or caught in the mesh fence, and dragged in the record volume flows of the Sheyenne River.

Figure 8. In 2011, spring flooding resulted in fence being destroyed by flood debris. Beavers gained access to high fenced plots that would ordinarily exclude them.

Despite the springtime floods experienced in 2009, 2010, and 2011, many seedlings were found to be intact and budded out before being faced with browsing pressure by deer and/or cattle. Repair and reinstallation of the fencing in 2011 proved to be a worthwhile effort to protect seedlings against herbivory, however, it is not known to what degree the flooding may have contributed to seedling mortality.

Our study showed that 75% of the seedlings in the high fence plots were alive near the end of 2009. The percentage of surviving trees in the control (high fence) declined to 32% at the end of three years. Our study's results demonstrate low survival in the control plots when compared to other studies (Keeton 2008). The lack of success in the control plots suggests the possible significance of other agents that may have reduced seedling survival, such as the herbivory by small rodents and drought/flood stress. Meadow vole populations, even during periods of low populations, have the ability to significantly influence mortality in old field succession situations (Ostfeld and Canham 1993). Due to the of the swiftness of the rodents frequently seen in plots, it is not know the exact species of rodent that was chewing on seedlings, however, physical signs of their presence were prevalent by the August survey of the second season (2010).

The lack of soil moisture for an extended period of time, or the overabundance of soil moisture could have played a role in the initial establishment of the seedlings. In 2009, during the months of May, June, July, and August below average rainfall was received in the region (Figure 1a). In contrast, the subsequent wet growing seasons began with record level of flooding in 2010 and 2011. The 2011 flood lasted until almost the end of June on the Sheyenne River. These types of environmental conditions have been seen in bottomlands elsewhere in the country. Reforestation efforts by restorationists in the Lower Mississippi Alluvial Valley were also negatively impacted by late flooding and droughty spring conditions after planting seedlings (Stanturf et al. 2001).

Our study did not find any significant differences in seedling survival between the mowed plots and the unmowed plots, except for hackberry in the third season. Mowing did not increase the survival of bur oak in any of the years of our study and concurs with the findings of McLeod et al. (2000). Mowing was not found to significantly increase survival of red oak species (overcup oak (*Q. lyrata* Walter), nuttall oak (*Q. nuttallii* Palmer), cherrybark oak (*Q. falcata* Michx. var. *pagodaefolia* Elliott), willow oak (*Q. phellos* L.), water tupelo (*Nyssa* *aquatica* L.) , or baldcypress (*Taxodium distichum* (L.) Rich.) in a riparian planting study along the Fourmile Branch of the Savannah River in North Carolina (McLeod et al 2000).

Conclusions

Based on three growing seasons of this riparian forest restoration tree planting, it is highly recommended that land managers protect seedlings from herbivory by ungulates. A fence 2.4 meters high comprised of barbed wire and plastic mesh did a superb job keeping the deer out of the study plots. Due to the design of our study, we were not able to test cattle grazing directly, and therefore recommendations for grazing management of cattle cannot be made. Browsing by deer and cattle combined showed a significant decline in survival versus the high fence exclosures where neither species was allowed to browse. Managers should employ seedling protection measures to mitigate unwanted browsing damages by large ungulates. The timing and intensity of grazing livestock and its effect on tree regeneration in riparian areas remains an ongoing subject of research. Granger et al. (2017) recommends carefully managing livestock, as they are much easier to manage than wildlife populations. This may including limiting grazing to seasons when young bur oaks are less susceptible to damage by trampling or browsing, however, in our area of the country it has not been shown how best to approach this type of management.

The protection of tree plantings using fencing is not without special considerations such as cost, time, maintenance and lifespan of the practice. The cost of protecting seedlings from ungulates can sometimes be expensive because of initial investment in fencing materials. It is not known if the materials of barbed wire and mesh fence used in our study are the most economical approach for land managers compared to other kinds of fences available, such as electric or high tensile fences. Future studies should look into cost effectiveness and level of protection provided to seedlings by other means, in particular electric fences.

Conducting inspection and maintenance of fencing is also a very important commitment for the landowner to make. Spring floods and debris catching in the fencing can tear down the fences, which then need to be rebuilt. Timely repair to torn or worn plastic mesh is essential to keep it from ripping further, or allowing unwanted animals into the exclosures. Barbed wire required much less maintenance, so primarily the time investment is expected in the plastic mesh fence. It is quite possible that other high fences made of more durable materials could be utilized. If a landowner is willing to commit to the necessary maintenance, using a high fence exclosure can be an effective way to prevent herbivory by large ungulates and increase seedling survival on afforestation sites in riparian areas.

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CHAPTER 3. STRATEGIES FOR ESTABLISHING STANDS OF DECIDUOUS SEEDLINGS IN THE PRESENCE OF HERBIVORY AND COMPETITIVE VEGETATION IN THE MIDDLE SHEYENNE RIVER VALLEY, N.D.

Abstract

Private landowners often desire to increase the quality of habitat for white-tailed deer (*Odocoileus virginianus* Zimmermann) on their rangeland by restoring or establishing wooded areas. A landowner working with the Red River Riparian Project implemented a large scale tree and shrub planting demonstration site on an old pasture in an effort to increase deer habitat. Competition by grasses can reduce available moisture for trees and shrubs. In an effort to increase survival and growth of seedlings planted in a landowner's demonstration site, vegetation control using fabric and/or herbicide treatments were utilized in a Randomized Complete Block Design. False indigo (*Amorpha fruticosa* L.) experienced a significant difference in height between the fabric with herbicide treatment compared to the no fabric with herbicide plots $p = 0.026$. Glyphosate applied in season 1 as a pre-planting treatment did not significantly improve height of seedlings in season 2 compared to untreated plots for the following species: golden willow (*Salix alba* L.), American plum (*Prunus americana* Marshall), redosier dogwood (*Cornus sericea* L.), peachleaf willow (*Salix amygdaloides* Andersson), eastern cottonwood (*Populus deltoides* Bartram *ex* Marshall), and bur oak (*Quercus macrocarpa* Michx.). The gradient of deer browsing experienced between fenced and unfenced plots suggests that deer are utilizing newly planted seedlings as a source of browse.

Introduction

Private landowners often wish to increase the quality of habitat for white-tailed deer (*Odocoileus virginianus* Zimmermann) on rangelands by restoring or establishing wooded areas.

Wooded areas also provide very important habitat to white-tailed deer in North Dakota (Knue 1991, Sternhagen 2016). In addition to providing habitat, trees help to scavenge nutrients from runoff, promote nutrient cycling, add forage for pollinators, and improve water quality (USDA 2008).

There can be many challenges to establishing large tracts of tree seedlings. Herbivory by white-tailed deer, livestock, and rodents can inhibit seedling survival (Allen et al. 2001). The success of a tree planting can also be limited by precipitation, poor site selection, soil health, competition by other vegetation, improper planting techniques, and species selection for the site (Stanturf et al. 2001).

Since the turn of the 21st century, tree plantings in Nelson County have not fared well in terms of overall survival and growth. Deer have been highly suspected in playing a role in the failure of plantings. In the Tolna, N.D. area, the deer population was high in winter of 2010 compared to population densities elsewhere in the state, with 23.5 deer per km^2 (NDG&F 2010). Two wildlife refuges in the Upper Souris Basin had higher deer densities; however, no privately owned area possessed the population density like that of the Tolna area. In addition, the Deer-Vehicle Collision (DVC) trends, which are used to detect deer population trends, increased between the years 2007 and 2009 (NDG&F 2010).

Deer populations are managed by the North Dakota Game and Fish Department through the issuance of hunting licenses. Hunters' preference for antlered deer in the Devils Lake management unit in 2009 resulted in less does being harvested than what was allocated by the Department. An aerial survey in the Tolna area determined the deer density was 23.5 deer per km^2 in the nearby Hamar Woods in January 2010 (NDG&F 2010).

Studies of deer herbivory in this region conducted by NDSU have shown that tall plastic mesh fence exclosures have been successful at increasing survival of seedlings (Murdoff 2010, Chapter 2, this thesis). In 2009 at the Pekin study, we found that fencing out large ungulates, such as deer and cattle, significantly increased seedling survival by the third year versus no fencing treatment (See Chapter 2). Any efforts to restore and improve habitat in further projects, such as this demonstration site study, have taken into account the evidence provided in our previous study of seedling survival and herbivory.

In 2010, the Red River Riparian Project located a private landowner who had the goal of providing cover and food for white-tailed deer in his recently acquired pasture south of Tolna, ND. We worked closely with the Red River Riparian Project, North Dakota Forest Service, and the landowner to design and install this demonstration site.

The purpose of this demonstration project was to observe different ways to establish several tree and shrub species in an old pasture invaded by highly competitive grasses, and in the presence of deer without livestock present. The landowner established electric fence in the hope that he could protect the planted trees against herbivory by deer. He also established two methods of controlling competition from grasses and other vegetation: Herbicide and weed barrier fabric.

The second objective of the landowner was to find the most economical approach to mitigate deer herbivory and increase the growth and survival of seedlings. If our observations of the landowner's treatments find fencing effective, it could be possible fencing would become a best management practice (BMP) that could be utilized by resource managers to establish large tracts of trees. Currently, landowner use tree tubes to protect trees from herbivory. Given the costs associated with tree tubes in large scale plantings, the landowner wanted to determine if fencing would be a more effective and economical approach. Costs associated with the application of herbicides could be warranted if the treatment proves effective in helping growth and establishment. The installation of landscape fabric at the time of planting, though a popular approach in this region, is also an upfront investment for the landowner. The evaluation of the effectiveness of these three treatments in regards to seedling growth and survival might allow land managers to be better informed on whether or not to invest in fencing, fabric, and herbicide at the time of establishing their tree planting.

Literature Review

North Dakota is a prairie state comprised of approximately 1.8% forest cover (Haugen 2016). Of North Dakota's 1.78 million hectares (44.1 million acres) of land, 312,580 hectares (772,400 acres) were forested in 2010. Public agencies own 30% of forest resources, while 70% of forest cover exists on private land (Haugen 2016). Funding agencies recognize that landowners are key stakeholders with the ability to establish and protect forest resources. Financial and technical resources are available to landowners through the North Dakota Forest Service, North Dakota Soil Conservation District Association, North Dakota Game and Fish Department, Natural Resource Conservation Service, and North Dakota Department of Health 319 program (USDA 2011, NDDOH 2016, NDG&F 2016b, NDSCD 2016).

Forests provide many benefits to the environment, especially in the areas of air quality, soil quality, and water quality (USDA 2008). Trees improve water quality when planted into riparian forest buffers. Trees help to capture non-point source pollution from runoff from agricultural fields. Nutrients, pesticides, and sediment can be captured before they enter a drainage or stream (USDA 2008). Tree roots hold streambanks in place and help to reduce energy of fast moving water which could cause erosion and increase downstream sedimentation (USDA 2008).

Northeastern North Dakota's forests provide important habitat to native fauna in riparian areas, shelterbelts, and farmsteads. Many birds and mammals utilize forested areas for habitat, including white-tailed deer, red fox (*Vulpes vulpes* Linnaeus), coyotes (*Canis latrans* Say), beavers (*Castor canadensis* Kuhl), badgers (*Taxidea taxus* Shreber), skunks (*Mephitis mephitis* Schreber), raccoons (*Procyon lotor* Linnaeus), otters (*Lontra canadensis* Schreber), and weasels (*Mustela rixosa* Bangs) (Bailey 1926). Northeastern North Dakota has a re-emerging population of fishers (*Martes pennanti* Erxleben) that are utilizing available stands of forest and non-traditional habitat (Loughry 2010). Forested areas, including riparian areas, shelterbelts, and wooded farmsteads are identified as critical habitat for white-tailed deer in North Dakota (Sternhagen 2016).

Eastern North Dakota has seen changes in forest community composition in the past three decades due mainly to Dutch elm disease. Along the Sheyenne River, American elm (*Ulmus americana* L.) made up 25% of the riparian forest community (Stroh 2002). This tree, which historically thrived until the epidemic of Dutch Elm disease starting in the 1980s, now accounts for 1.24 million snags in North Dakota (Haugen 2016). Standing dead trees provide opportunities to cavity nesting birds (Haugen 2016). North Dakota has several species of bats that rely on trees for nesting sites. The little brown bat (*Myotis lucifugus* Le Conte) is listed as species of concern on the North Dakota State Wildlife Action Plan (SWAP), and is a priority species for conservation efforts. The little brown bat can be found in dead snags of riparian areas and connected upland forest areas in N.D. (NDG&F 2016a, Sternhagen 2016). Despite changes in forest composition and mortality of American elm, forests play a key role in providing habitat for wildlife.

White-tailed deer in North Dakota have a history of habitat adaptation over time. Population dynamics over the 20th century show how trends in deer populations changed their habitat use. In the early days of big game management, deer in North Dakota were thought to have relied on primarily wooded areas for habitat (Bailey 1926, Knue 1991). Populations dwindled to near extirpation in North Dakota by 1920 (Bailey 1926). Populations later revived towards the late 1940s (Hunt and Mangus 1954, Knue 1991). When a dramatic increase in deer populations occurred at that time, deer expanded their habitat far beyond wooded areas. Their adaptation to grassland as important habitat dubbed them as “prairie deer”. Despite deer in North Dakota now being found residing on prairie sites more often than before, deer still rely heavily on wooded corridors because these areas provide shelter and browse in winter months (Knue 1991). Forested areas, including riparian forests are identified as critical habitat for northeastern North Dakota’s deer population (Sternhagen 2016).

Deer in North Dakota use different types of browse in different seasons. When forb sources are not available as is the case in cold and snowy winter months in North Dakota, deer are in search of woody browse or supplemental feedings (Smith et al.2007). Often times in deep snow deer are not able to find sufficient woody browse, and instead feed on corn and bales of hay (Knue 1991). Food plots can help supplement winter deer diets in addition to woody browse in North Dakota, and reduce natural mortality that would occur in harsh winters (Smith et al. 2007).

Restorationists often seek to minimize factors known to affect establishment of tree seedlings. It is recommended that biotic and abiotic factors affecting mortality and growth should be considered when planning a tree planting project (Stanturf et al. 2004). Climatic issues such as temperature stress, poor site selection, flooding, competitive vegetation and drought can affect growth and survival of tree seedlings even on the best soils (Allen et al. 2001). In some areas of the country, other challenges can include browsing by ungulates and rodents (Allen et al. 2001).

Herbivory by deer can significantly hamper growth and height of seedlings. In studies where seedlings have naturally germinated and established, such as within a forest stand or grassed areas, herbivory can significantly affect growth (Lawson et al 1999, Krueger et al. 2009). One study of 60 year old abandoned fields in east central MN found seedlings of northern red oak (*Quercus rubra* L.), bur oak (*Quercus macrocarpa* Michx.), and quaking aspen (*Populus tremuloides* Michx.) growing within proximity for seed dispersal from neighboring forest containing these species (Lawson et al. 1999). The seedlings over 30 cm in height often showed no growth or even a reduction in height after two years due to deer herbivory (Lawson et al. 1999). These studies demonstrated that when natural recruitment of seedlings occurred, growth to a size class of 2.5 cm dbh could not be met without significant challenges from deer herbivory. It is important to note that deer are keystone herbivores, directly influencing the ecosystems they reside within, and having the ability to shape forest composition and structure (Wallers and Alverson 1997). With deer herbivory, the structure and species composition of forest vegetation can be expected to continue in a direction determined by that keystone herbivore (Ruzicka et al. 2009).

Studies of white-tailed deer browsing have demonstrated that herbivory can have a significant negative effect on seedling growth compared to areas excluded from deer (Krueger et al. 2009, Long et al. 2012). A study in Pennsylvania found browsing pressure from white-tailed deer had significantly impacted vertical growth of northern red oak (Long et al. 2012). Acorns planted in 2004 later resulted in seedlings that in 2009 were taller in plots fenced with 2.4 m high woven fence than unprotected seedlings (i.e., seedlings averaged 32 cm in fenced and 17 cm in unprotected plots). Another study in Pennsylvania found significantly more growth in seedlings that regenerated in windthrow areas protected by hardware cloth exclosures around individual seedlings (Krueger et al. 2009).

Tree and shrub species respond differently to browsing in terms of annual production and relative abundance of the species in an area. A study in Minnesota showed that browse tolerant tree species, such as willow (*Salix*), responded with increase in abundance in two years' time, despite being heavily utilized as a primary browse species by deer in the winter (Hunt and Magnus 1959). The fast growth rate of stems is also attributed to its success as a deer browse species. In the study area, willow species were more prevalent and robust compared to red osier dogwood (*Cornus sericea* L.), and as a result comprised a larger portion of the winter browse diet than the more preferred dogwood (Hunt and Magnus 1959). A clipping study that imitated browsing scenarios found that willow and dogwood were both affected by simulated clipping (Aldous 1952). Red osier dogwood only responded with positive increase in production if the browsing pressure was light (10% of the new growth removed), and responded negatively if browsing was more intense (exceeding 10%). Growth was measured in terms of annual production using the length of twigs and weight. Dogwood that experience heavy browsing pressure had inhibited growth, lower production, and a spiny appearance. In contrast, willow flourished under heavy browse conditions (50% of new growth removed) and responded with 855% more production after five years of heavy browsing (Aldous 1952). Northern red oak growth has been shown to significantly decrease under intensified browsing pressure (Oswalt et al. 2006).

Some managers aim to protect trees and shrubs from herbivory as a way to increase survival, growth, and natural regeneration opportunities (Allen et al. 2001). Methods employed in deterring herbivores include liquid repellants, plastic tree tubes, plastic or wood snow fencing, woven wire, electric wire, electric braided rope, high tensile fence, plastic mesh fences, and ultimately the hunting of animals to control numbers (Curtis et al. 1994, Vercauteren et al. 2006, Stange 2008). Several factors determine the type of protection selected. The number of trees, size of seedling, size of the area needing protection, ease of use, maintenance, time frame protection is needed and cost are factors to evaluate in the planning stage.

Plastic tree tubes can be applied onto seedlings to protect them from ungulates and rodents in the portion of the tube covering the tree. They are one effective approach to handling herbivory by deer (Stange and Shea 1998, Dubois et al. 2000). Tubes are costly in a large scale tree planting (Allen et al. 2001). Tree tubes typically cost around $3.75 to $4.75 per 1.2 m (4 ft) tree tube and wooden stake ensemble sold (Joleen Swartz personal communication). They are commonly used in shelterbelt plantings in North Dakota. Many cost share programs pay for this popular herbivory prevention treatment (NDFS 2016, NDDOH 2016, NRCS 2016).

Exclosure fencing is a method of protecting seedlings in a large scale planting when ungulate herbivory is problematic. Studies have found the erection of electric fencing to protect areas prone to herbivory by deer can significantly deter deer entering the site (Beringer et. al 2003, Seamans and Vercauteren 2006). Deer browsing can be significantly reduced using electric fences (Tierson 1969). In North Dakota, deer exclosure fencing is not a frequently used approach for protecting seedlings, unless it is to protect high value crops, such as the case in nurseries (Stange 2008).

Deer behavior is an important consideration when designing a fence. Fences can be a physical deterrent, psychological deterrent, or both (VanCauteren 2006a). A 2.4 m high fence made of woven wire, welded wire, or chain link is found to be 90-99% effective physical deterrent against deer entering an area via jumping (Vercauteren et al. 2006a, `1uteren et al. 2010, Long et al. 2012). Polypropylene mesh fence at 2.1 m in height has been effective in physically deterring deer from leaving an area when held in captivity (Lavelle et al. 2010). Deer have the ability to crawl under fences, taking advantage of as little as a 25 cm gap on a 5 strand vertical electric fence (Palmer et al. 1985). The electric fence was 147 cm high and could be jumped; however, deer that penetrated the fence chose to crawl under the bottom strand. The fence was effective in deterring deer for about 30 days.

Individual deer have the ability to learn how to penetrate a fence or avoid it through behavior modification. Beringer et al. (2003) tested the efficacy of exclusion using monofilament lines and an alarm activated scarecrow system. Observations showed that adult deer accustomed to staying out of the fence were less respectful of the fence after seeing other deer cross it (Beringer et al. 2003). Fawns slipped under the bottom strand of the fence and the adults chose to walk through the second and third strands of the fence.

Deer can be trained to avoid electric fencing by the added use of attractants, such as peanut butter (Porter 1983). Peanut butter applied to foil flags attached to the top strand of the electric fence provided visual and odor stimuli to attract the deer. Deer touched the fence with their noses, and then would avoid the fence that they could easily jump over or crawl through being the fence was only 1 m in height and consisted of one strand of wire. This type of fence resulted in significantly more new growth of apple trees compared to unprotected seedlings (Porter 1983).

Competition from vegetation is another factor that can affect the growth of tree seedlings. A field study in Minnesota (Davis et al. 1998) of newly planted two year old bur oak (*Quercus macrocarpa* Michx.) and northern pin oak (*Quercus ellipsoidalis* E.J. Hill) seedlings found competition for moisture resources between bur oak and dominant grasses smooth brome (*Bromus inermis* Leyss), Kentucky bluegrass (*Poa pratensis* L.), and quackgrass (*Agropyron repens* L.) increased as the available moisture decreased. Weekly soil water measurements were taking in three different moisture regimes: dry, moderate, and wet. The competition between the dominant grasses and tree seedlings lessened with increases in moisture that favored trees because the resource supply was adequate (Davis et al. 1998).

There are several methods of controlling unwanted vegetation at planting sites, including mowing, herbicide treatment, cultivation, mulching and landscape fabric (Stanturf et al. 2004, NDFS 2003). Herbicide treatment of competitive vegetation has been found to be either effective or ineffective in increasing growth and survival of trees (Dubois et al. 2000, McLeod et al. 2000, Baer and Groninger 2004). Glyphosate herbicide treatment significantly increased growth of green ash (*Fraxinus pennsylvanica* Marshall) in a reforestation project in southern Illinois (Baer and Groninger 2004). In another study, controlling vegetation using glyphosate-(phosphononomethyl) glycine had no significant effects on survival and growth of oak (*Quercus*) species after four years (McLeod 2000). While the herbicide was effective in killing the vegetation, it was inferred that the lack of effect on the seedlings growth was due to light, water and nutrient requirements having been met. In this instance, money could be saved by not applying herbicide on a site where vegetation control is not essential to establishing seedlings (McLeod 2000). Cherrybark oak (*Quercus pagoda* Raf.) seedlings grown in Alabama using herbicide treatment did not significantly affect height. Herbicide control of vegetation did result, however, in greater ground line diameter of the main stem, and stem volume growth after two years (Dubois et al. 2000).

Fabric is one method of controlling unwanted vegetation without the use of herbicides. Landscape fabric, also called weed barrier fabric or polyethylene mulch sheets, can provide effective vegetation control in tree plantings (Stange 2003). The North Dakota Forest Service, NRCS, and Soil Conservation Districts recommend to landowners that fabric is applied to tree plantings to increase growth rates and retain soil moisture (NDFS 2003, Stange 2003, Joleen Swartz personal communication). The use of fabric can be a considerable upfront investment for landowners. One disadvantage of fabric is that it can girdle trees if it is not properly maintained, and does not allow for the suckering of shrubs (Stange 2003).

Some studies demonstrate negligible or negative effects of fabric on seedling survival and growth. A study by Stange and Shea (1998) in southcentral Minnesota showed negative effects of using landscape fabric on seedling growth largely due to deer targeting seedlings, possibly due to more apparent existence of seedlings against the fabric denude of vegetation to hide them. Four of six blocks showed a significant reduction in seedling height on northern red oak seedlings.

Landowners and agencies that want to establish or restore forested areas on their land primarily have an upfront investment. Investment into resources that increase establishment of seedlings during the first five years is considered worthwhile in many instances because after five years' time, the chances of continued survival are high (McPherson et al. 2006). Services and supplies are often available locally. County Soil Conservation Districts offer tree planting services for landowners in North Dakota. Many Soil Conservation Districts also install landscape fabric and tree tubes (Joleen Swartz, personal communication). The initial investment for fabric and tubes can be expensive for the landowner, especially in large scale plantings (Stange 2003). We seek to find economical and effective ways to protect plantings from deer herbivory and increase growth.

Methods

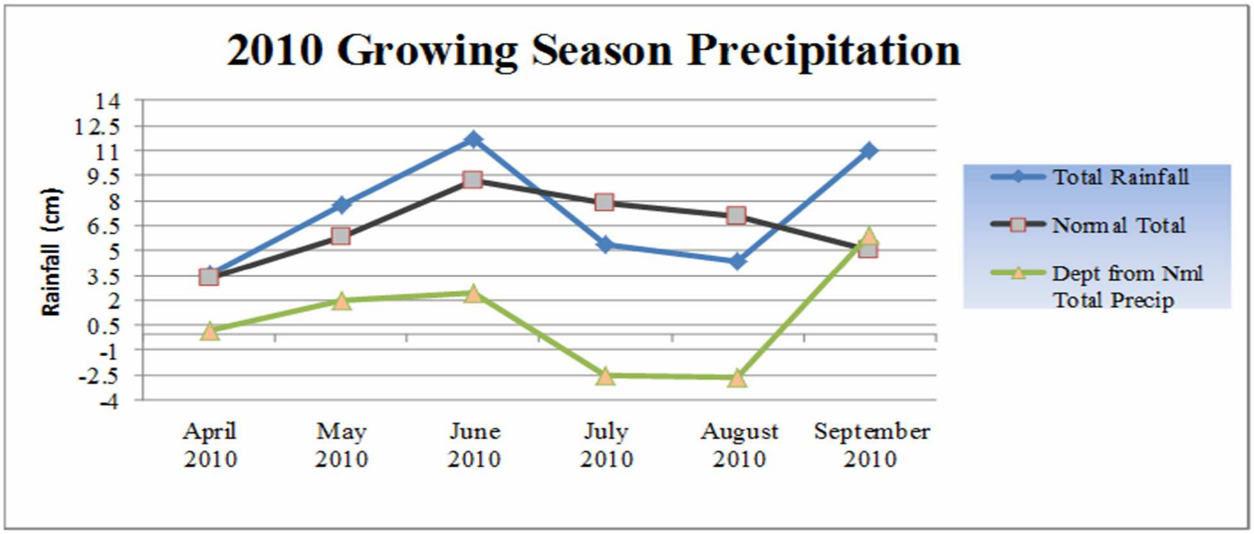
The study site is located two miles south of Tolna, ND in the Middle Sheyenne Watershed on privately owned property (47º47'23.24" N, 98º26'02.49" W). The site had a long history of grazing. Recent new ownership stated that the site would not be grazed, but rather, improved upon for deer habitat and hunting opportunities on approximately 16 hectares (40 acres), which was located adjacent to the riparian corridor. Plots were established on the upland portion of the parcel, on a south facing slope, where a natural drainage leads to the Sheyenne River below (Figure 9).

Figure 9. A view of the Tolna, N.D. study site shortly after planting in the first season, facing south towards the river valley. Photo by Aaron Sawatzky, Red River Riparian Project.

Woody species present at the site include primarily western snowberry (*Symphoricarpos occidentalis* Hook.), however, there was one area of red hawthorn (*Crataegus chrysocarpa* Ashe). Predominant grasses included Kentucky bluegrass, big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), and porcupine grass (*Hesperostipa spartea* (Trin.) Barkworth).

Forb species included wild licorice (*Glycyrrhiza lepidota* Pursh), sow thistle (*Sonchus arvensis* L.), Canada thistle (*Cirsium arvense* (L.) Scop.), curly cup gumweed (*Grindelia squarrosa* (Pursh) Dunal), blue lettuce (*Lactuca pulchella* (Pursh) DC), Canada goldenrod (*Solidago canadensis* L.), wild bergamot (*Monarda fistulosa* L.), prairie coneflower (*Ratibida columnifera* (Nutt.) Wooton & Standl.), black-eyed Susan *(Rudebeckia serotine*), white sagebrush (*Artemisia ludoviciana* Nutt.), and leafy spurge (*Euphorbia esula* L.). This list is not all inclusive; however, it captures the most prevalent species at the site. All scientific names are credited to the USDA Plants Database 2016.

The average rainfall for the months of April to September totals 39.9 cm at the McHenry weather station approximately 28 km from the study site (NDAWN 2012). The actual amount of precipitation received in the first growing season was 43.7 cm. The first growing season (2010) experienced an above normal amount of precipitation in the months (April, May, June, and September) and below normal amounts of precipitation in July and August (Figure 10.) The second growing season (2011) experienced above average precipitation for all months except May, which was over 1.5 cm below normal precipitation (NDAWN 2012).



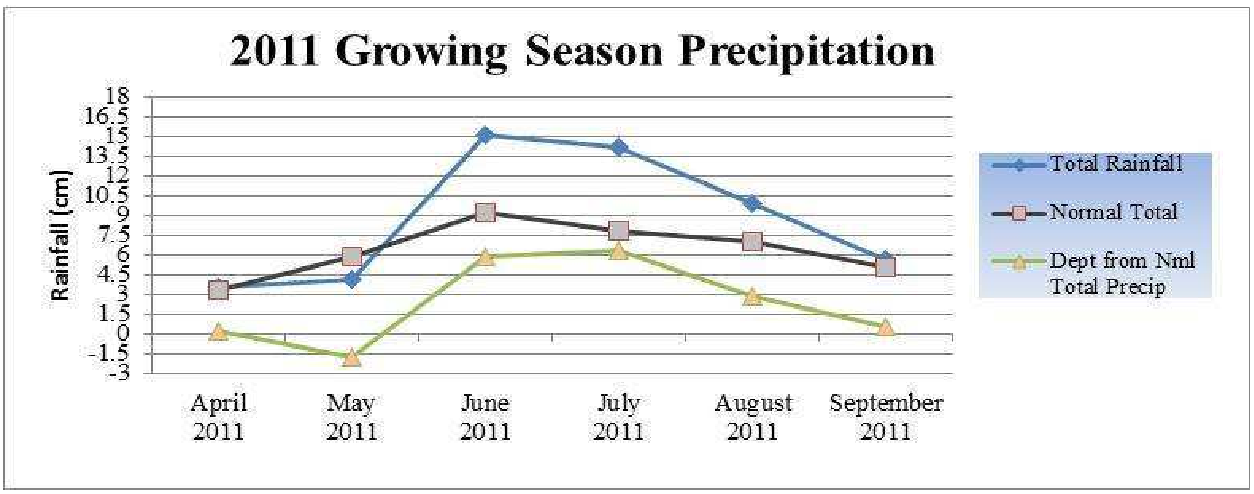


Figure 10. Precipitation received at the McHenry, ND weather station for 2010 and 2011 (NDAWN 2012)

Soils at the site are comprised of the Barnes, Sioux, and Arvilla soil series. The Barnes-Sioux complex (G680D) has a slope of six to fifteen percent according to Web Soil Survey (USDA WSS 2016). Barnes is found on the backslope of knolls. It is comprised of fine-loamy till parent material, and the typical profile is loam throughout the Ap, Bw, Bk, and C horizons. The ecological site is classified as Loamy. Salinity is rated at 0.0 to 4.0 mmhos/cm. Depth to water table is greater than 203.2 cm in this deep and well-drained soil. Sioux is found on the summit or shoulder of hill ridges. The typical profile includes sandy loam in the A horizon, gravelly sandy loam in the ABk horizon, very gravelly loamy sandy in the BCk, and very gravelly sand at the C horizon. The ecological site is Very Shallow and the natural drainage class is “excessively drained” soil (USDA 1989).

The Arvilla-Sioux complex (G272B) has slopes of two to six percent (USDA WSS 2016). Arvilla soils are found on the backslope of rises. The typical profile is comprised of Ap sandy loam, A, sandy loam, Bw sandy loam, 2Bk gravelly coarse sand, and 2C gravelly coarse sand. The natural drainage class is “somewhat excessively drained”. Both the Barnes-Sioux and Arvilla-Sioux are rated as having a low potential for seedling mortality (USDA 2016). Each is also classified as “well suited” for hand plantings because there are no limitations for tree plantings at the site (USDA WSS 2016).

The Randomized Complete Block Design utilized four blocks, including two that were fenced (Figure 11). Four blocks spanning 50 m x 50 m and a 3.65 m buffer was included between blocks. Each block was divided into four treatment plots that measured 25 x 25 m.
Treatment plots included: fabric, herbicide, fabric and herbicide, and the untreated control.

(Figure 11). There were a total of 16 plots, four of each treatment, randomly assigned within each block. Weed barrier fabric treatment and/or herbicide treatment were nested within the blocks.

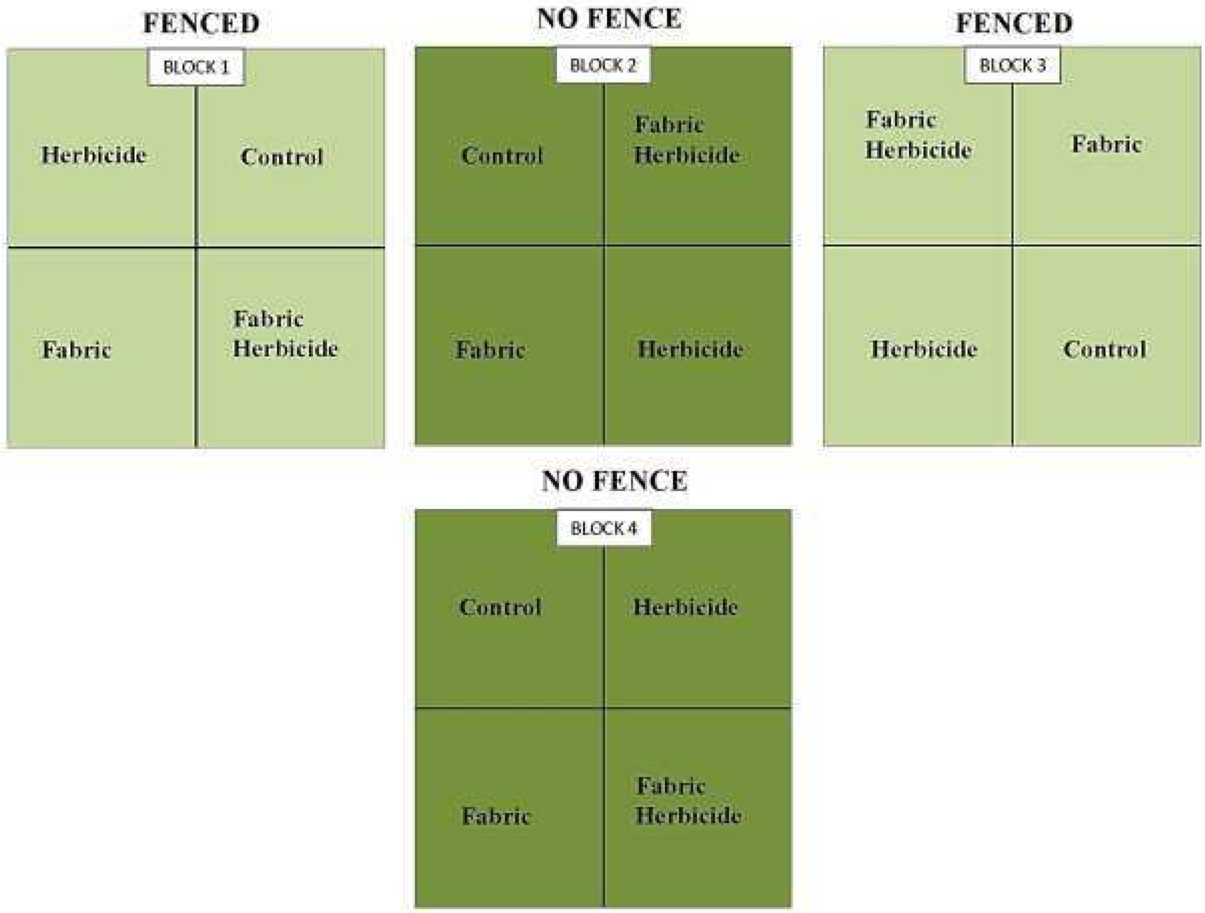


Figure 11. Configuration of herbicide and/or fabric treatments nested within blocks of the Randomized Complete Block Design.

The number of rows per quadrant of the block varied depending on the location of the quadrant. The upper right and upper left quadrants had seven rows of 25 seedlings, and the lower right and lower left quadrants had eight rows of 25 seedlings (Figure 12).

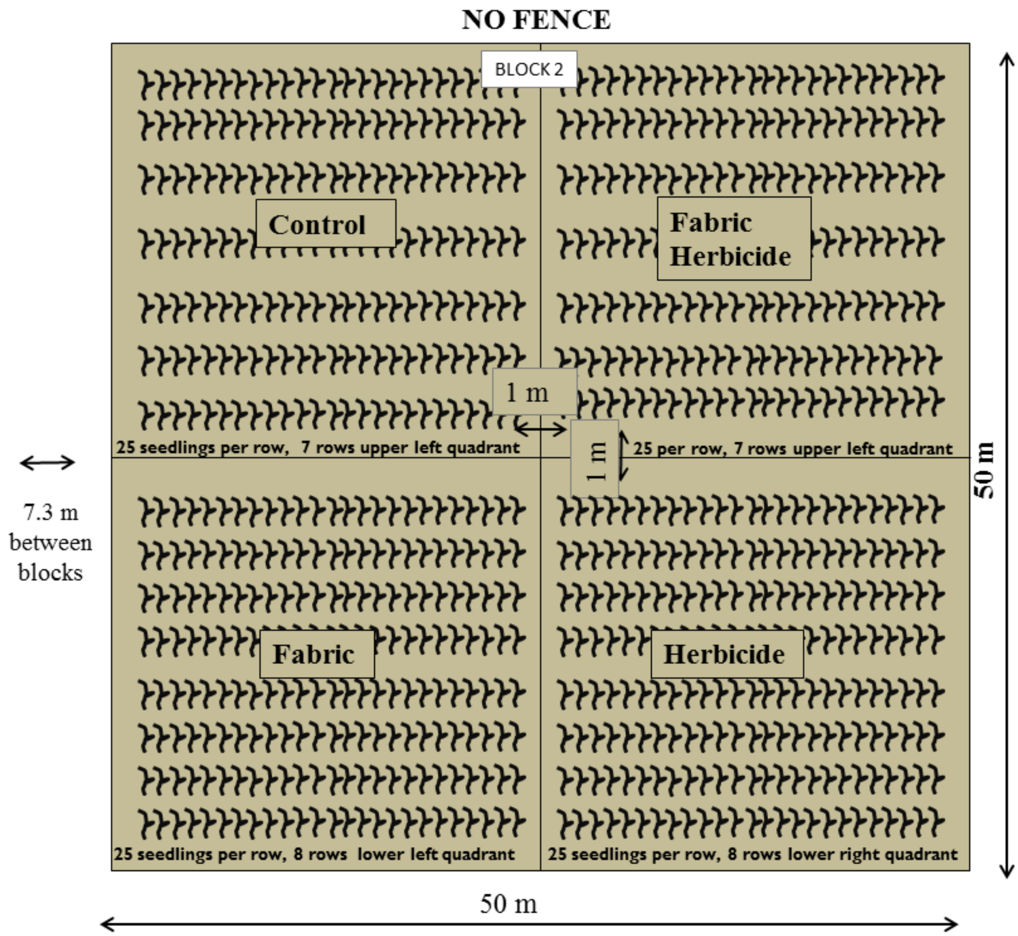


Figure 12. Illustration of rows of seedlings in herbicide and fabric treatments within Block 2.

The study site was prepared for planting in mid-May of 2010. Widespread site preparation included brush mowing in all blocks the week prior to planting. In the herbicide treatment plots, glyphosate herbicide was planned to be applied four days prior to seedling planting to reduce competition of weeds and cool season grasses. Due to adverse weather conditions for herbicide application, only a portion of the area received treatment prior to planting as planned. The remaining areas were treated after planting with herbicide in early June when conditions improved. Herbicide was applied evenly over the treated plots, however, it is not known what rate of application the landowner used.

Fencing was applied to two of the four blocks. Block 3 received a high tensile 7000 volt electric fence with a height of 2.43 m (Figure 13). The fence was comprised of tall wooden posts 3.04 m tall with 3.66 m corner posts for reinforced stability. Each fence strand was ratcheted to optimum tension near the northwest corner gate of the fence line. A power cutoff bar was installed to be able to disconnect power quickly to the fence. The gate was comprised of stretched wires with bungee type of springs. This type of fence gate allowed for easy access to the plots to collect data and complete maintenance.

Block 1 was surrounded by a 1.52 m electric fence comprised of flexible fiberglass poles that held five electric strands of wire. The second wire to the top was not a live wire to ensure the fence would ground for a jumping deer, and the other three transferred charge. Sturdy 2.43m wooden posts were installed on the corners of this fenced area. The landowner smeared bolt nuts with peanut butter and molasses and hung from the top live wire. He also hung aluminum foil flags hung on the top strand baited with peanut butter to lure deer towards this fence, in hopes of training them to stay away from the fence through shock treatment. Block 2 and block 4 were not treated with electric fences, and therefore access by herbivores was unrestricted.

Because there was not an adequate power source nearby to power the electric fencing, the landowner used a solar fence charger to power both blocks of fencing. A solar fence charger (Figure 14) allowed for 7000 volts of power to be supplied on a continual basis to the low fence (Block 1) and high fence (Block 3).

Seven species of trees and shrubs were randomly hand planted one meter apart in rows one meter apart. Species planted were bur oak, American plum (*Prunus americana* Marshall), redosier dogwood, peachleaf willow (*Salix amygdaloides* Andersson), golden willow (*Salix alba* L.), eastern cottonwood (*Populus deltoides* W. Bartram ex Marshall), and false indigo (*Amorpha* *fruticosa* L.). A total of 2,995 individual stems were planted on May 25, 2010. Seedlings were bareroot nursery stock in the conservation grade size from Lincoln Oakes Nursery, Bismarck, N.D. A group of seventeen volunteers hand planted the seedlings using spade shovels. The North Dakota Forest Service and NDSU Extension Service also assisted the group, providing instruction on proper planting techniques. Roots were trimmed to less than 30 cm on seedlings that had long roots to allow for roots to fit better in the spade openings and prevent J-rooting. The soils were moist at the time of planting due to recent rainfall. According to NDAWN records, 6.9 cm of rain had fallen during the three days prior to planting (NDAWN 2012).

Landscape fabric was applied to the designated treatment blocks the same day the seedlings were planted. Fabric was carefully unrolled by hand spanning the length of each row. When a seedling was reached, a slit was cut into the fabric using a utility knife, and the seedling was fit through the opening. The sizes of slits ranged from 15 to 25 cm on each side of the seedling to allow for growth and prevent fabric rubbing on the bark. Fabric staples were applied along the margins of the fabric every 1.2 to 1.5 m.

After seedlings had broken bud, each was labeled with a color coded zip tie to accurately designate the seedling species. Inventory of the quantity of each species was conducted. Not all treatment blocks had the same number of each species because the planting was completed at random. Seedlings were determined to be dead or alive. Data was collected on a sample portion of the 2,995 seedlings in August of each field season. Five of each of the seven species were measured in each plot for height, average leaf length and leaf width. The average number surveyed per plot was n=35. If less than five specimens of each species were living in the plot, the available number of living seedlings for the species was used (e.g. three bur oak). If no specimens of a species were found alive, specimens were not replaced by another species in the total number of seedlings measured.

Seedlings were inspected for herbivory. The typical browse signs recorded showed either complete leaf removal where only the petiole of the leaf remained, or a ragged bite or tear mark on the leaves. Small chew marks located low on the main stem were considered to be rodent damage. If the seedling was found to be dead, notations were made of possible causes, (e.g. if evidence of browsing, girdling, or spray damage may have occurred).

Some maintenance was necessary over the growing season. During the first growing season, the fence charger quit working for a period of one to two weeks. As the growing season progressed, the application of herbicides along the fence lines became necessary to prevent weeds from shorting out the fence. On one occasion during the second summer, the 1.52 m fence shorted out for one to two weeks. The tall weeds that were touching the fence were trimmed off by hand before being sprayed. Glyphosate was applied along the fence line weeds using a single nozzle sprayer, either hand held or mounted to an ATV.

Analysis of the data was completed using SAS Enterprise Guide 7.1 of the SAS System for Windows (Copyright © 2000-2017 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). A blocked one-way ANOVA was run with a general linear model to compare survival percentages across the herbicide and fabric treatment combinations. The experimental design consisted of a Randomized Complete Block Design (RCBD) with fabric and herbicide treatment combinations nested within each block. Blocks were used to account the variability due to the browsing gradient caused by the different fencing levels. Tukey's test for multiple comparisons of means was utilized at $\alpha = 0.05$. Differences in individual species of seedlings were also analyzed using one-way ANOVA and Tukey's test for comparisons on treatment means. Fence was used to create a grazing gradient on two of the four blocks, however, due to a small experiment size and no fencing replications, statistical analysis was not appropriate, but rather general comparisons using descriptive statistics are incorporated into our results. Descriptive statistics and graphical representations were constructed using Microsoft Excel 2010.

Figure 13. High tensile electric fence surrounds Block 3. Note the fabric treated rows and small size of seedlings immediately after planting in season 1. Photo by Aaron Sawatzky, Red River Riparian Project.

Figure 14. A five strand electric fence in Block 1 contained the solar fence charger that powered both fenced blocks. Photo by Aaron Sawatzky, Red River Riparian Project.

Results

The differences in vegetation control treatments fabric and/or herbicide on seedling mortality was not significantly different (Table 18). Seedling mortality during the first growing season (2010) totaled 657 dead seedlings out of 2995 seedlings across all treatments (Table 19). Mortality at the end of 2010 was 21.9%, equating to 78.1% survival at the end of season 1.

Table 18. Analysis of Variance (ANOVA) of Treatments on Seedling Mortality in 2010 at the Tolna, N.D. Site.

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	Pr > F
Treatments	3	0.04	0.012	1.42	0.30
Block	3	0.05	0.02	1.99	0.19

Table 19. First Season Seedling Mortality per Block

Block	Dead Seedlings
1 (Fenced)	75
2 (No Fence)	175
3 (Fenced)	202
4 (No Fence)	205
Total	657

The survival of tree seedlings after two growing seasons in 2011 was not significantly different across treatments (Table 20). Survival between fabric and/or herbicide treatments was not statistically significant from untreated plots.

Table 20. Analysis of Variance (ANOVA) for Treatments on Seedling Survival in 2011 at the Pekin, N.D. Site

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	Pr > F
Treatments	3	0.0173	0.0058	0.80	0.5223
Block	3	0.1182	0.040	5.49	0.0202

Survival in Season 2 (2011) averaged 44.5% across all treatments. By August 2011, of the sample seedlings surveyed 592 seedlings were found to be alive in the unfenced plots, and 741 seedlings were alive in the fenced plots. This totals 1333 living seedlings out of the original 2,995 planted.

Individual Species

There was a significant difference in the height of false indigo seedlings treated with only fabric compared to seedlings with only herbicide (Table 21 and 22).

Table 21. Analysis of Variance (ANOVA) for Treatments on the Height of False Indigo in 2011 at the Tolna, N.D site.

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	Pr > F
Treatment	3	191.5	63.83	4.96	0.0266
Block	3	910.6	303.52	23.58	0.0001

Table 22. Standard Deviation and Average Seedling Height for False Indigo at the Tolna, N.D. Site

Treatments		Seedling Height in cm	Standard Deviation	Significance
Fabric	Herbicide	30.9	9.8	AB
	No Herbicide	35.2	8.0	A
Average Height of Seedlings in Fabric		33.1		
No Fabric	Herbicide	25.6	9.4	B
	No Herbicide	29.3	9.6	AB
Average Height of Seedlings in No Fabric		27.5		
Average Height All Treatments		30.3		

*Treatments labeled with different letters are significantly different at p= 0.05

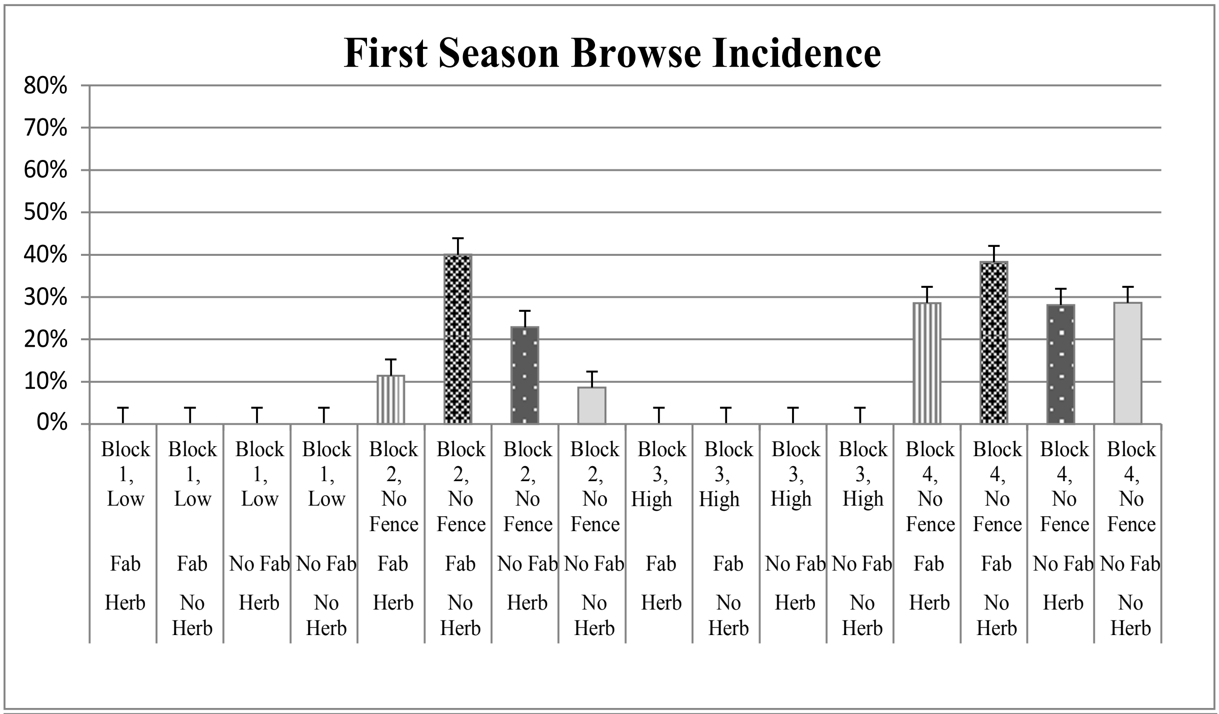
Bur oak, American plum, peachleaf willow, golden willow, redosier dogwood and cottonwood did not show significant differences in height across treatments at a = 0.05.

Browsing gradient

The electric fencing treatment provided a gradient of browsing in seasons 1 and 2. In season 1, deer browsing occurred in unfenced blocks (blocks 2 and 4) and did not occur in fenced blocks (blocks 1 and 3) between May 25th and August 12th in 2010 (Figure 15). Blocks 1 and 3 received low or high electric fence treatments showed no signs of deer browse in season 1. Season 2 browse incidence was recorded on August 19th, 2011. In Season 2, all blocks received browsing by deer.

Browse incidence was highest on fabric covered plots (Figure 15). In block 1 and block 4, the fabric treatment had the highest browse incidence in season two, when deer were entering the fences. In block 2 and block 3, deer were browsing most frequently on the fabric plus herbicide block. The fabric only treatment plot in block 3 had a browsing incidence 6% less than the control treatment, and had the lowest browse incidence.

a)



b)

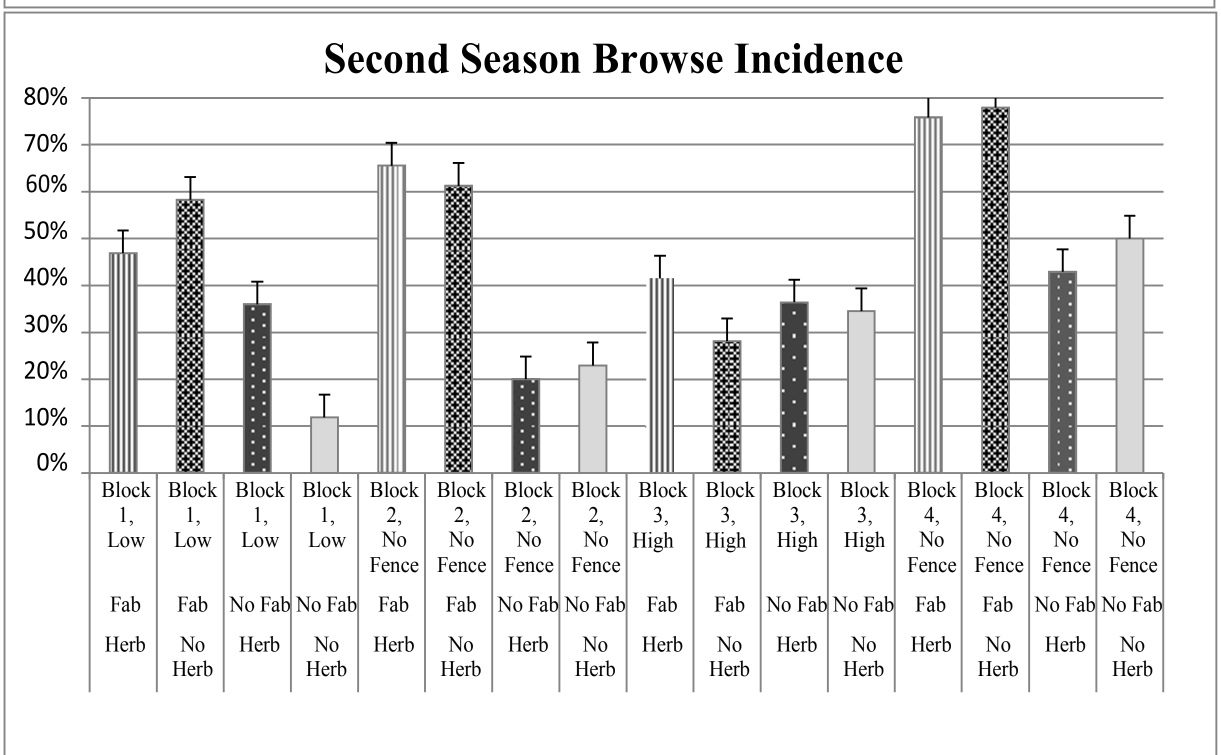


Figure 15. a) First season incidence of browsing by deer from the date of planting on May 25th, to August 12th of the first growing season; b) Second season browse incidence during the summer of season 2. Blocks 1 and 3 were protected by electric fences

Discussion

The main goal of this demonstration site was to determine what effects fabric and herbicide treatments may have on tree survival and growth. The application of glyphosate herbicide was found to have no significant positive effect on height between herbicide treated plots and the control. This concurs with Dubois et al. (2000) who found no statistically significant difference in growth after 2 years of seedlings planted in areas where glyphosate was applied to control competition by vegetation. In contrast to our results, George et al. (1991) found that seedlings grew taller when herbicide was applied to weedy areas. A single application of glyphosate prior to planting green ash was found to significantly enhance growth as well (Baer and Groninger 2004).

Our results may differ because of complications during herbicide application. Because the herbicide had to be applied to plots on days when wind speeds would later halt application efforts, it is highly probable that herbicide drift occurred on other plots. Herbicide was applied on some plots after planting and could have also played a role in lower survival rates. Evidence of herbicide damage was seen on seedlings with curling yellow or dry brown leaves on a portion of the seedling. The lower left quadrant of the high fence was a herbicide treated plot where herbicide may be responsible for low survival because it was applied after planting.

We found significant differences between the Fabric only vs. Herbicide only treatments. Comparing the mean height of treatment combinations shows that the Herbicide only treatment mean height was less than the control mean height, and the Fabric only treatment showed greater height than the control. The sandwiching of the control between treatments suggests that herbicide application has hindered growth of false indigo, and an interaction of these treatments had taken place. This was also confirmed by looking at treatment means. The Fabric/Herbicide combination showed mean height of 30.9 cm $\pm$ 9.8 cm, and the Fabric only showed a height of 35.2 $\pm$ 8.0 cm for false indigo (Table 22). The Herbicide only treatment had a mean of 25.6 $\pm$ 9.4 cm, which is less than the control mean of 29.3 $\pm$ 9.6 cm. Adding herbicide to fabric lowers the mean height, and herbicide produces shorter false indigo seedlings than the control. While it is noteworthy to explain differences using means, it should be kept in mind that the differences in heights are not statistically significant, but rather just the Herbicide only vs. Fabric only treatments find a significant difference through the inhibition of height.

Competition from vegetation can create moisture stress on seedlings as available moisture is reduced (Davis et al. 1998), however, in our study the fabric only treatment did not yield significant differences in height compared to the control in any of our tree or shrub species. A greater mean height was achieved with fabric on false indigo, but the results are not significant between Fabric only and the control. Despite the lack of significance of the fabric treatment, that is not to say that fabric didn't possibly contribute to additional moisture for this species in the drier months. July and August of the first growing season received 2.5 cm of precipitation below normal in both of those months. Because it was not clear whether or not competitive vegetation played any role, testing available soil moisture with a Hydrostat meter would be helpful in future studies to determine levels of soil moisture. This could allow for determination as to whether or not a threshold for moisture competition was reached between species. If there is sufficient moisture for both trees and grasses simultaneously, so that the competition gradient is low and the threshold for resource competition is not met, then the resource competition does not exist strongly enough to see results with vegetation control (Davis et al. 1998).

Fabric may have played a role in browse incidence; however, that role is unclear. Browse incidence was highest in fabric treated plots of block 1 (low fence) and block 4 (no fence) in season 2. In block 2 and block 3, the herbicide plus fabric combination had the highest browse incidence. Stange and Shea (1998) found that fabric increased browse incidence on seedlings, possibly because deer were able to spot the seedlings much easier. All utilization of fabric plots in our study concur with Stange and Shea (1998), except for the fabric only plot of block 3, which had the lowest incidence of browse for the block. Perhaps deer did not like where the plot was located; on the far edge of the site near a ravine with much animal traffic. Stange and Shea (1998) found deer favored fabric covered plots closest to the protection of the existing forest versus those plots further away, suggesting the deer had a need for nearby shelter.

Survival in this study was surprisingly similar to the Pekin study we had conducted concurrently only 7 miles away from the Tolna site. The Tolna site yielded 39.5% survival in unfenced plots and 49% in fenced plots after two years. This overall seedling survival in the study was similar to the Pekin study which had 33% survival in low fence with deer only, and 49% survival with total exclusion of deer and cattle (See Chapter 2). In the August survey of Season 1 at the Tolna site, the initial loss of survival since planting was 21.9% averaged across all treatments. Given this information, other factors in seedling survival are influencing survival and mortality of seedlings. Seedling handling conditions, planting techniques, rodent damage, heavy browse by deer immediately after planting, transplant shock, herbicide damage or carryover, are possible factors that could contributed to this result at the Tolna site. At the Pekin site, browsing by deer and cattle caused a significant difference in survival between high fence and no fence in Season 3 of the study, which is during the same time of the Tolna study. We did not have a large enough demonstration site with adequate sample sizes to determine whether or not electric fences made a difference in seedling and survival and growth.

In an area with a deer population of 23.5 deer per km^2, it was no surprise to see deer immediately browsing on seedlings in June just after they were planted. Less than one month after planting, on June 21, 2010, deer were discovered browsing seedlings in the unfenced plots (Figure 16). Nearby at the Pekin study, on June 8 of the same year, browsing by deer was also taking place on unprotected seedlings. The incidence of browsing shows us that deer are using the seedlings for a source of browse in the late spring and early summer when other food sources are limited. This coincides with findings of another study (Sternhagen 2016) that mid-May and into June is fawning time for deer in northeastern North Dakota. Given the limitations of adequate browse in some areas, tree seedlings should be protected immediately after planting to avoid deer taking the first buds.

Figure 16. Deer browse an unprotected plot of seedlings less than one month after being planted at the Tolna, N.D. site. Photo courtesy Aaron Sawatzky of the Red River Riparian Program, 2010.

In addition to studying fabric and herbicide at this demonstration site, we also wanted to find out if tubes or fencing would be a more economical approach to protecting trees from deer herbivory. Much of costs associated with restoration plantings are upfront costs on the part of the landowner in the installation phase (International Soc. of Arboriculture 1991). Tubes have been found to be very effective in improving growth in the first few years (Stange and Shea 1998, Dubois et al. 2000). Tree shelters increased the survival of trees in the presence of deer herbivory by 31.4% over unprotected seedlings (Stange and Shea 1998).

The following is a hypothetical situation to determine the best situation for a landowner with a planting like the one we studied. In this situation, we will assume that fence had efficacy in reducing herbivory by deer, much like our browsing gradient tried to accomplish but fell short on. Using the Tolna landowner's case, what would happen if he had used tree shelters instead of treating with fence on 1497 seedlings (the half needing treatment)? What is the initial investment? He would have invested $5,988 for tree tubes for 1,497 trees (Table 23).

Table 23. Herbivory Treatment Cost Comparisons

Treatment as Applied		Cost
Fence Supplies		(Fence, charger, posts)
Fenced area of 1497 trees	$	2,650.00
Labor	$	-
Total	$	2,650.00
Cost of protection/tree	$	1.77 ea.

Treatment Alternative		Cost
Tree tube shelters		(Tubes and stakes)
Qty for 1497 trees	$	4.00/ea.
Labor	$	-
Total	$	5,988.00
Cost of protection/tree	$	4.00/ea.

The fencing treatment cost him $2,650 for fencing supplies, which included the spider fence, high tensile fence, solar powered fencer, and site preparation. His time and labor are not factored into the supply costs because this is not a direct expense to him, though his time is still of value in the form of opportunity and in-kind costs. The cost to protect each tree was calculated by the total cost $2,650 divided by 1,497 fenced seedlings, which equated to $1.77 per tree. Since we do not know how much survival would change in the next several years for fence or tubes, we will use two years' time for calculations. In lieu of an electric fence treatment, a total of 1,497 tree tubes would be needed at a cost of $4.00 per tube and stake ensemble. Labor is not calculated into the $5,988 total cost of this treatment. At first glance, tree tubes appear to be a very costly investment for a large scale tree planting (Table 23).

The degree to which survival increases with treatment is also a consideration. In our Tolna study, about 49.5% or 741 seedlings that were fenced survived to year two, and 39.5% of unfenced seedlings survived. In Stange and Shea (1998), shelters increased survival by 31.4% over the unprotected plots. In our situation, hypothetically if we added tree tube shelters with a 31.4% increase in survival to our baseline survival of 39.5%, in the unprotected plots it would equate to around 70.9% anticipated survival using tree tubes in year 2. Assuming the mortality percentage was the same for both tubes and fences, 29.1% of the first two years seedlings would perish in the tube.

We will not have any way to show this in real numbers because it is hypothetical, and would be an interesting study topic for the future. So the question to the landowner really becomes, in looking at survival rates of 49.5% in fenced plots versus hypothesized survival of 70.9% in tubed plots, would the extra 21.4% of survival be worth the additional $3,338 cost of tree tubes? To help answer this question, we can look a few years ahead and make assumptions on minimum tree spacings (Table 24) and survival rates with fence or tree tubes over the course of five years (Table 25).

There is also the question of how many trees in the planting need to reach over 2.5 cm dbh for the planting to be a success? In our case, we should assume canopy closure is desired. While it is up to the landowner to determine how much mortality he is willing to accept and on what species, we do have guidelines on spacing to follow (Table 24). In the end, the seedlings were planted at 1 m x 1 m spacing, and not all of the trees can grow to mature heights without thinning. NRCS recommends shrub and tree spacings based on species and distance within the row or between rows (Table 24). For example, cottonwoods are considered tall trees. The landowner could decide if he would like to replant trees in the future if spaces are not going to be filled in by growth of surrounding trees and shrubs.

Table 24. NRCS Specifications for Tree Plantings- Practice 380 Windbreak Establishment

Shrub/tree type	In-Row Spacing (m)	Between Row Spacing (m)*
Shrub, suckering	1.2-2.4	1.8-3.6
Shrub, non-suckering	1.2-1.8	1.8-2.7
Deciduous tree, short-medium	1.8-3.0	2.7-4.5
Deciduous tree, tall	2.4-4.3	3.6-6.5

*Between row spacing multiplied 1.5 times In-Row Spacing Distance
**Cottonwood are to be planted at least 7.6m from other trees on all sides
***Distances are slightly closer on shrub species in a block planting for wildlife

It is also unknown how well the fence will deter deer given the high deer population with an expected, but unknown, decline of efficacy over time. The level of efficacy of the electric fence deterring deer browsing, level of seedling survival, level of maintenance of the fence, and the level of upfront investment are all considerations for the landowner. We have some baseline hypothesized survival numbers for tree tubes or fence treatment. Now, if we assume that survival could continue to drop 10% each year through year five (when additional protections aren't planned because of tree height), the following survival and tree spacings are calculated (Table 24 and 25). Compare these final survival numbers at year five and note that the tubes allow for higher survival than the fence, with twice as many seedlings surviving in tubes than fence. However, looking at the adequate tree spacing, we see that there may be the need to thin trees depending on the species planted and their spacing requirements. Table 24 does provide for windbreak planting spacings, and wildlife plantings can be slightly closer to provide higher density, especially if total closed canopy is the goal. With that said, either tubes or fence provide adequate space in year 5. Tubes are still very costly compared to fence ($5,988 vs. $2,650). If the landowner wanted to increase density in the fenced plot by year 5, one strategy that he/she could use to keep using the fence is to replant trees in years 3 or 4 for $2.25 per tree (direct cost of seedling not including time spent planting). Planting an additional 100 trees during those years increasing the total project cost by $225, but would eventually increase the number of established trees. Replants as a strategy in addition to fence is still less costly than tree tubes. Replants would be placed in the gaps where trees or shrubs are needed the most. The landowner would want to do replants while the existing trees are still quite small and don't compete for resources with new seedlings.

Table 25. Proposed Decline in Survival Over Time and Effects on Tree Spacing

Year	Treatment	Survival	# Survived (of 1497)	Spacing (m)
2	Tubes	71.0%	1061	1.4
	Fence	49.5%	741	2.0
3	Tubes	60.9%	912	1.6
	Fence	39.5%	591	2.5
4	Tubes	50.9%	762	2.0
	Fence	29.5%	441	3.4
5	Tubes	40.9%	612	2.4
	Fence	19.5%	292	5.1

While costs are main considerations for many landowners in afforestation project, some may only focus on wildlife benefits and may disregard financial returns (Stanturf et al. 2001). Managers have realized that these decisions can be difficult to make, and additional research is needed to come up with cost benefit figures. Cost comparisons could be further researched using the USDA's Best Fence Selection Model (BFSM) devised to answer complex economic questions (Vercauteren et al.2006b). This model was developed using a variety of variables to calculate net present value of plantings involving vegetation, such as crops, or orchards (Vercauteren et al.2006b). Managing costs of herbivory treatment requires further research and analysis into the levels of protection needed, efficacy of those treatments in our study area, and practicality of the maintenance amongst other factors.

Conclusions

Fabric can be used to increase the height false indigo. Herbicide treatment will significantly inhibit the change in height of false indigo compared to fabric. Fabric has no significant benefits to growth of golden willow, bur oak, cottonwood, redosier dogwood or American plum, and therefore, may not be of major importance to apply to these species in terms of increasing their growth. Additional studies should be conducted on these species in areas with lower deer density because fabric mats had a higher incidence of deer browsing, possibly due to seedling apparency (Stange and Shea 1998). It is important that managers take this into account and plan for higher rates of browsing incidence when fabric is used. Also, managers should protect seedlings immediately after planting seedlings in the spring because deer have been observed browsing on seedlings immediately after they break bud.

The pre-planting herbicide treatment showed no significant difference in seedling growth after two years in most species studied. Time and money can be saved by not applying herbicide in site preparation of pastures in this area. False indigo treated with herbicide resulted in significantly less height than those treated with fabric, and more studies involving false indigo are needed to determine if it was the herbicide itself that reduced the growth, or if fabric really offered many benefits. In order to find out how fabric and herbicide are affecting survival in the presence of herbivory, we would require a larger demonstration site with additional blocks of fencing. Additional research in North Dakota is needed on what site preparation methods increase seedling growth and survival on pasture sites, and this research could include the use of a method I would like to see explored. Kentucky bluegrass dominated pastures often have a thick duff layer that is formed, and perhaps treating the pasture areas using sod cutting to remove the grasses could reduce the need for herbicide in areas where trees are planted.

Fabric should be monitored over time to ensure that openings in the fabric are not girdling the trees as they grow. There is a new fabric on the market that is biodegradable after five years of use, and said to be less likely to girdle seedlings. The wind may lift up fabric, so additional staples may need to be added to reinforce areas.

Landowners may want to consider allowing hunting as a method of herbivory management. Hunting would help balance carrying capacity and available forage on parcels where browse lines on trees are evident and seedlings are heavily browsed. If deer are browsing noticeably on trees and shrubs in established habitat, it should be expected that deer will be browsing on restoration tree plantings. If this is the case, it is important to strategize on the best methods for reducing herbivory and increasing survival. Practices that allow for increased survival and rapidly increasing height of seedlings beyond the reach of deer will likely prove to be worthwhile investments in an area with a high deer population.

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CHAPTER 4. GENERAL CONCLUSIONS

I studied the effects of herbivory and competition by vegetation on tree seedling survival and growth in two restoration demonstration sites in northeastern North Dakota. Treatments studied included two type of fencing (woven plastic mesh and electric fence), and three kinds of vegetation control (mowing, fabric, and herbicide). Both studies were in the presence of a white-tailed deer population of 23.5 deer per km^2.

The first conclusion that can be made from our studies is that herbivory by deer and cattle as an ungulate group are playing a significant role in the survival of tree seedlings in riparian areas. Given this information, it is highly recommended that land managers protect tree seedlings from ungulate herbivory. If a manager forgoes protection from herbivory in an area of high deer density, one should expect a high incidence of browsing to take place, possibly impacting seedling survival and overall growth. In our case, survival was as low as 13% in unprotected plots of the riparian study (See Chapter 1).

Fence types differ on their ability to deter deer. A tall plastic mesh fence physically excluded deer during the three years of our riparian study. The fence was so effective at deterring deer, I highly recommend it as a way to protect tree plantings. Deer could not browse within protected plots, nor could they jump into the 2.4 meter fence. One caveat of installing fencing in a riparian area is the issue of flood waters tearing down or damaging the fence. Also, beaver could be an issue if they find their way into fences. That caveat does not hold on higher sites, and it would be easier to maintain on a site on higher ground. The electric fence created a gradient of browsing because eventually some deer figured out how to enter it. Deer that are new to the fence may not penetrate it and may avoid it entirely. Baited electric fence has shown some success on reducing deer browsing, however, our study was not able to analyze this.

Further research may determine whether or not this type of fencing is practical to use as a temporary measure to protect seedlings in northeastern North Dakota.

Maintenance is a major consideration of the use of fencing as a tool to manage herbivory by ungulates. The first study's mesh and barbed wire fences sustained damages by flooding. A day or two of work with a team of three people was needed to get fences operational again. Fences need to be checked weekly to ensure they are working properly. If a solar fence charger is used on an electric fence, it should be checked regularly to make sure it is collecting energy. Deer have the ability to undermine both types of fences. Understanding the skillfulness of deer penetrating different types of fencing will help the landowner prevent breaches.

Any signs of browsing within exclosures should be an indication that deer are penetrating the fence. Mesh fence needs to be checked for holes and gaps. Mesh fence can be secured at the ground level using fabric staples. Electric fences may require an adjustment of wire spacing so that wires are closer to the ground, assuming that all weeds are well controlled as to not short out the fence.

Controlling competition from vegetation is a strategy that can be used to increase height growth for some tree and shrub species in our studies. However, we had both success and lack of success in our demonstration site studies. Mowing smooth brome and Kentucky bluegrass in riparian areas significantly increased survival of hackberry in the first study, however, treatments showed an interaction. We did not have significant results with fabric and herbicide combinations compared to the control in the second study. Herbicide significantly decreased the mean height of false indigo compared to the fabric treatment. Caution should be taken when applying herbicide near seedlings because some species could be more prone to herbicide injury.

While fabric is frequently used in the Red River Valley on tree plantings, our study did not find it to be significantly effective in increasing the height of seedlings after three years with the exception of false indigo. This result is possibly due to there not being enough moisture competition between grass and the seedlings for the fabric to mitigate. In a climate with adequate moisture, using fabric on cottonwood, plum, golden willow, or bur oak does not significantly improve height compared to not using fabric. Because of the limitations of our study, additional research would be beneficial in measuring growth, especially height. In the meantime fabric can be used for other reasons not studied in this thesis, including weed suppression, and increasing thermal temperatures of the soil environment.

While our work may confirm the utilization of tree seedlings by ungulates is detrimental to survival in year three of a riparian demonstration site, the effects of cattle by themselves was not determined due to experimental limitations of confining cattle for this purpose. Shelterbelt plantings are sometimes fenced and mob grazed in northeastern North Dakota. This concept could be a source of experimentation to explore the effects of cattle grazing on seedling survival.

Seedling survival was low in control plots of both project sites, and this warrants additional research into other factors that affect seedling establishment, growth and survival (i.e. rodent damage, drought, soil nutrients). Many seedlings were affected by rodent damage at the riparian site, and mortality by rodents should be included in future studies. Both sites had experienced livestock use throughout the years and there may be nutrient pools affecting establishment. Also invasive grasses may have altered underground processes to an extent where tree survival is severely hindered due to changes in soil fauna. Last, but not least, another area to explore is the timing of grazing riparian woodlands in N.D. and the effects on seedling survival and growth. All of these areas would be of great interest to explore further.

Landowners experiencing high levels of herbivory on seedlings and forbs should consider how they are managing both their livestock and wildlife on their property. As our study shows, landowners may find it difficult to maintain or restore habitat using tree seedlings with too many ungulates present. Landowners who graze cattle in areas with abundant deer have the option to change their carrying capacity, timing of grazing, and possibly implement exclusion areas around tree plantings to increase success.

Landowners that find the need to reduce the deer population may find it beneficial to encourage hunting on their land at some point in the deer season. If hunting is used as a control method, hunters should be encouraged to apply for antlerless deer in the Devils Lake management unit, which historically has a very low incidence of doe tags being sought after by hunters. Working with the North Dakota Game and Fish Department would be a good place for landowners to begin for information regarding wildlife management on private land. Land closed to deer hunting in areas where deer are plentiful can create challenges for seedling survival because deer are utilizing seedlings at some level of herbivory, and thus habitat restoration becomes a challenge when herbivory interferes with establishment. Carrying capacity for deer should be researched on these land uses because deer can negatively impact seedling survival, and possibly contribute to the lack of regeneration. Landowners can monitor browse lines, seedling mortality and crop damage to determine if management should be evaluated. It is very important that landowners continue to responsibly manage and restore North Dakota's riparian areas because deer and other wildlife species in northeastern North Dakota rely on forested areas as critical habitat.