EFFECTS OF GRAZING OF REED CANARYGRASS (*PHALARIS ARUNDINACEA*) IN RESTORED WET MEADOWS IN THE NORTHERN TALL GRASS PRAIRIE

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

MASTER OF SCIENCE

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ABSTRACT

Reed canarygrass (*Phalaris arundinacea*) is a grass species that can dominate wet meadow plant communities. This study investigated if grazing by cattle on restored wet meadows suppresses reed canarygrass, thereby promoting the restored plant community. This study was conducted at two locations in northwest Minnesota. Management practices used were a patch-burn grazing treatment and a four-pasture high intensity-short duration grazing rotation. A pretreatment survey was conducted before grazing followed by annual surveys every five years after grazing. Both treatments reduced reed canarygrass canopy cover by 49 percent compared to non-grazed control sites. Grazed patches were moving towards a *Carex* dominated community. The community not invaded with reed canarygrass had similar native species richness at the end of the experiment in the rotational grazing treatment, and improved plant richness in the patch-burn grazing treatment. This study demonstrates grazing reduces cover of reed canarygrass, while maintaining or increasing native plant species richness.

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INTRODUCTION

Invasive plants in wetland restorations are a common problem and affect the success of restoration. Reed canarygrass (*Phalaris arundinacea*) is a prolific invader that can easily spread throughout wetlands and create monospecific stands (Lavergne and Molofsky 2004, Adams and Galatowitsch 2005). These stands of pure reed canarygrass are undesirable due to low plant diversity (Kercher et al. 2004), creating less desirable habitat and forage for wildlife (Kirsch et al. 2007, Evans-Peters et al. 2012).

Many methods have been used to varying degrees of success to reduce the invasion of reed canarygrass. Herbicide application of glyphosate and willow plantings on reed canarygrass invaded sites have been shown to be marginal to ineffective at controlling its spread (Adams and Galatowitsch 2005, Kim et al. 2006). Fertilizing with nitrate wasn't effective at reducing reed canarygrass canopy cover (Green and Galatowitsch 2002). Grazing has been shown to be ineffective on controlling reed canarygrass expansion while burning has been ineffective in wet meadow environments (Adams and Galatowitsch 2006, Kim et al. 2006, Hillhouse et al. 2010).

The goal of this study was to investigate if grazing cattle could be an effective practice for reducing the canopy cover of reed canarygrass in two restored wetland complexes in western Minnesota. Our wetland complexes included northern wet prairie, prairie mixed-cattail marsh, and prairie wet meadow/sedges; while the uplands included northern dry prairie and northern mesic prairie (MN DNR 2019). The hypothesis is that grazing will be effective at reducing reed canarygrass canopy cover because cattle defoliate the plant, suppressing flower development and reducing or eliminating seed production and spread. Reed canarygrass is a palatable grass with high crude protein and low content of alkaloids, creating a desirable feed for livestock (Vetsch et al. 1999). When reed canarygrass is grazed the plant does not create monoculture stands (Paine and Ribic 2002, Kidd and Yeakley 2015, James et al. 2017).

Two grazing treatments were studied in this project. The first treatment used targeted grazing with a high stock density of cattle using a short grazing duration (seven days or less). Cattle were rotated through four paddocks three times (spring, early summer and fall). This treatment design is similar to previous studies by Oates et al. (2011), Rinella and Bellows (2016), and James et al. (2017). These previous research studies showed a decrease in invasive plant abundance and increase in native species richness from targeted grazing.

The second treatment used patch-burn grazing. This treatment used one large pasture, grazed season-long with cattle, with portions burned periodically. Biondini et al. (1999) showed bison selectively grazed new burned sites over unburned and previously burned. Diamond et al. (2012) showed combining grazing and burning reduced the abundance of invasive species from the dominate species to a component of the plant community. While this study is not designed to reduce reed canarygrass with burning alone, which Lavergne and Molofsky (2006) showed to be ineffective, it is believed burning paired with grazing may enhance reed canarygrass suppression compared to burning alone. We predict the grazing in both approaches will reduce canopy cover of reed canarygrass.

Our second hypothesis is if reed canarygrass is reduced, the plant communities will change to a more diverse community. While much research has been conducted on reed canarygrass and grazing practices (patch-burn, targeted, rotational) only a few studies address controlling reed canarygrass on restored wet meadows (Green and Galatowitsch 2002, Adams and Galatowitsch 2005, Adams and Galatowitsch 2006). No studies have looked at both targeted rotational and patch-burn grazing as control methods for reed canarygrass on restored wet meadows.

The study objectives include:

1) Determine the effects of targeted rotational and patch-burn grazing on reed canarygrass cover in restored wetland complexes.
2) Determine the effects of targeted rotational and patch-burn grazing on the wetland and upland plant communities in the restored wetland complexes.
3) Determine if the reduction of reed canarygrass through targeted rotational and patch-burn grazing will effect native plant richness in the restored wetland complexes.

CHAPTER 1. LITERATURE REVIEW

Reed canarygrass is a native to Asia, Europe, and North America, but is considered invasive in the US (Cronquist et al. 1977). It has become invasive in the US due to hybridization with other genotypes (Merigliano and Lesica 1998, Galatowitsch et al. 1999, Kim et al. 2006). Wet meadow environments within wetlands are especially subject to invasion by reed canarygrass. Reed canarygrass is a prolific invader in wetlands found across the prairie landscape and creates monoculture stands that can dominate wet meadow zones (Adams and Galatowitsch 2005).

Adams and Galatowitsch (2005) showed after establishing aboveground biomass, reed canarygrass quickly spreads through its belowground root system. Reed canarygrass invasiveness is due to its hybrid nature, allowing it withstand multiple disturbance events and hydrologic changes - such as a change in environmental conditions created by beaver engineering in riparian zones (Galatowitsch et al. 1999, Lavergne and Molofsky 2004, Perkins and Wilson 2005). Lord (2015) also found reed canarygrass grows and expands on non-farmed lands because of its abilities to establish before natives and its rapid growth.

Reed canarygrass has been used as a forage source for livestock, fuel, and environmental plantings to treat wastewater and control erosion. These anthropogenic uses have led to the spread of reed canarygrass across landscapes (Galatowitsch et al. 1999, Green et al. 2002, Kercher and Zedler 2004, Adams and Galatowitsch 2005, Kim et al. 2006, Kidd and Yeakley 2015). Reed canarygrass can also exist and thrive in a variety of growing conditions such as increased nitrate (N) in the soil, high amounts of soil organic matter, flooding conditions, shade, and heavy soil disturbance (Green and Galatowitsch 2002, Kellogg et al. 2003, Kercher and Zedler 2004). This grass is also tolerant to fluctuating water levels (Galatowitsch et al. 2000).

These earlier studies demonstrate how adaptable and invasive reed canarygrass is at invading wetlands, and why reed canarygrass has become such a management problem for wetlands and riparian zones in the Northern Great Plains.

Wetlands are an important ecological site preforming a wide array of function such as livestock and wildlife forage and habitat, water quality improvement/maintenance, ground water recharge, and flood control (Burbridge1994, Keddy 2000, Richardson and Vepraskas 2001, Kirby et al. 2002a & 2002b, Paradeis et al. 2010). Wetlands are invaded by undesirable plants and these invasions limit the function the wetlands due to poor hydrologic and biotic function that naturally occur in a native plant species environment (Galatowitsch et al. 1999). These invasions of undesirable plants need be controlled or minimized to maintain effective functioning in wetlands.

Reed canarygrass has negative effects on multiple organisms such as lowering *Homopteran* abundance and diversity, less mice populations, lower plant diversity, and lower floristic quality (Spyreas et al. 2010). Swamp sparrows avoid areas of high reed canarygrass cover (Kirsch et al. 2007).

Natural occurrences, such as floods, can open wetlands to invasion of reed canarygrass. Storm water rich in sediment can make native vegetation more susceptible to invasion by changing microtopography, species richness, and native canopy cover by increasing nutrients desired by reed canarygrass (Maurer et al. 2003).

Sheaffer et al. (1990) found that reed canarygrass has high forage nutrient quality. Kidd and Yeakley (2015) found grazed wet meadow areas have higher native species richness than areas that were non-grazed. They showed a 40 percent reduction of reed canarygrass on grazed areas compared to non-grazed area. One study that grazed goats using a rotational grazing treatment to control common reed (*Phragmites australis*) reduced canopy cover from 100 percent to 20 percent. Cows and horses also prefer and consume common reed (Silliman et al. 2014). Since reed canarygrass has a similar or higher palatability than common reed, the grazing selection of common reed and subsequent reduction in the plant community suggests grazing reed canarygrass could be an effective means of controlling invasion in wetlands.

Targeted grazing is a form of control used for negatively impacting invasive species (Rinella and Bellows 2016). Tohiran et al. (2017) showed that bird abundance was higher in pastures that had target grazing for weed control, demonstrating the effectiveness of targeted grazing to benefit wildlife. In Nevada, targeted cattle grazing and prescribed fire not only shifted downy brome (*Bromus tectorum*) from a dominant to non-dominate plant species, but also lowered its abundance in the seed bank (Diamond et al. 2012). In California, targeted grazing was used to reduce medusahead (*Taeniatherum caput-medusae*) abundance and increase native plant abundance using a high stock density with shorter grazing durations (James et al. 2017).

Targeted grazing using a rotational grazing system has led to other positive effects on the landscape. Rotational grazing consists of putting a certain number of livestock in one pasture of cell, moving them to a new pasture or cell after a set number of days or desired grazing use (Frost et al. 2012, Tohiran et al. 2017). Cattle grazing on pastures have been shown to positively affect grassland bird species by creating a diversity of habitats at the landscape level (Ahlering and Merkord 2016). Oates et al. (2011) showed rotational grazing improves forage production and quality, but not root production. Rotational and continuous grazing was applied to wet meadow pastures in Wisconsin and negatively impacted reed canarygrass to the point of being rare in the grazed pastures (Paine and Ribic 2002). Paine and Ribic (2002) also claim that rotationally grazing pastures are an alternative to buffer strips. Hillhouse et al. (2010)

investigated one-time spring grazing on the vegetation of reed canarygrass invaded wetlands and found grazing did not reduce reed canarygrass abundance but reduced litter, increased bare ground, and did not change the species richness. These studies demonstrate that grazing, specifically rotational grazing may have effects towards managing reed canarygrass.

Proper functioning native plant communities are less prone to reed canarygrass invasion. Restoration of native species structure and composition is important in preventing new invasions of reed canarygrass (Lavergne and Molofsky 2006). Sedges (*Carex spp.*) are native wetland vegetation that, while slow to recolonize on a disturbed area, in becoming dominant can prevent invasion from reed canarygrass (Kettenring and Galatowitsch 2007). An innovative method for controlling reed canarygrass is to use willow stakes on sloped wetland edges (Kim et al. 2006). They found willows planted 0.75 to one meter apart can reduce reed canarygrass aboveground biomass after two consecutive growing seasons by 56 to 68 percent.

Herbicide is a chemical treatment measure for controlling reed canarygrass. Treating reed canarygrass every year with glyphosate herbicide is cost-effective for re-establishment of native trees in riparian zones (Miller et al. 2008). Adams and Galatowitsch (2006) also found that late season (Aug-Sept.) glyphosate application was more successful in controlling reed canarygrass then early (mid-May) application. Time of spraying is important when using chemical control methods. A properly managed restoration has the ability to increase wetland plant composition and quality. Time and sustained management will improve restoration (Paradeis et al. 2010). Paradies et al. (2010) showed recovery from invasion is possible with the right formula of management and time.

While much research has been conducted on reed canarygrass and grazing practices (patch-burn, targeted, rotational) only a small number of publications address controlling reed canarygrass on restored wet meadows (Adams and Galatowitsch 2005, Adams and Galatowitsch 2006). Adams and Galatowitsch (2006) found burning lowered the seedbank of reed canarygrass and late summer/early fall (August/September) spraying of glyphosate was effective at reducing reed canarygrass biomass. Adams and Galatowitsch (2005) showed reed canarygrass establishes aboveground biomass early than native plant species and spreads below ground, ensuring its place on the landscape. The knowledge of targeted rotational and patch-burn grazing on restored wet meadows has yet to be explored as an alternative to controlling reed canarygrass spread.

Burning has been studied as a control method for reducing reed canarygrass. Burning has been shown to control other invasive species such as smooth brome (*Bromus inermis*) decreasing plant abundance (Diamon et al. 2012). Adams and Galatowitsch (2006) found burning areas invaded with reed canarygrass reduced the seed bank of this grass but not biomass. Roy et al. (2014) found burning had a positive effect on native plants because it lowers competition with invasive plants and native pathogens. Foster and Wetzel (2005) reported burning had no effect on root and shoot biomass, or cover of reed canarygrass. Burning when paired with another control method such as grazing has potential to be an effective control method for reed canarygrass invasions.

Matthews et al. (2009) reported wetland restoration research shows restorations are quickly reaching reference state but then declining. Matthews et al. (2009) also reported the current “simple, rapid, and predictable trajectories” currently used by people conducting restorations is not realistic. Strehlow et al. (2017) points out that understanding the seed bank in restorations is advantageous, allowing for better identification of native species that are lacking and identify potential invasive species. This will allow more realistic and obtainable goals.

Mulhouse and Galatowitsch (2003) point out that restoring wetlands with native vegetation is ineffective after investigating 64 wetlands across the Midwest. Forty-one of these wetlands had reed canarygrass present, with many having 75-100% reed canarygrass cover. This demonstrates that not all restorations are successful. Salaria et al. (2018) found restored wetlands have low species richness and showed early establishment of invader plant species along with a depleted native plant seed bank is the probable cause for restoration failure. Paradeis et al. (2010) reported when properly managed, prescribed fire and rotational grazing were successful methods for wetland restoration and restoring native plant communities.

Literature cited

Adams, C.R. and S.M. Galatowitsch. 2005. Phalaris arundinacea (Reed canarygrass): Rapid Growth and Growth Pattern in Conditions Approximating Newly Restored Wetlands. Ecoscience 12(4):569-573.

Adams, C.R. and S.M. Galatowitsch. 2006. Increasing the Effectiveness of Reed canarygrass (*Phalaris arundinacea* L.) Control in Wet Meadow Restorations. Restoration Ecology 14:441-451.

Ahlering, M.A. and C.L. Merkord. 2016. Cattle Grazing and Grassland Birds in the Northern Tallgrass Prairie. The Journal of Wildlife Management 80(4):643–654.

Burbridge, P.R. 1994. Integrated Planning and Management of Freshwater Habitats, Including Wetlands. Hydrobiologia 285:311-322.

Cronquist A., A.H. Holmgren, N.H. Holmgren, J.L. Reveal, P.K. Holmgren. 1977. Intermountain Flora: Vascular Plants of the Intermountain West, U.S.A. The Monocotyledons 6:584.

Diamond, J.M., C.A. Call, and N. Devoe. 2012. Effects of Targeted Grazing and Prescribed Burning on Community and Seed Dynamics of a Downy Brome (Bromus tectorum)-Dominated Landscape. Invasive Plant Science and Management 5(2):259-269.

Foster, R.D. and P.R. Wetzel. 2005. Invading Monotypic Stands of Phalaris arundinacea: A Test of Fire, Herbicide, and Woody Herbaceous Native Plant Groups. Restoration Ecology 13(2):318-324.

Frost R, J. Walker, C. Madsen, R. Holes, J. Lehfeldt, J. Cunningham, K. Voth, B. Welling, T. Z. Davis, D. Bradford, J. Malot and J. Sullivan. 2012. Targeted Grazing: Applying the Research to the Land. Rangelands 34:2–10.

Galatowitsch, S.M., N.O. Anderson, and P.D. Ascher. 1999. Invasiveness in Wetland Plants in Temperate North America. Wetlands 19(4):733-755.

Galatowitsch, S.M., D.C. Whited, R. Lehtinen, J. Husveth, and K. Schik. 2000. The Vegetation of Wet Meadows in Relation to their Land-Use. Environmental Monitoring and Assessment 60:121-144.

Green, E.K. and S.M. Galatowitsch. 2002. Effects of *Phalaris arundinacea* and Nitrate-N Addition on the Establishment of Wetland Plant Communities. Journal of Applied Ecology 39:134-144.

Hillhouse, H.L., S.J. Tunnell, and J. Stubbendieck. 2010. Spring Grazing Impacts on the Vegetation of Reed Canarygrass-Invaded Wetlands. Rangeland Ecology and Management 63:581-587.

James, J.J., J. Davy, M.P. Doran, T. Becchetti, P. Brownsey, and E.A. Laca. 2017. Targeted Grazing Impacts on Invasive and Native Plant Abundance Change with Grazing Duration and Stocking Density. Rangeland Ecology and Management 70(4):465-468.

Keddy, P.A. 2000. Wetland Ecology: Principles and Conservation. Cambridge University Press, Cambridge, U.K.

Kellogg, C.H., S.D. Bridgham, and S.A. Leicht. 2003. Effects of Water Level, Shade and Time on Germination and Growth of Freshwater Marsh Plants along a Simulated Successional Gradient. Journal of Ecology 91:274-282.

Kettenring, K.M. and S.M. Galatowitsch. 2007. Tools for Carex Revegetation in Freshwater Wetlands: Understanding Dormancy Loss and Germination Temperature Requirements. Plant Ecology 193:157-169.

Kercher, S.M., Q.J. Carpenter, and J.B. Zedler. 2004. Interrelationships of Hydrologic Disturbance, Reed Canarygrass (Phalaris arundinacea L.), and Native Plants in Wisconsin Wet Meadows. Natural Areas Journal 24(4):316-325.

Kidd, S.A. and J.A. Yeakley. 2015. Riparian Wetland Plant Response to Livestock Exclusion in the Lower Columbia River Basin. Natural Areas Journal 35(4):504-514.

Kim, K.D., K. Ewing, and D.E. Giblin. 2006. Controlling *Phalaris arundinacea* (Reed Canarygrass) with Live Willow Stakes: A Density-Dependent Response. Ecological Engineering 27:219-227.

Kirby, D.R., K.D. Krabbenhoft, K.K. Sedivec, and E.S. DeKeyser. 2002a. Wetlands in Northern Plains Prairies: Benefiting Wildlife and Livestock. Rangelands 24:22-25.

Kirby, D.R. K.D. Krabbenhoft, K.K. Sedivec, and E.S. DeKeyser. 2002b. Wetlands in Northern Plains Prairies: Offer Societal Values too. Rangelands 24:26-29.

Kirsch, E.M., B.R. Gray, T.J. Fox, and W.E. Thogmartin. 2007. Breeding Bird Territory Placement in Riparian Wet Meadows in Relation to Invasive Reed Canarygrass, Phalaris arundinacea. Wetlands 27:644-655.

Lavergne, S. and J. Molofsky. 2004. Reed Canarygrass (Phalaris arundinacea) as a Biological Model in the Study of Plant Invasions. Critical Reviews in Plant Sciences 23(5):415-429.

Lavergne, S. and J. Molofsky. 2006. Control Strategies for the Invasive Reed Canarygrass (Phalaris arundinacea L.) in North American Wetlands: the Need for an Integrated Management Plan. Natural Areas Journal 26(2):208-214.

Lord R.A. 2015. Reed Canarygrass (Phalaris arundinacea) Outperforms Miscanthus or Willow on Marginal Soils, Brownfield and Non-Agricultural Sites for Local, Sustainable Energy Crop Production. Biomass and Bioenergy 78:110-125.

Matthews, J.W., G. Spyreas, and A.G. Endress. 2009. Trajectories of Vegetation-Based Indicators Used to Asses Wetland Restoration Progress. Ecological Applications 19(8):2093-2107.

Maurer, D.A., R. Lindig-Cisneros, K.J. Werner, S. Kercher, R. Miller, and J.B. Zedler. 2003. The Replacement of Wetland Vegetation by Reed Canarygrass (Phalaris arundinacea). Ecological Restoration 21(2):116-119.

Merigliano, M.F., P. Lesica. 1998. The Native Status of Reed Canarygrass (Phlaris arundinacea L.) in the Inland Northwest, USA. Natural Areas Journal 18:223-230.

Miller, T.W., L.P. Martin, and C.B. MacConnell. 2008. Managing Reed Canarygrass (Phalaris arundinacea) to Aid in Revegetation of Riparian Buffers. Weed Technology 22(3):507-513.

Mulhouse, J.M. and S.M. Galatowitsch. 2003. Revegetation of Prairie Pothole Wetlands in the Mid-Continental US: Twelve Years Post-Reflooding. Plant Ecology 169:143-159.

Oates, L.G., D.J. Undersander, C. Gratton, M.M. Bell, and R.D. Jackson. 2011. Management-Intensive Rotational Grazing Enhances Forage Production and Quality of Subhumid Cool-Season Pastures. Crop Science 51:892-901.

Paine, L.K. and C.A. Ribic. 2002. Comparison of Riparian Plant Communities Under Four Land Management Systems in Southwestern Wisconsin. Agriculture, Ecosystems and Environment 92:93-105.

Paradeis, B.L., E.S. DeKeyser, and D.R. Kirby. 2010. Evaluation of Restored and Native Prairie Pothole Region Plant Communities Following an Environmental Gradient. Natural Areas Journal 30(3):294-304.

Perkins, T.E. and M.V. Wilson. 2005. The Impacts of Phalaris arundinacea (Reed Canarygrass) Invasion on Wetland Plant Richness in the Oregon Coast Range, USA Depend on Beavers. Biological Conservation. 124:291–295.

Richardson, J.L. and M.J. Vepraskas. 2001. Wetland Soils: Genesis, Hydrology, Land-Scapes, and Classification. Lewis Publishers, Boca Raton, Fla.

Rinella, M.J. and S.E. Bellows. 2016. Evidence-Targeted Grazing Benefits to Invaded Rangelands Can Increase over Extended Time Frames. Rangeland Ecology and Management. 69(3):169-172.

Roy, B.A., K. Hudson, M. Visser, and B.R. Johnson. 2014. Grassland Fires may Favor Native over Introduced Plants by Reducing Pathogen Loads. Ecology 95(7):1897-1906.

Salaria, S., R. Howard, S. Clare, and I.F. Creed. 2018. Incomplete Recovery of Plant Diversity in Restored Prairie Wetlands on Agricultural Landscapes. Restoration Ecology 0(0):1-11.

Sheaffer, C.C., G.C. Marten, D.L. Rabas, N.P. Martin, and D.W. Miller. 1990. Reed canarygrass. Station Bulletin 595-1990 (Item No. AD-SB-5533) Minnesota Agricultural Experiment Station University of Minnesota, St. Paul, Minnesota.

Silliman, B.R., T. Mozdzer, C. Angelini, J.E. Brundage, P. Esselink, J.P. Bakker, K.B. Gedan, J. van de Koppel, and A.H. Baldwin. 2014. Livestock as a Potential Biological Control Agent for an Invasive Wetland Plant. PeerJ (2)567 DOI 10.7717/peerj.567.

Spyreas, G., B.W. Wilm, A.E. Plocher, D.M. Ketzner, J.W. Matthews, J.L. Ellis, and E. J. Heske. 2010. Biological Consequences of Invasion by Reed Canarygrass (Phalaris arundinacea). Biological Invasions 12:1253–1267.

Strehlow, T., S. DeKeyser, and B. Kobiela. 2017. Managing Seedbank Composition to Enhance Wetland Restoration. Ecological Restoration 35(1):12-16.

Tohiran, K.A., F. Nobilly, R. Zulkifli, T. Maxwell, R. Moslim, and B. Azhar. 2017. Targeted Cattle Grazing as an Alternative to Herbicides for Controlling Weeds in Bird-Friendly Oil Palm Plantations. Agronomy for Sustainable Development 37:62 https://doi.org/10.1007/s13593-017-0471-5.

CHAPTER 2. IMPACTS OF TARGETED AND PATCH-BURN GRAZING ON REED CANARYGRASS INVADED RESTORED WET MEADOWS

Study site

This experiment was conducted at two study sites, the Brantner and Williams site, each located near Glyndon, MN in Clay County (Figure 1). The sites were located in the north-eastern region of the Tallgrass Prairie. The northern Tallgrass Prairie is characterized by deep, fertile soils and plants that grow one to two meters tall and found in western MN, western IA, and eastern North and South Dakota (USDI, US Fish and Wildlife Service 2019).

According to the USDA National Resources Conservation Service (2006), both sites are found in Major Land Resource Area 56 - Red River Valley of the North. The geology of the area is mainly gravel beaches resistant to erosion and dunes where sand has built up. The land ownership is 79 percent private and predominantly use farmland with mollisols and vertisols as the dominant soil types (USDA, Natural Resources Conservation Service 2006).

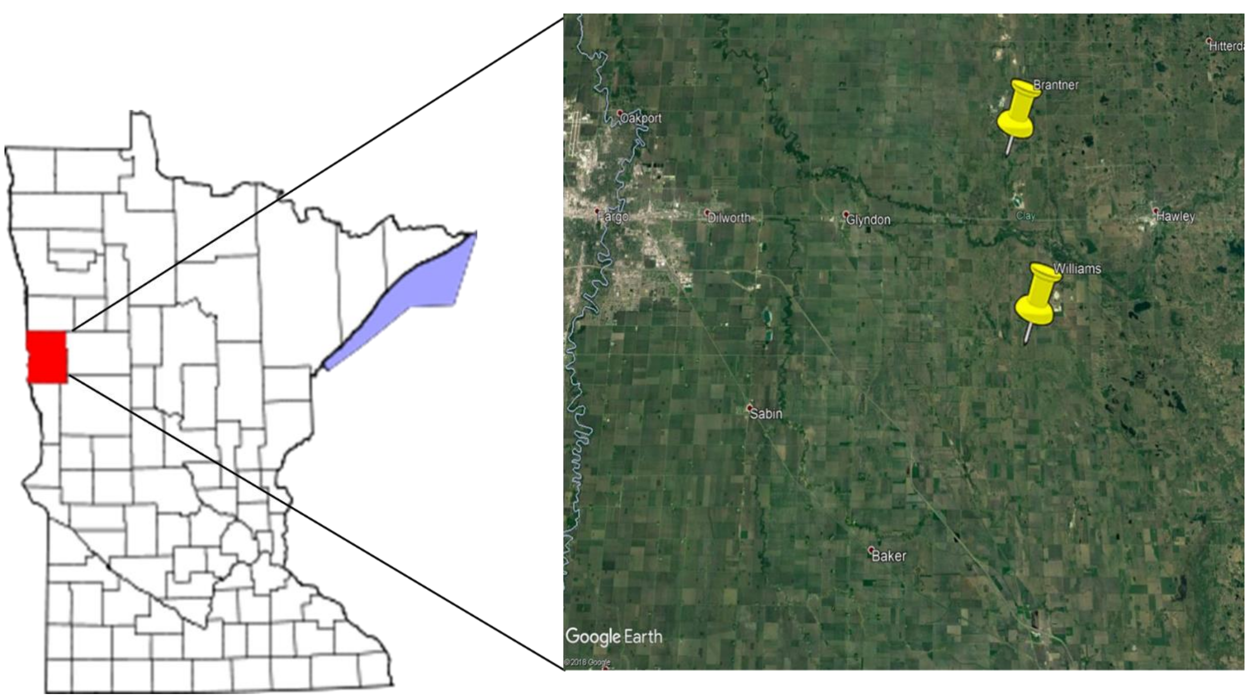


Figure 1. Location of the Brantner and Williams study sites in Clay County, MN, and in relation to Fargo, ND.

Brantner site

The Brantner study site was a restored wetland complex that was mowed, burned then reseeded using the Minnesota Board of Water and Soil Resources (BWSR) approved mesic prairie and wetland fringe seed mixes (Personal Communication, Lynn Foss). The Brantner site (latitude 46°54'33.70"N and longitude 96°26'8.83"W) is managed by a private landowner and part of the BWSR wetland bank (Figure 2). The site is 36 ha in size. The soils are typically poorly drained loams with fine texture and classified as mollisols (USDA, Natural Resource Conservation Service 2006). The native plant communities in the region are dominated by tallgrasses such as prairie cordgrass (*Spartina pectinata*), big bluestem (*Andropogon gerardii*), tufted hair grass (*Deschampsia cespitosa*), slimstem reedgrass (*Calamagrostis stricta*) and prairie dropseed (*Sporobolus heterolepis*); as well as mountain rush (*Juncus arcticus*) and Buxbaum's sedge (*Carex buxbaumii*). Canada goldenrod (*Solidago canadensis*) and giant sunflower (*Helianthus giganteus*) are the most common forbs (MNDNR 2019). All taxonomic plant names follow the USDA, Natural Resource Conservation Service (2019) plants database.

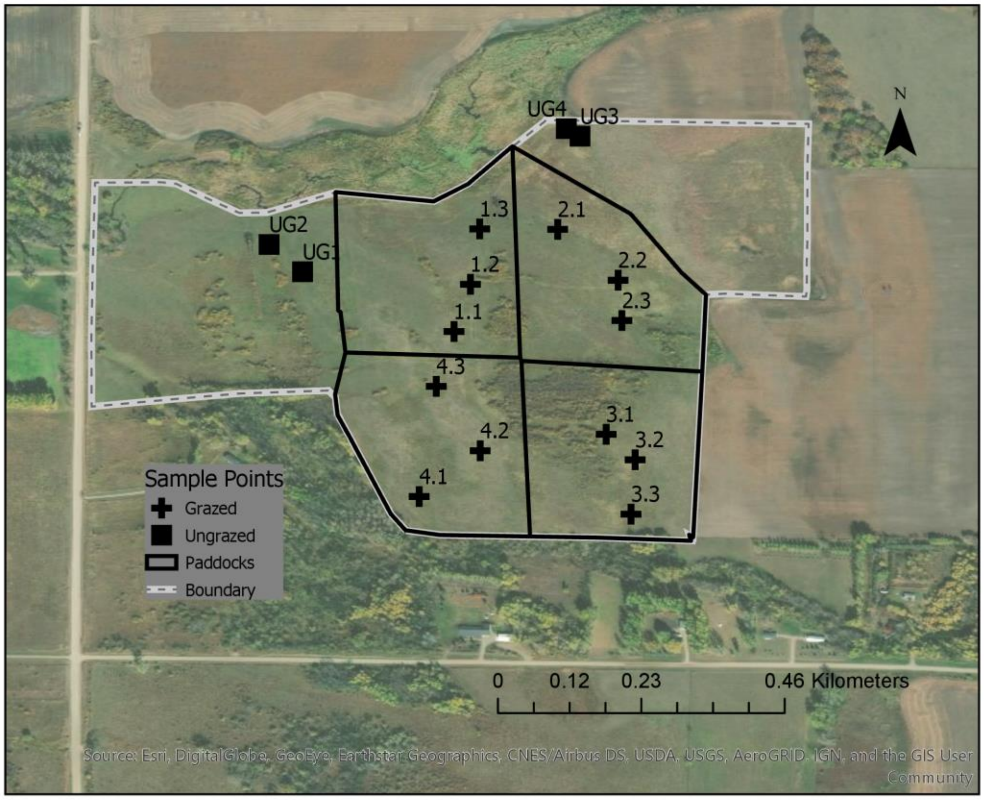


Figure 2. The Brantner site showing the boundary, paddock fences, and labeled sample points. The UG label represents ungrazed exclosures. The first number of the sample point labels denotes the paddock while he number after the decimal is the point ID.

The restoration of the Brantner site began in 2003 with the restoration of a 22 ha wetland complex. It was previously used as pasture, then cropped, and then placed into the Conservation Reserve Program (CRP). Ditch plugs were used to reestablish wetland hydrology. The site was sprayed with glyphosate at the recommended rate provided on the label in August 2003, and burn with a prescribed fire to prepare the soils for restoration. The site was seeded using a grass drill in October 2003. The mesic prairie seed mix #3 was used on the six hectare upland prairie area and the wetland fringe mix #1 on the 11 ha wet meadow area with seed mix names being assigned by BWSR (Appendix A). Areas with minor erosion were repaired, reseeded and vegetation mowed.

Williams site

The Williams site is managed by The Nature Conservancy (TNC) and is part of the Bluestem Prairie Scientific and Natural Area. The site is 534 ha in size and located at latitude 46°48'41.46"N, longitude 96°25'48.87"W (Figure 3). The Nature Conservancy acquired the site in 2005 and began restorations in 2008, completing the first phase of the restoration in 2010. A perimeter fence was established on the site in 2011 and 2012, and a patch-burn grazing program implemented.

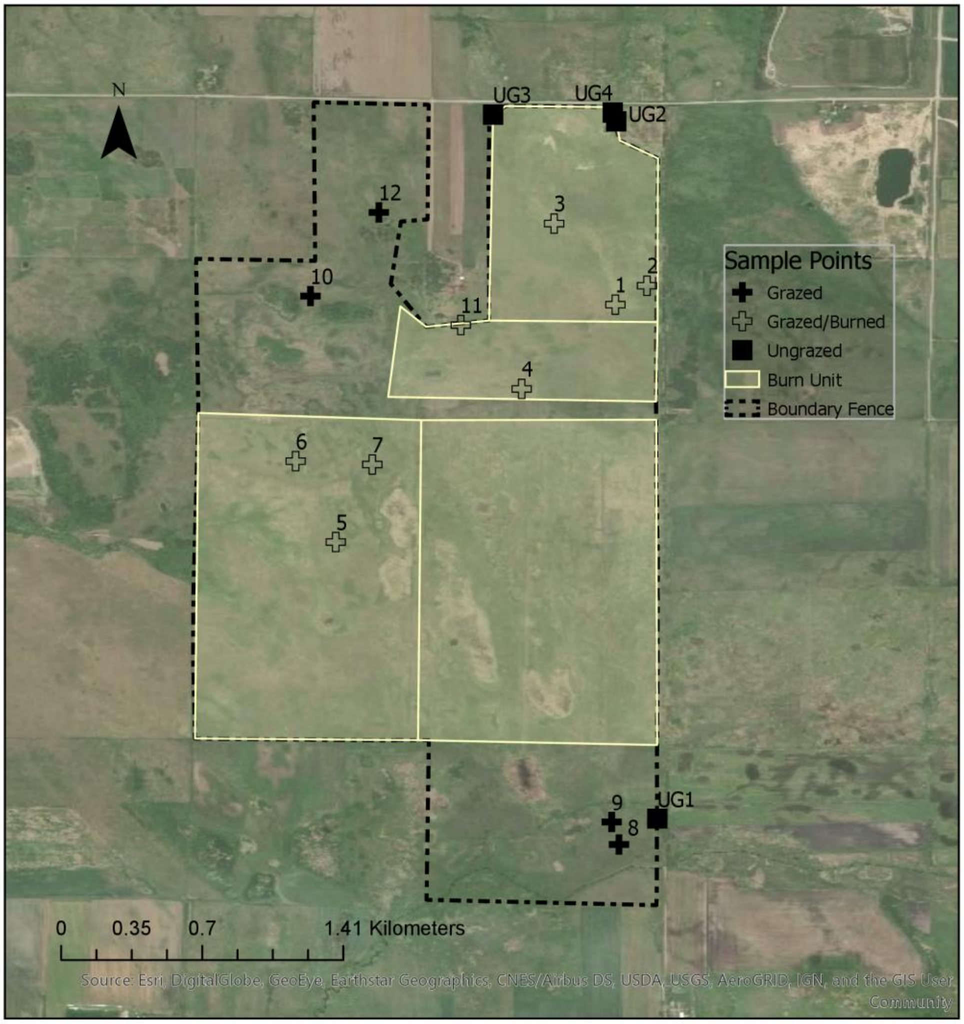


Figure 3. The Williams site showing the sample points, boundary fence, and the burn units that were burned during the study. The UG label is the ungrazed exclosures. The clear crosses denote points that were both grazed and burned while the filled black crosses denote points that were just grazed.

Upland soils were highly permeable sands, loamy sands, poor to well drained, moderately permeable to permeable, to fine and medium textured loams (USDA, Natural Resource Conservation Service 2006, MNDNR 2019). The wetland soils ranged from inundated shallow basins and classified as mollisols. Native plant communities are tallgrasses and sedges with rushes in flooded areas (see plant list for Brantner site) (MNDNR 2019).

The TNC directed the restoration using a local contractor, Prairie Restoration Inc., who provided locally sourced seed. The restoration began with spraying glyphosate and clopyralid herbicides at the recommended rate provided on the label in July 2008, June 2009 and June 2010. The site was seeded in 2008, July and August 2009, and July 2010. The seed used was harvested directly from several local native prairie sites and broadcasted over the site as a bulk seed. The 2008 bulk seed mix was made up of 39 percent big bluestem and 4.1 percent Indiangrass (*Sorghastrum nutans*). Other species seeded including two invasive grasses (*Poa pratensis* and *Bromus* spp.) and nine native grasses at 5.8 percent, and three percent native forb species. The remaining 48.1 percent was inert matter (Appendix B). Snow seeding of the bulk seed collected during the fall of 2010 was conducted in March 2011, with big bluestem at 20 percent, Indiangrass 19 percent, leadplant (*Amorpha canescens*) 8.2 percent, and prairie dropseed (*Sporobolus heterolepis*) 5.4 percent of the mix. Five percent of the seed mixture contained 12 native and one non-native grasses, and one percent forb species. The remaining 42.4 percent was inert matter (Appendix B).

Areas seeded in 2009 and 2010 were clipped for weed control. Bird's-foot trefoil (*Lotus corniculatus*), and invasive legume, was sprayed on the previously seeded areas with aminopyralid at the recommended rate provided on the label in 2010. In September 2011, 21 ha of the site was mowed and 40 ha invaded with bird's-foot trefoil sprayed using aminopyralid at the recommended rate provided on the label. The restoration project restored 476 ha upland prairie and 40 ha of wetlands.

Study treatments

This study used two different grazing practices, 1) targeted rotational grazing (TRG) using a high stock density of cattle for short periods (seven days) and 2) patch-burn grazing (PBG). The Brantner site used the TRG within a four paddock system. The four-pasture rotation occurred when reed canarygrass was vigorously growing and designed to rotate twice through in late May through July, and then a single rotation in the fall starting in late August. The cattle were kept in other pastures on the site when not used in the rotations. Each of the four paddocks was considered replicates and approximately six hectares each. A herd of 25 to 30 cross-bred cattle with calves was used to graze the TRG.

The TRG was designed to start in 2011 and end in 2019. Due to unforeseen watering problems, the cows were not properly rotated and a more continuous grazing regime was used to accommodate the watering issues. When the watering system did not work there was only one watering source, a perennial stream a short distance to the west of the four paddocks. During these times all the gates to each paddock were open so the cattle could move freely through each paddock. This resulted in a moderately grazed unit (Jeff Duchene, regional range specialist, NRCS, personal communication). Approximately half the time the watering system did not work while the other times the TRG was utilized.

Four locations were selected outside the four paddocks and used as non-grazed controls. These sites were fenced creating an exclosure measuring 10 x 10 m. In the areas around the grazing exclosure cattle were allowed to graze at different times. The non-grazed locations were dispersed over the site to decrease the chance they were subject to conditions that would invalidate them as controls.

The Williams site had the PBG installed with season-long grazing every year and a burn conducted every year at a return interval of six years (Figure 3). The Williams site was one 485 hectare paddock. Not all sampling points had a burn occur at their location by the end of the study in 2017. An average, 578 AUMs were grazed on the site for four to five months per year. This stock density resulted in the site being lightly to moderately grazed over the time of the study (Jeff Duchene, regional range specialist, NRCS, personal communication). Because watering locations were not uniformly distributed, certain areas had less cattle use than others - though the intent of PBG is to attract cattle to sites away from watering locations so they get use for a year or two after a burn. Four non-grazed locations were selected on similar soils and plant communities and used as controls. These locations were areas with fencing built in 2011 that contain reed canarygrass patches. The non-grazed locations were dispersed over the site to decrease the chance they were subject to conditions that would invalidate them as controls. The burning resulted in 50 percent of points being burned once. Approximately 50 percent of study site was burned at least once.

Methods

The Brantner site had three randomly selected sampling points within each of the four paddocks. This resulted in a total of 12 points assessed along with four non-grazed control plots. The Williams site had 12 points randomly located in the fenced paddock. If a random point did not fall within a reed canarygrass patch, the point was moved to the closest patch. A Global Navigation Satellite System receiver was used to navigate to the sampling points and again over the different sampling periods. At each sampling point, three $1m^2$ quadrats were arranged in a triangle one meter from the sample point (Figure 4). In each quadrat the canopy cover of all species was estimated to the nearest percent (Daubenmire 1959). The cover of bare ground and litter were also recorded. Canopy cover estimation was determined by the same observer to maintain consistency over time. A 4 m^2 plot (2 x 2m) was arranged around the sampling point and three quadrats to identify additional plant species. Plants not present in the quadrats were recorded if found within the 4m^2 plot. The additional species within the 4m^2 plot were given a 0.5% canopy cover in the analysis.

A second sampling point was located outside the reed canarygrass patch at 25m to the west from the reed canarygrass sampling point (Figure 4). When this distance was still inside a patch of reed canarygrass, a different direction and distance were used to get outside the patch of reed canarygrass. These points outside the patch were measured in the same frame pattern as the reed canarygrass patch. This out patch point was designed to sample restored vegetation not influenced by reed canarygrass. The out patch point was to be a check on how restored vegetation was reacting to grazing and burning (Figure 4). All sampling occurred in September to capture the effects of grazing over the growing season.

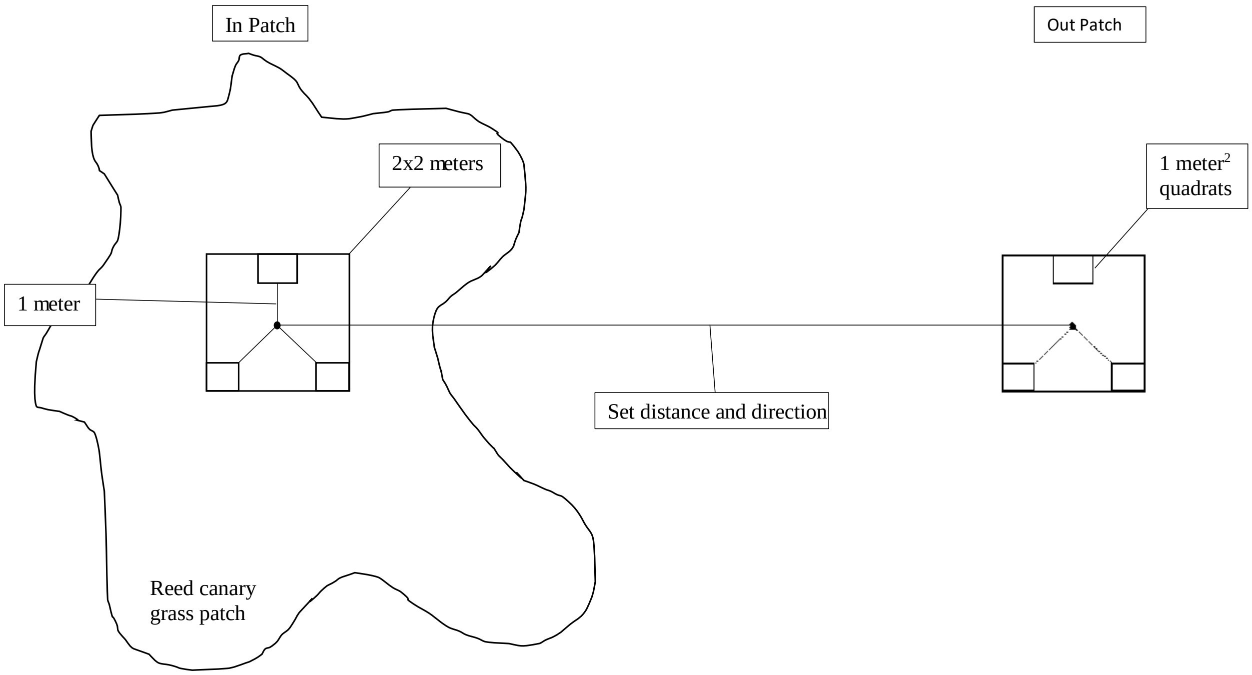


Figure 4. Data collection method showing the quadrats used in the reed canarygrass invaded patches (In Patch) and in areas not invaded with reed canarygrass (Out Patch).

Data analysis

The experimental design for the Brantner site was a block design with paddocks treated as blocks, replicated four times. The blocks were treated as a random factor. The main treatment was grazing where pretreatment was compared to later years with grazing. Reed canarygrass canopy cover and native plant richness were analyzed in SAS® software, Version 9.4 of the SAS System for Windows (Copyright © 2015 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) using a mixed model design where block was the random factor and grazing as a fixed factor. Least square mean comparison tests used the Tukey procedure at the $P<0.05$ significance level. The plant community data (species canopy cover) was analyzed as mixed model with blocks as the random factor and grazing as the fixed factor using PerMANOVA (Anderson et al. 2008) as implemented in PRIMER-e™ (Quest Research Limited). The Bray-

Curtis distance measure was used in the analysis. There was no adjustment to the paired comparison as recommended by Anderson et al. (2008).

The Williams site was treated as a completely randomized design. Because separate pastures were not established, the different sample points are not true replications but are samples within a large pasture. Reed canarygrass cover and native plant richness were analyzed as a completely randomized design using SAS.® software, Version 9.4 of the SAS System for Windows (Copyright © 2015 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). Least square mean comparison tests used the Tukey procedure at $P<0.05$ significance level. The plant community data (species canopy cover) were analyzed as completely randomized design using PerMANOVA (Anderson et al. 2008) as implemented in PRIMER-e™ (Quest Research Limited). The Bray-Curtis distance measure was used in the analysis. There was no adjustment to the paired comparison as recommended by Anderson et al. (2008). Paired comparison tables were only reported if the main effects of grazing over time were significantly different ($P>0.05$)

Plant community data (species canopy cover) was analyzed using Nonmetric Multidimensional Scaling (NMS) as a way to graphically display how the plant communities have changed over time. The NMS analysis was completed using PC-ORD Version 7 software (McCune and Grace 2011). The Bray-Curtis distance measure was used to assess the dissimilarity in the data which was the same used in the PerMANOVA analysis. Patterns in the data were found by doing 500 iterations of the data in PC-ORD reducing to one axis from six with an instability criterion of 0.0001. The number of axes (dimensions) and model selection was based on: (1) a significant Monte Carlo test ($P<0.05$); (2) a model with a stress <25; (3) an instability <0.0001; and (4) axes selection was discontinued if the next axis did not reduce stress

>5. Successional vectors connected samples over time and were used as an aid to interpreting if there was a pattern over time. Pearson's Correlation Coefficients $r \geq 0.4$ or $r \leq -0.4$ between species cover and axes scores were used to interpret the ordination and appropriately reflect an interpretable effect size (McCune and Grace 2011).

Results

Results will be presented on the Brantner property six and seven years after the start of grazing and the Williams site four and five years after the start of grazing. Analysis of patches in reed canarygrass will be presented first and then the out patches. The NMS analysis is presented before the species richness analysis.

Reed canarygrass patch

The grazed reed canarygrass patches for both the Brantner and Williams sites had reductions in reed canarygrass canopy coverage seven and five years after grazing, respectively (Figure 5 and 6). The canopy cover reductions were lower ($P<0.05$) than the pre-treatment levels and reduced approximately 50% from pre-treatment levels for both sites. In contrast, the non-grazed locations at both the Brantner and Williams sites did not show any reductions in reed canarygrass canopy coverage over the same time period ($P>0.05$) (Figures 7 and 8). The pictures of fence line contrasts (Figures 9 and 10) show that with a reduction in canopy cover from grazing there was a reduction in height and old stems of reed canarygrass.

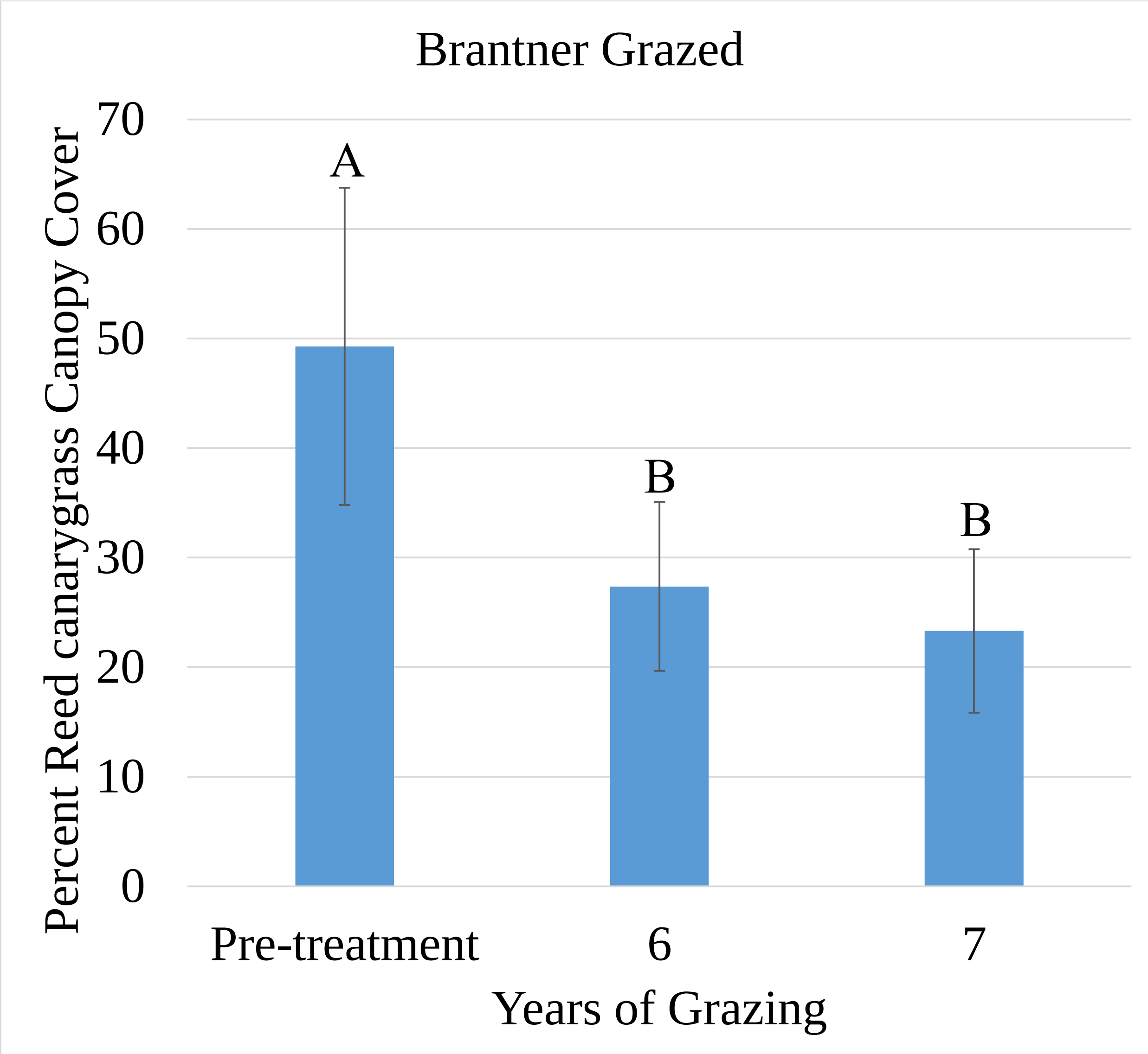


Figure 5. Percent canopy coverage of reed canarygrass at grazed sample sites before grazing (pre-treatment) and six and seven years after grazing for the Brantner site in Clay County, MN. Treatments with the same letters are not significantly different (*P*>0.05). The error bars represent standard deviation.

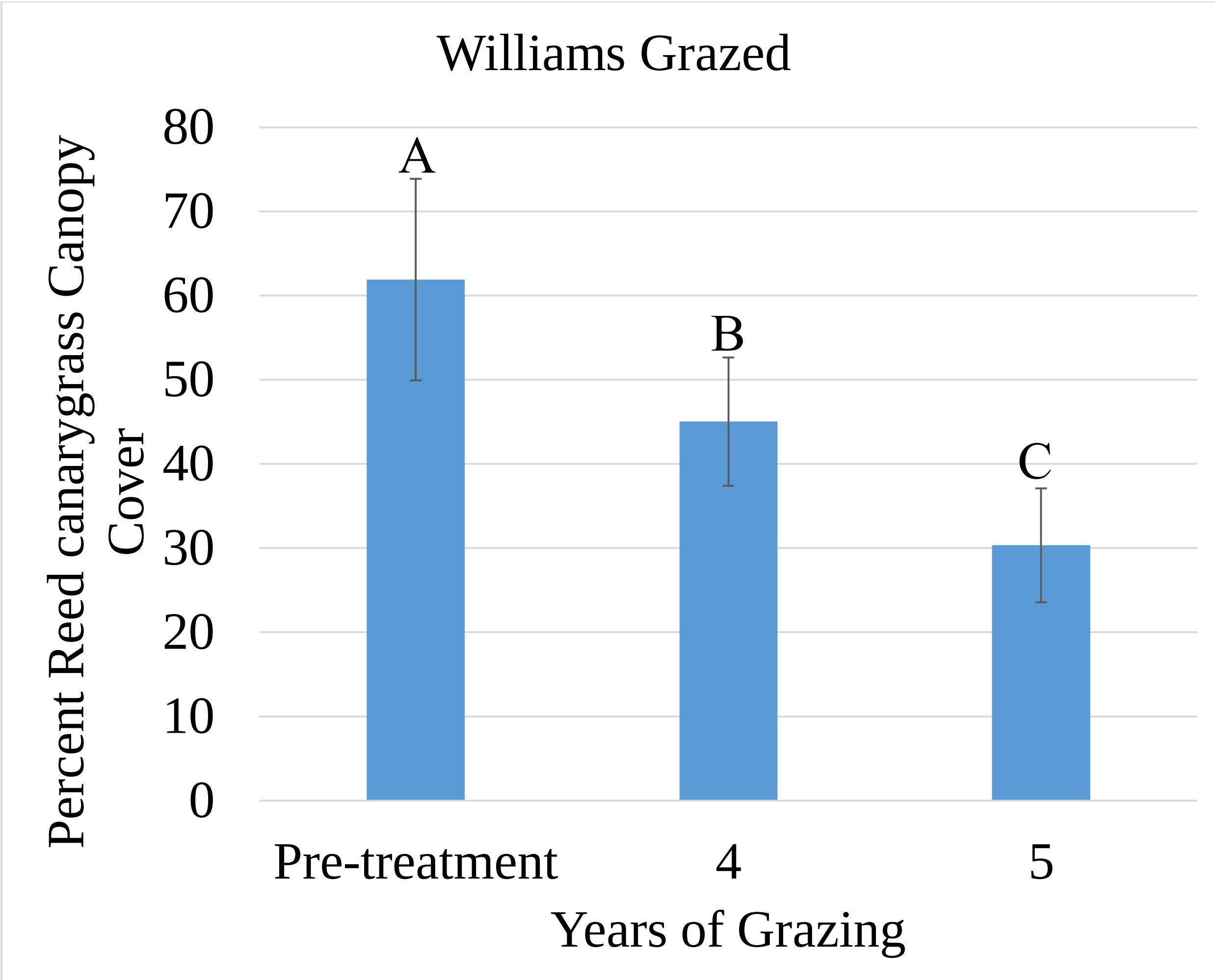


Figure 6. Percent canopy coverage of reed canarygrass at grazed sample sites before grazing (pre-treatment) and four and five years after grazing for the Williams site in Clay County, MN. Treatments with the same letters are not significantly different (P>0.05). The error bars represent standard deviation.

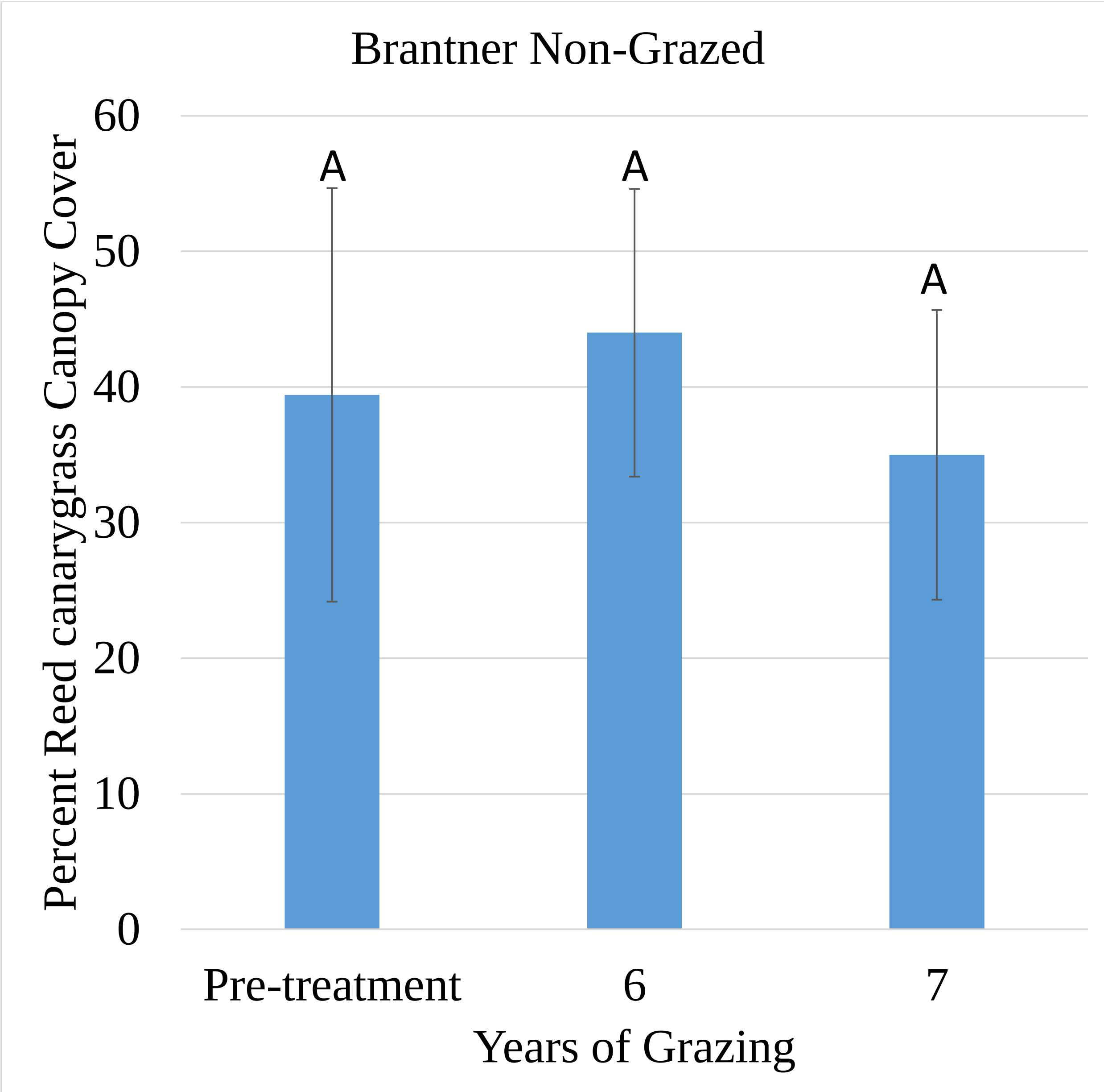


Figure 7. Percent canopy coverage of reed canarygrass at non-grazed sample sites before grazing (pre-treatment) and six and seven years after grazing for the Brantner site in Clay County, MN. Treatments with the same letters are not significantly different (P>0.05). The error bars represent standard deviation.

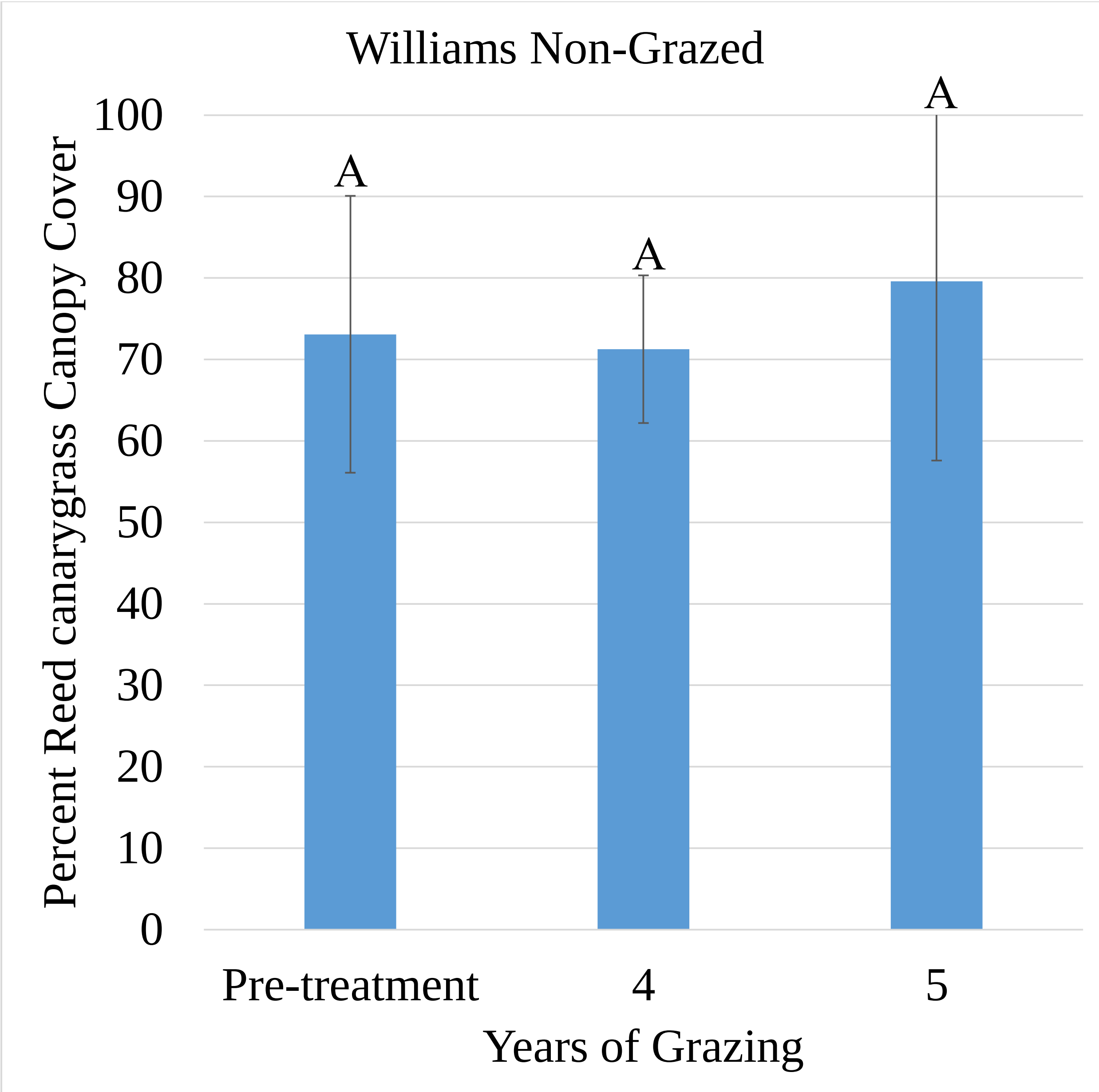


Figure 8. Percent canopy coverage of reed canarygrass at non-grazed sample sites before grazing (pre-treatment) and four and five years after grazing for the Williams site in Clay County, MN. Treatments with the same letters are not significantly different (P>0.05). The error bars represent standard deviation.

Figure 9. Fence line contrast at the Brantner site in Clay County, MN. The left side of the fence shows the grazed area and the right side of the fence was non-grazed. This demonstrates the reduction in cover, height, and old stems of reed canarygrass from grazing.

Figure 10. Fence line contrast at the Williams site in Clay County, MN. Left of the fence was the non-grazed area and right of the fence was the grazed area. This demonstrates the reduction in cover, height and old stems of reed canarygrass from grazing.

The grazed reed canarygrass patch plant communities did differ ($P<0.05$) compared to the pre-treatment communities for both the Brantner and Williams sites seven and five years after grazing, respectively (Table 1). The non-grazed plant communities did not differ compared to the pre-treatment communities for both Brantner and Williams sites both five and seven years after grazing, respectively (Williams $P = 0.191$, Brantner $P = 0.11$). Paired comparisons not shown since main effects of grazing over the years were not significant.

Table 1. Paired comparisons of the different treatments (pre-treatment vs years after grazing) showing the *P* values from the PerMANOVA analysis for the Brantner and Williams reed canarygrass patch plant communities in Clay County, MN.

Paired Treatment Comparisons	*P*-value
Brantner in patch	
Pre-treatment vs 6 years after grazing	0.033
Pre-treatment vs 7 years after grazing	0.029
6 years of grazing vs 7 years after grazing	0.056
Williams in patch	
Pre-treatment vs 4 years after grazing	0.001
Pre-treatment vs 5 years of grazing	0.001
4 years after grazing vs 5 years of grazing	0.001

Non-metric Multidimensional Scaling Ordinations of the reed canarygrass patch plant community data for the Brantner site found three explanatory axes where the stress was 10.8 (Figure 11). In the Williams site, only two explanatory axes were found with a stress of 18.4 (Figure 12). The Brantner in patch had 80% of data represented by the first two axes with the third only representing 11%. Because only 11% of the variability was explained by the third axis, this axis was not included in the results. The Williams in patch analysis was represented by just two axes accounting for 81 % of the variability in the data.

The directional vectors in the Brantner site show all the grazed samples moving from the positive end of axis 1 where a high cover of reed canarygrass was correlated, to the negative end of axis1 where a high cover of wooly sedge (*Carex pellita*) and Kentucky bluegrass were correlated. The negative end of the axis 1 has two exotic grass species, Kentucky bluegrass and redtop (*Agrotis gigantea*), with correlations of higher cover (Table 2). Axis 2 has several native forb species correlated with the positive end to the axis. Axis 2 appears to be related to sample differences as opposed to change over time due to grazing which axis 1 shows. The NMS ordination of the Williams sites shows the same patterns as the Brantner site though the grazing response and axes scores are reversed (Table 3). The native species correlated with axis 2 are different but the patterns are the same. There were no directional changes noted for both the Brantner and Williams non-grazed samples, which matches the analysis that showed the communities were not significantly different over the study.

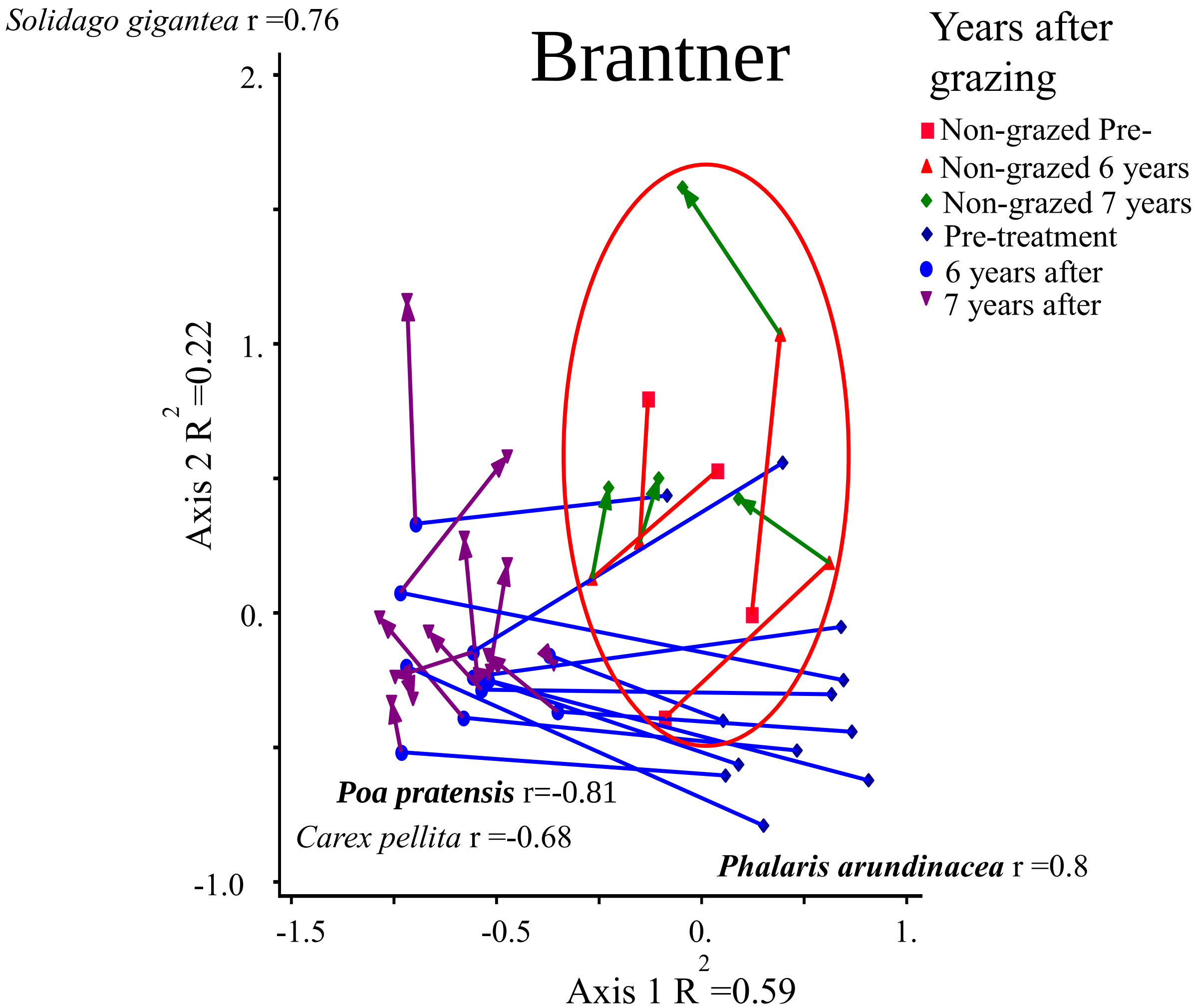


Figure 11. Ordination NMS graph representing the shift in the plant communities over time for the Brantner site for both grazed reed canarygrass patches and non-grazed patches. The directional successional arrows show the shift in the plant community in the reed canarygrass patches from the start of the experiment (light blue) to the end of the experiment (purple). The red circle highlights the non-grazed patches (red and green) with directional successional arrows showing the shift from the start (red) of the experiment to seven years after grazing (green). Certain species that were highly correlated with the axes are represented on the graph (see Table 2 for other species correlated with the axes).

Table 2. Species cover correlations (r-values) with the axes scores for the Brantner site in Clay County, MN. Axis 1 is the x-axis and Axis 2 is the y-axis for the Brantner NMS graph. These are the species that had r-values that were deemed interpretable. The bolded plants are reed canarygrass (*Phalaris arundinacea*), redtop (*Agrostis gigantea*) and Kentucky bluegrass (*Poa pratensis*) and are bolded to represent they are invasive. The non-bolded plants are natives. The higher or lower the number, the more strongly correlated is the plant to that axis.

Species	Axis 1	Axis 2
Agrostis gigantea	-0.520	
Carex pellita	-0.678	
Phalaris arundinacea	0.803	
Poa palustris	0.520	
Poa pratensis	-0.806	
Apocynum cannabinum		0.552
Helianthus nuttallii		0.543
Solidago canadensis		0.641
Solidago gigantea		0.756

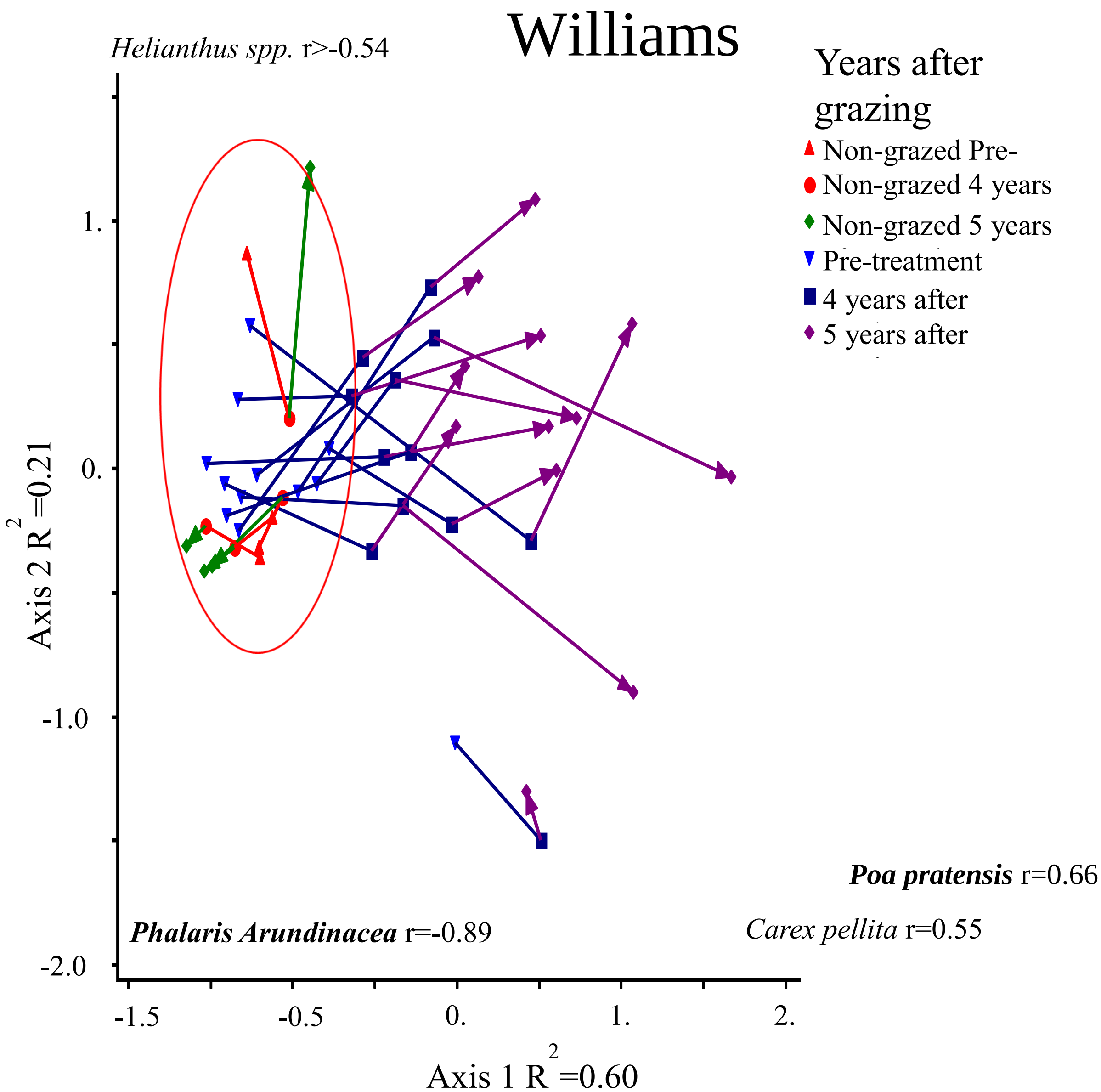


Figure 12. Ordination NMS graph representing the shift in the plant communities for the Williams site for both grazed reed canarygrass patches and non-grazed patches. The directional successional arrows show the shift in the plant community in the reed canarygrass patches from the start of the experiment (light blue) to the end of the experiment (purple). The red circle highlights the non-grazed patches (red and green) with directional successional arrows showing the shift from the start (red) of the experiment to five years after grazing (green). Certain species that were highly correlated with the axes are represented on the graph (see Table 3 for other species correlated with the axes).

Table 3. Species cover correlations (r-values) with the axes scores for the Williams NMS graph . Axis 1 is the x-axis and Axis 2 is the y-axis. These are the species that had r-values that were deemed interpretable. The bolded plants are reed canarygrass (Phalaris arundinacea), redtop (Agrostis gigantea) and Kentucky bluegrass (Poa pratensis) and are bolded to represent that they are invasive. The non bolded plants are natives. The higher or lower the number, the more strongly correlated is the plant to that side of the axis.

Species	Axis 1	Axis 2
Agrostis gigantea	0.517	
Carex pellita	0.545	
Phalaris arundinacea	-0.894	
Poa pratensis	0.664	
Helianthus maximiliani		-0.609
Helianthus nuttallii		-0.547
Zizia aurea		-0.546

Non-reed canarygrass patch

The non-reed canarygrass patches were located 25m west from the reed canarygrass patches. These patches were chosen to have little to no reed canarygrass in them and were designed to be a check on grazing effects outside the reed canarygrass patches. The non-reed canarygrass patch plant communities did differ (P<0.05) compared to the pre-treatment communities for both the Brantner and Williams sites seven and five years after grazing, respectively (Table 4). Non-metric Multidimensional Scaling Ordinations of the non-reed canarygrass patch plant community data for the Brantner site found two explanatory axes and a stress of 15.7 (Figure 13). Stress for the non-reed canarygrass patch plant communities at the Williams site was 11.8 and found three explanatory axes (Figures 14 and 15). Axis 1 explained 43% of the variability in the data while axes 2 explained 21% and axes 3 explained 22% of the data. Only one species cover had interpretable r-values with the Brantner analysis axes scores and it was Kentucky bluegrass (r = 0.67) on axis 1. The Williams analysis had only two species cover with interpretable r-values with the axes, birds-foot trefoil (r = 0.62), which is an invasive species and was correlated to axis 1, and redtop (r = 0.54) which was correlated to axis 3 and also an invasive species.

Table 4. Paired comparisons of the different treatments (pre-treatment vs years after grazing) showing the *P* values from the PerMANOVA analysis for the Brantner out patch and Williams out patch in Clay County, MN.

Paired Treatment Comparisons	*P*-value
Brantner out patch	
Pre-treatment vs 6 years after grazing	0.029
Pre-treatment vs 7 years after grazing	0.033
6 years of grazing vs 7 years after grazing	0.027
Williams out patch	
Pre-treatment vs 4 years after grazing	0.071
Pre-treatment vs 5 years of grazing	0.008
4 years after grazing vs 5 years of grazing	0.006

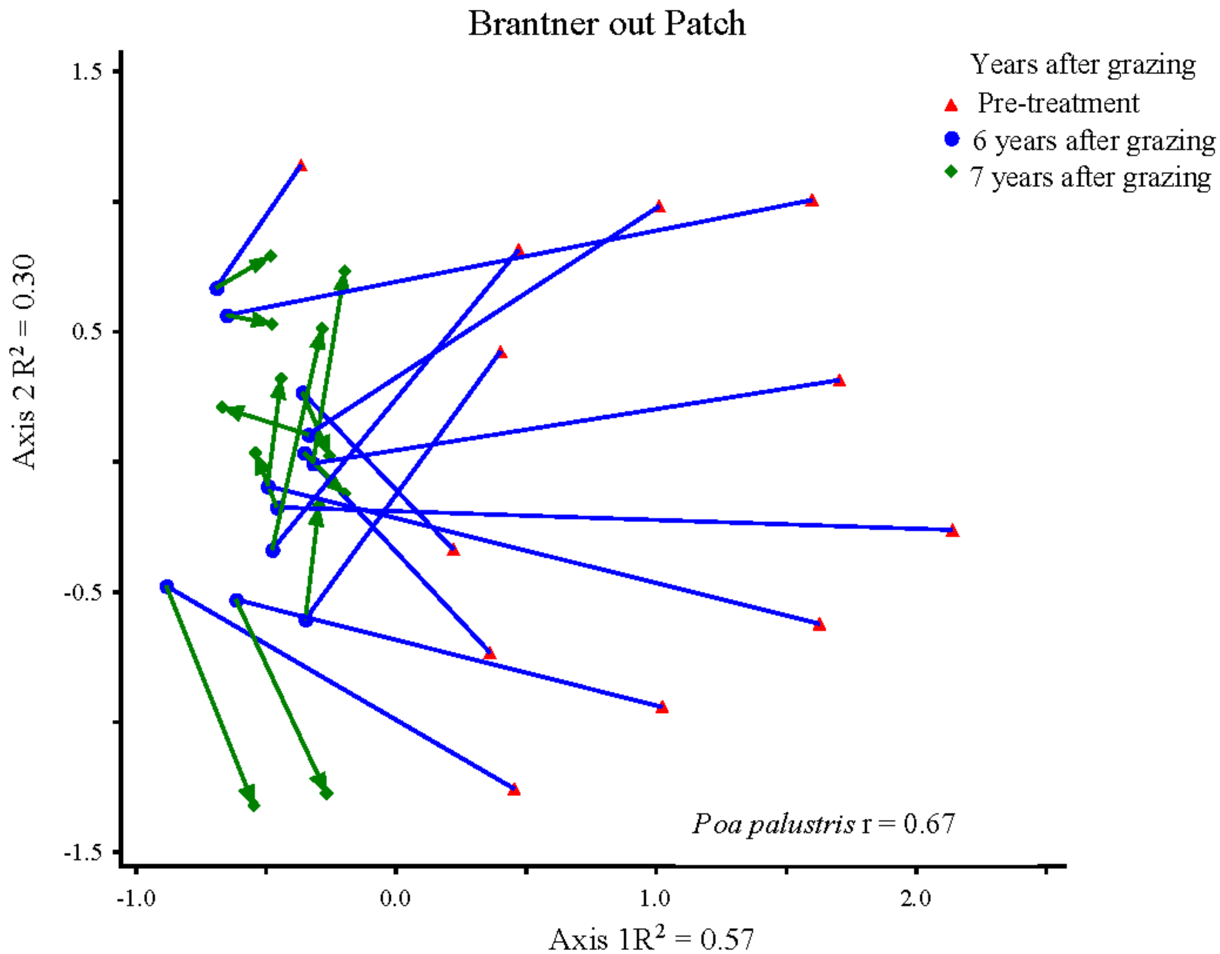


Figure 13. Ordination NMS graph representing the shift in the plant communities for the Brantner site for the grazed out reed canarygrass patches. The directional successional arrows show the shift in the plant community in the out patches from the start of the experiment (red) to the end of the experiment (green). Certain species that were highly correlated with the axes are represented on the graph.

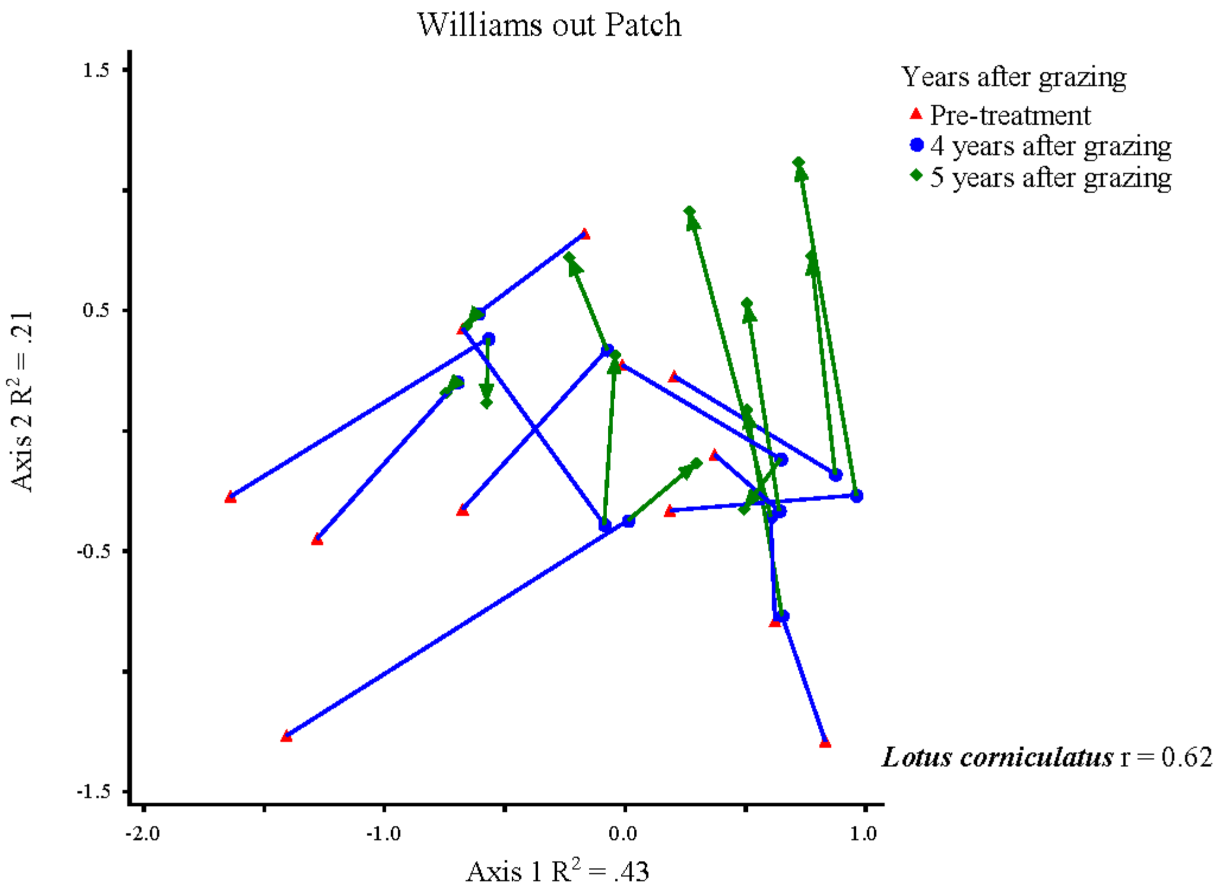


Figure 14. Ordination (NMS) graph representing the shift in the plant communities for the Williams site for the grazed out reed canarygrass patches. The directional successional arrows show the shift in the plant community in the out patches from the start of the experiment (red) to the end of the experiment (green). Certain species that were highly correlated with the axes are represented on the graph.

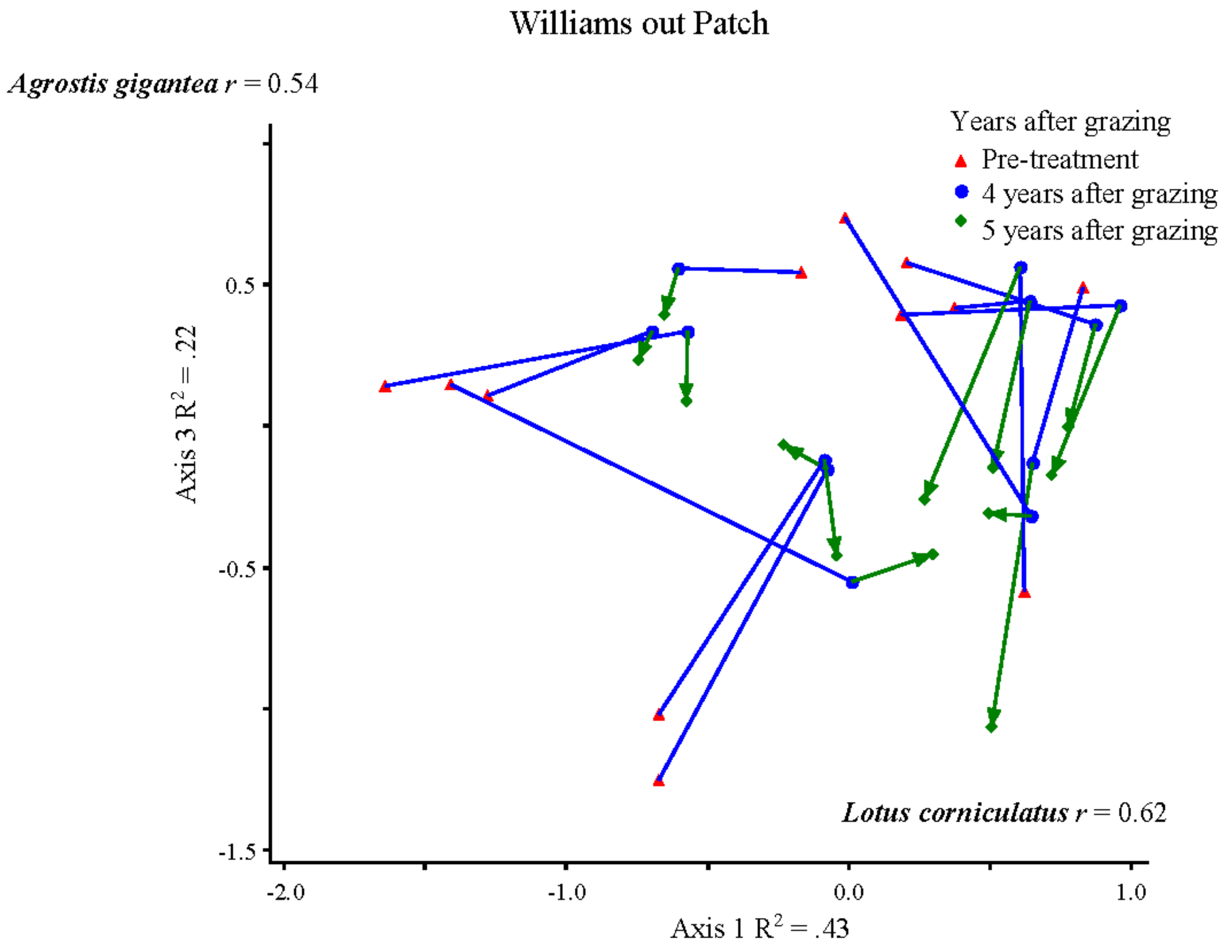


Figure 15. Ordination (NMS) graph representing the shift in the plant communities for the Williams site for the grazed out reed canarygrass patches using the first and third axes. The directional successional arrows show the shift in the plant community in the out patches form the start of the experiment (red) to the end of the experiment (green). Certain species that were highly correlated with the axes are represented on the graph.

Native species richness

Native species richness was compared from pre-treatment levels to seven and five years after grazing for the Brantner and Williams sites, respectively. For the Brantner site reed canarygrass patches native species richness did not differ (*p*=0.976) between pre-treatment levels and seven years after grazing (Figure 16). The out of patch native species richness for Brantner did not differ from the pre-treatment levels (*p*=0.085) (Figure 17). Native species richness for the Williams reed canarygrass grazed patches increased (*p*=0.039) from the pre-treatment level after four years (Figure 18). There was no difference in native species richness for the Williams out patch (p=0.466) in (Figure 19).

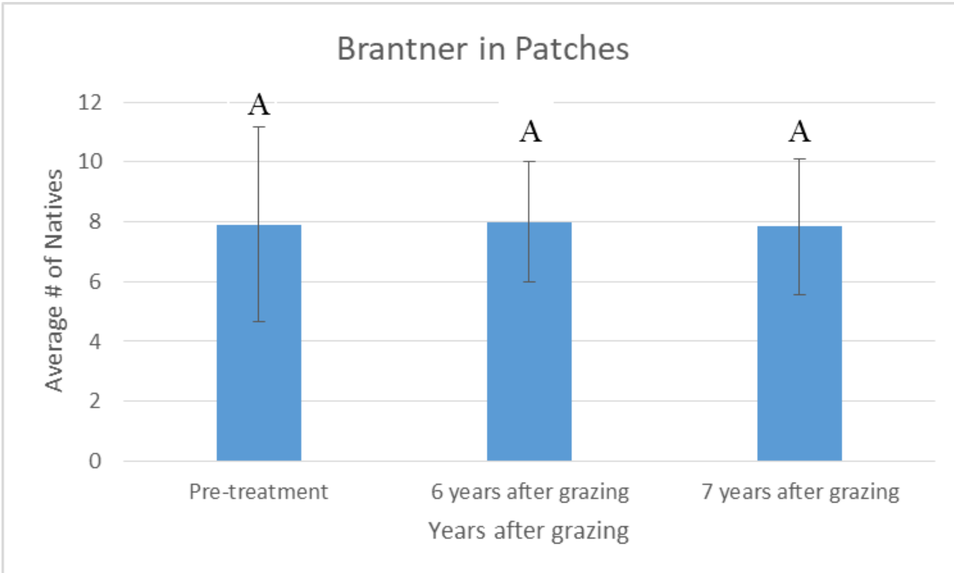


Figure 16. Change in native species richness for the Brantner in reed canarygrass patches. Treatments with the same letters are not significantly different (p>0.05). The error bars represent the standard deviation in the average number of native species.

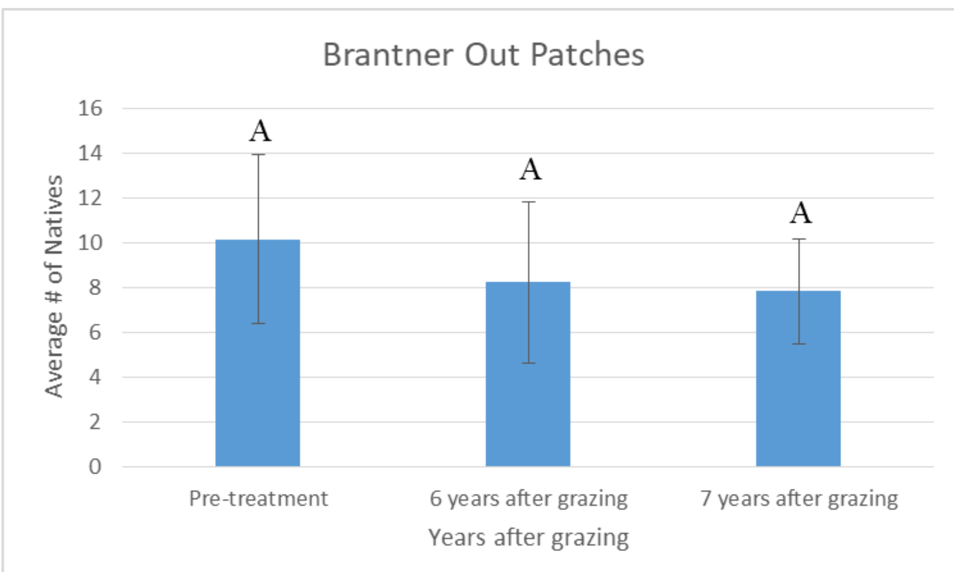


Figure 17. Change in native species richness for the Brantner out reed canarygrass patches. Treatments with the same letters are not significantly different (p>0.05). The error bars represent the standard deviation in the average number of native species.

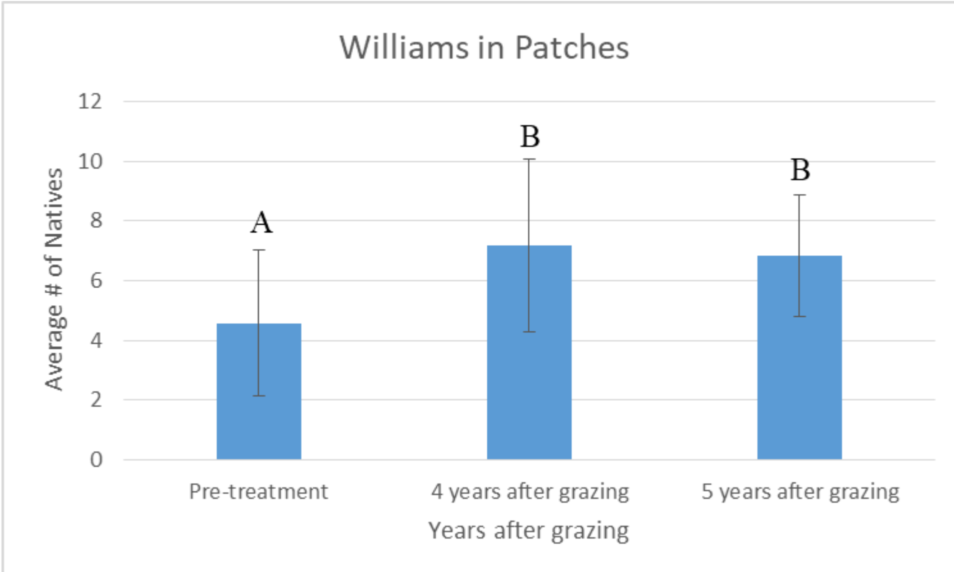


Figure 18. Change in native species richness for the Williams in reed canarygrass patches. Treatments with the same letters are not significantly different (p>0.05). The error bars represent the standard deviation in the average number of native species.

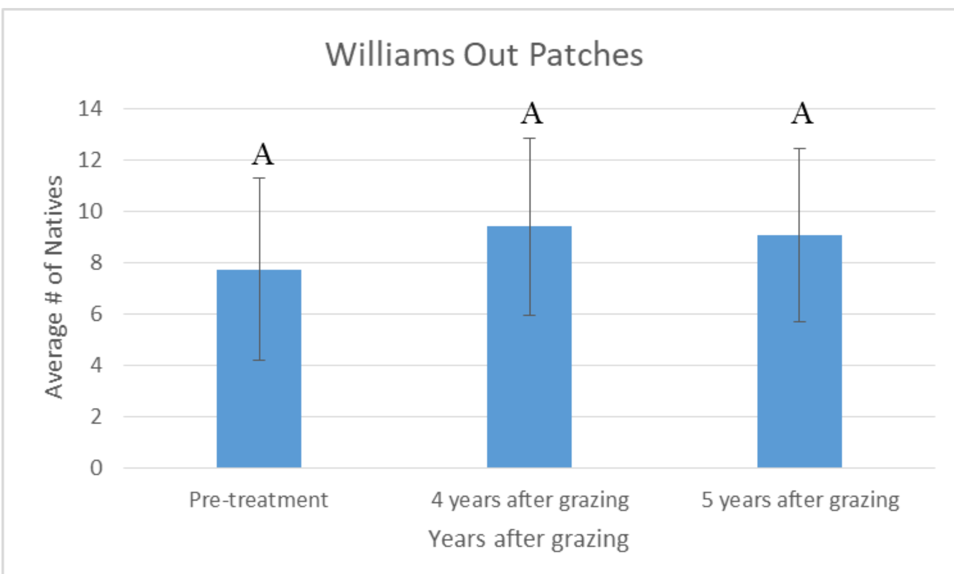


Figure 19. Change in native species richness for the Williams out reed canarygrass sites. Treatments with the same letters are not significantly different (p>0.05). The error bars represent the standard deviation in the average number of native species.

Discussion

Cattle grazing can impact reed canarygrass cover and plant community composition. Plant community changes achieved through both grazing treatments reflected some restoration of the native plant community and a reduction in canopy cover of reed canarygrass. While this study shows grazing can reduce the cover of reed canarygrass, there are some consequences of this reduction.

Cattle grazing either increased or did not harm the average number of natives found within the pasture. Hillhouse et al. (2010) found grazing did not increase species richness, which is similar to our study. James et al. (2017) reported targeted grazing increased native species abundance, which we also found on the Williams site treated with a PBG treatment after four years after grazing.

Based on our study findings, we would expect grazing to either not effect or increase native species richness. However, with grazing may come a tradeoff of species that fill the space created by reed canarygrass reduction. When reed canarygrass canopy cover was reduced, Kentucky bluegrass filled in the gaps. This trade off could be studied further as to discern if native species could fill the gap, rather than an exotic species. We also speculate that grazing, regardless of the intensity, is the factor driving the change in the plant communities that was observed. The Brantner site had a greater amount of sedge species, which is speculated to be because they are more grazing tolerant than reed canarygrass (Allen and Marlow 1994).

Kentucky bluegrass is more grazing tolerant then either sedges or reed canarygrass because of its ability to produce rhizomatous tillers (DeKeyser et. al. 2015). Reduction of height and old stems from grazing is probably conducive to the increase of native sedges and other species. By reducing the height and old stems, more of the area is open to sunlight and competition was decreased so other species were able to establish and grow such as native sedges (Hillhouse et al. 2010).

Even though there was a reduction in reed canarygrass and the plant community shifted to more native plant species like wooly sedge, certain exotic species also increased abundance. The exotic species abundance increase is important to recognize because as one exotic is being controlled, another exotic plant moves in – thus requiring a different control method. Based on the findings of Kidd and Yeakley (2015), we agree rest would not be beneficial and would only aid in the invasions of these other exotic species such as Kentucky bluegrass and bird's foot trefoil. The tradeoff between reducing reed canarygrass and increasing exotic species is to be expected, as some plants will fill the niche created after reed canarygrass is reduced. In this study, the intensity of grazing did not make a difference in the total amount of invasive species canopy cover reduced as demonstrated in James et al. (2017).

Targeted grazing has mixed results in the literature, with some studies showing a reduction in exotic plants and others no change (Paine and Ribic 2002, Hillhouse et al. 2010, James et al. 2017). Our study demonstrated a reduction in reed canarygrass from TRG and PBG. We speculate some of the conditions that made targeted grazing successful was the burns attracting cattle (Biondini et al. 1999) and reed canarygrass is a palatable forage (Sheaffer et al. 1990). While our study showed a reduction of reed canarygrass from both TRG and PBG, Hillhouse et al. (2010) found no change in reed canarygrass abundance from grazing. However, James et al. (2017) and Paine and Ribic (2002) found reductions in reed canarygrass from grazing treatments.

Our study found no change in species richness using TRG, similar to what was reported in other studies (Paine and Ribic 2002). We believe burning enhanced the grazing pressure, creating an increase in species richness after four years after grazing. The speculation with the increase in native species richness at the Williams site is that it reached the same number as the Brantner site but then did not increase further with both sites topping out at eight species. This could be a threshold for these systems as the max amount of native diversity.

Sedge species appear to increase, filling a niche created when reed canarygrass was reduced. This could be compounded due to the high palatability of reed canarygrass, with cattle selectively grazing reed canarygrass over the sedge species. The result of more sedge species may also be a result of saturated soils and spring flooding, with sedges more tolerant to wet conditions than upland plants such as Kentucky bluegrass. The grazing treatments did increase the presence of Kentucky bluegrass in the upland prairie areas. Kentucky bluegrass can be a more difficult plant suppress and reduce, creating a new concern in the ecosystem (DeKeyser et al. 2013).

Management implications/conclusions

- Rotational grazing and patch-burn grazing were both effective grazing practices of reducing the canopy cover of reed canarygrass on restored wetlands, with up to 50% canopy cover reduction on grazed areas.
- We recommend the use of either patch-burn grazing or rotational grazing as effective forms of grazing management for reducing reed canarygrass canopy cover in restorations.
- While an effective means of reducing reed canarygrass canopy cover, these grazing patterns do not guarantee eradication but rather a means of limiting the extent of reed canarygrass invasion on restored wetlands.
- While grazing lowered the target species reed canarygrass canopy cover, other invasive species (bird's foot trefoil and Kentucky bluegrass) moved in and a tradeoff was

observed between the loss of one invasive species and the introduction of another invasive species.

Literature cited

Adams C.R. and S.M. Galatowitsch. 2005. Phalaris arundinacea (Reed Canarygrass): Rapid Growth and Growth Pattern in Conditions Approximating Newly Restored Wetlands. Ecoscience 12(4):569-573.

Adams C.R. and S.M. Galatowitsch. 2006. Increasing the Effectiveness of Reed Canarygrass (*Phalaris arundinacea* L.) Control in Wet Meadow Restorations. Restoration Ecology 14:441-451.

Ahlering M.A. and C.L. Merkord. 2016. Cattle Grazing and Grassland Birds in the Northern Tallgrass Prairie. The Journal of Wildlife Management 80(4):643–654.

Allen D.R. and C.B. Marlow. 1994. Shoot Population-Dynamics of Beaked Sedge Following Cattle Grazing. Journal of Range Management 47(1):64-69.

Anderson M.J., Gorley R.N. and Clarke K.R. 2008.PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E: Plymouth, UK.

Biondini M.E., A.A. Steuter and C.E. Grygiel. 1989. Seasonal Fire Effects on the Diversity Patterns, Spatial Distribution and Community Structure of Forbs in the Northern Mixed Prairie, USA. Vegetatio 85:21-31.

Biondini M.E., A.A. Steuter, and R.G. Hamilton. 1999. Bison Use of Fire-managed Remnant Prairies. Journal of Range Management 52(5):454-461.

Cronquist A., A.H. Holmgren, N.H. Holmgren, J.L. Reveal, P.K. Holmgren. 1977. Intermountain Flora: Vascular Plants of the Intermountain West, U.S.A. The Monocotyledons 6:584.

Daubenmire, R. 1959. A Canopy-Coverage Method of Vegetational Analysis. Northwest Science 33:43-64.

DeKeyser E.S., M. Meehan, G. Clambey and K. Krabbenhoft. 2013. Cool Season Invasive Grasses in Northern Great Plains Natural Areas. Natural Areas Journal 33(1):81-90.

Dekeyser E.S., L.A. Dennhardt and J. Hendrickson. 2015. Kentucky Bluegrass (*Poa pratensis*) Invasion in the Northern Great Plains: A Story of Rapid Dominance in an Endangered Ecosystem. Invasive Plant Science and Management 8:255-261.

Diamond J.M., C.A. Call, and N. Devoe. 2012. Effects of Targeted Grazing and Prescribed Burning on Community and Seed Dynamics of a Downy Brome (Bromus tectorum)-Dominated Landscape. Invasive Plant Science and Management 5(2):259-269.

Evans-Peters G.R., B.D. Dugger, and M.J. Petrie. 2012. Plant Community Composition and Waterfowl Food Production on Wetland Reserve Program Easements Compared to Those on Managed Public Lands in Western Oregon and Washington. Wetlands 32:391-399.

Foster R.D. and P.R. Wetzel. 2005. Invading Monotypic Stands of Phalaris arundinacea: A Test of Fire, Herbicide, and Woody Herbaceous Native Plant Groups. Restoration Ecology 13(2):318-324.

Galatowitsch S.M., D.C. Whited, R. Lehtinen, J. Husveth and K. Schik. 2000. The Vegetation of Wet Meadows in Relation to their Land-Use. Environmental Monitoring and Assessment 60:121-144.

Galatowitsch S.M., N.O. Anderson and P.D. Ascher. 1999. Invasiveness in Wetland Plants in Temperate North America. Wetlands 19(4):733-755.

Green E.K. and S.M. Galatowitsch. 2002. Effects of *Phalaris arundinacea* and Nitrate-N Addition on the Establishment of Wetland Plant Communities. Journal of Applied Ecology 39:134-144.

Hillhouse H.L., S.J. Tunnell and J. Stubbendieck. 2010. Spring Grazing Impacts on the Vegetation of Reed Canarygrass-Invaded Wetlands. Rangeland Ecology and Management 63:581-587.

James J.J., J. Davy, M.P. Doran, T. Becchetti, P. Brownsey and E.A. Laca. 2017. Targeted Grazing Impacts on Invasive and Native Plant Abundance Change with Grazing Duration and Stocking Density. Rangeland Ecology and Management 70(4):465-468.

Kellogg C.H., S.D. Bridgham and S.A. Leicht. 2003. Effects of Water Level, Shade and Time on Germination and Growth of Freshwater Marsh Plants along a Simulated Successional Gradient. Journal of Ecology 91:274-282.

Kercher S.M., Q.J. Carpenter and J.B. Zedler. 2004. Interrelationships of Hydrologic Disturbance, Reed Canarygrass (Phalaris arundinacea L.), and Native Plants in Wisconsin Wet Meadows. Natural Areas Journal 24(4):316-325.

Kercher S.M. and J.B. Zedler. 2004. Multiple Disturbances Accelerate Invasion of Reed Canarygrass (*Phalaris arundinacea* L.) in a Mesocosm Study. Oecologia 138:455-464.

Kettenring K.M. and S.M. Galatowitsch. 2007. Tools for Carex Revegetation in Freshwater Wetlands: Understanding Dormancy Loss and Germination Temperature Requirements. Plant Ecology 193:157-169.

Kidd S.A. and J.A. Yeakley. 2015. Riparian Wetland Plant Response to Livestock Exclusion in the Lower Columbia River Basin. Natural Areas Journal 35(4):504-514.

Kim K.D., K. Ewing and D.E. Giblin. 2006. Controlling *Phalaris arundinacea* (Reed Canarygrass) with Live Willow Stakes: A Density-Dependent Response. Ecological Engineering 27:219-227.

Kirsch E.M., B.R. Gray, T.J. Fox and W.E. Thogmartin. 2007. Breeding Bird Territory Placement in Riparian Wet Meadows in Relation to Invasive Reed canarygrass, Phalaris arundinacea. Wetlands 27:644-655.

Lavergne S. and J. Molofsky. 2006. Control Strategies for the Invasive Reed Canarygrass (Phalaris arundinacea L.) in North American Wetlands: the Need for an Integrated Management Plan. Natural Areas Journal 26(2):208-214.

Lavergne S. and J. Molofsky. 2004. Reed Canarygrass (Phalaris arundinacea) as a Biological Model in the Study of Plant Invasions. Critical Reviews in Plant Sciences 23(5):415-429.

Lord R.A. 2015. Reed canarygrass (Phalaris arundinacea) outperforms Miscanthus or Willow on Marginal Soils, Brownfield and Non-agricultural Sites for Local, Sustainable Energy crop production. Biomass and Bioenergy 78:110-125.

Matthews J.W., G. Spyreas and A.G. Endress. 2009. Trajectories of vegetation-based indicators used to asses wetland restoration progress. Ecological Applications 19(8):2093-2107

Maurer D.A., R. Lindig-Cisneros, K.J. Werner, S. Kercher, R. Miller and J.B. Zedler. 2003. The Replacement of Wetland Vegetation by Reed Canarygrass (Phalaris arundinacea). Ecological Restoration 21(2):116-119.

Merigliano M.F., P. Lesica. 1998. The Native Status of Reed Canarygrass (Phlaris arundinacea L.) in the Inland Northwest, USA. Natural Areas Journal 18:223-230.

Miller T.W., L.P. Martin and C.B. MacConnell. 2008. Managing Reed Canarygrass (Phalaris arundinacea) to Aid in Revegetation of Riparian Buffers. Weed Technology 22(3):507-513.

Minnesota Department of Natural Resources. 2019. Native Plant Communities: System Summaries & NPC Factsheets. Accessed 20 March 2019 <https://www.dnr.state.mn.us/npc/index.html>.

Minnesota Board of Water and Soil Resources. 2019. Minnesota Wetland Restoration Guide. Accessed 10 April 2019. <http://bwsr.state.mn.us/restoration/>.

Mulhouse J.M. and S.M. Galatowitsch. 2003. Revegetation of Prairie Pothole Wetlands in the Mid-Continental US: Twelve Years Post-Reflooding. Plant Ecology 169:143-159.

Oates L.G., D.J. Undersander, C. Gratton, M.M. Bell and R.D. Jackson. 2011. Management-Intensive Rotational Grazing Enhances Forage Production and Quality of Subhumid Cool-Season Pastures. Crop Science 51:892-901.

Paine L.K. and C.A. Ribic. 2002. Comparison of Riparian Plant Communities under Four Land Management Systems in Southwestern Wisconsin. Agriculture, Ecosystems and Environment 92:93-105.

Paradeis B.L., E.S. DeKeyser and D.R. Kirby. 2010. Evaluation of Restored and Native Prairie Pothole Region Plant Communities Following an Environmental Gradient. Natural Areas Journal 30(3):294-304.

Perkins T.E. and Wilson M.V. 2005. The Impacts of Phalaris arundinacea (Reed Canarygrass) Invasion on Wetland Plant Richness in the Oregon Coast Range, USA Depend on Beavers. Biological Conservation. 124:291–295.

Rinella M.J. and S.E. Bellows. 2016. Evidence-Targeted Grazing Benefits to Invaded Rangelands Can Increase over Extended Time Frames. Rangeland Ecology and Management. 69(3):169-172.

Roy B.A., K. Hudson, M. Visser and B.R. Johnson. 2014. Grassland Fires may Favor Native over Introduced Plants by Reducing Pathogen Loads. Ecology 95(7):1897-1906.

Salaria S., R. Howard, S. Clare and I.F. Creed. 2018. Incomplete Recovery of Plant Diversity in Restored Prairie Wetlands on Agricultural Landscapes. Restoration Ecology 0(0):1-11.

Sheaffer C.C., G.C. Marten, D.L. Rabas, N.P. Martin and D.W. Miller. 1990. Reed Canarygrass. Station Bulletin 595-1990 (Item No. AD-SB-5533) Minnesota Agricultural Experiment Station University of Minnesota, St. Paul, Minnesota.

Silliman B.R., T. Mozdzer, C. Angelini, J.E. Brundage, P. Esselink, J.P. Bakker, K.B. Gedan, J. van de Koppel and A.H. Baldwin. 2014. Livestock as a Potential Biological Control Agent for an Invasive Wetland Plant. PeerJ (2)567 DOI 10.7717/peerj.567.

Spyreas G., B.W. Wilm, A.E. Plocher, D.M. Ketzner, J.W. Matthews, J.L. Ellis and E. J. Heske. 2010. Biological Consequences of Invasion by Reed Canarygrass (Phalaris arundinacea). Biological Invasions 12:1253–1267.

Strehlow T., S. DeKeyser and B. Kobiela. 2017. Managing Seedbank Composition to Enhance Wetland Restoration. Ecological Restoration 35(1):12-16.

The Nature Conservancy. 2019. Restoring Your Invasive Perennial-Dominated Grassland to Conservation Prairie. Accessed 10 April 2019. <https://www.nature.org/content/dam/tnc/nature/en/documents/Restoration-Guide-Invasive-Perennial-to-Conservation-Prairie.pdf>.

Tohiran K.A., F. Nobilly, R. Zulkifli, T. Maxwell, R. Moslim and B. Azhar. 2017. Targeted Cattle Grazing as an Alternative to Herbicides for Controlling Weeds in Bird-Friendly Oil Palm Plantations. Agronomy for Sustainable Development 37:62.

USDA, Natural Resources Conservation Service. - 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296:152-153.

USDA, Natural Resources Conservation Service. – 2019. USDA Natural Resources Conservation Service plants database. https://plants.usda.gov. Accessed April 18, 2019.

USDI, US Fish and Wildlife Service. 2019. Northern Tallgrass Prairie: Wildlife and Habitat. Accessed 21 March 2019 <https://www.fws.gov/refuge/northern_tallgrass_prairie/wildlife_and_habitat/index.html>.

Vetsch J.A., G.W. Randall and M.P. Russelle. 1999. Reed Canarygrass Yield, Crude Protein, and Nitrate N Response to Fertilizer N. Journal of Production Agriculture 12(3):465-471.

APPENDIX A. SEED MIXTURES FOR THE MESIC PRAIRIE SEED MIX #3 AND WETLAND FRINGE MIXTURE #1 USED ON THE BRANTNER SITE

Wetland Fringe Mix #1

Scientific Name	**Common Name**
Beckmannia syzigachne	American sloughgrass
Bromus ciliatus	Fringed brome
Calamagrostis canadensis	Bluejoint
Elymus submuticus	Virginia wildrye
Lolium perenne	Italian ryegrass
Poa palustris	Fowl bluegrass
Scirpus cyperinus	Woolgrass
Schoenoplectus tabernaemontani	Softstem bulrush
Scirpus atrovirens	Green bulrush
Spartina pectinata	Prairie cordgrass
Asclepias incarnata	Swamp milkweed
Symphyotrichum novae-angliae	New England aster
Alisma subcordatum	American water plantain
Eutrochium maculatum	Spotted joe pye weed
Eupatorium perfoliatum	Common boneset
Heliopsis helianthoides	Smooth oxeye
Lobelia siphilitica	Great blue lobelia
Bidens cernua	Nodding beggartick
Helenium autumnale	Common sneezeweed
Verbena hastata	Swamp verbena
Sagittaria latifolia	Broadleaf arrowhead

Mesic Prairie Mix #3

Scientific Name	**Common Name**
Andropogon gerardii	Big bluestem
Avena sativa	Common oat
Elymus canadensis	Canada wild rye
Lolium perenne	Italian ryegrass
Panicum virgatum	Switchgrass
Schizachyrum scoparium	Little bluestem
Sorghastrum nutans	Indian grass
Symphyotrichum laeve	Smooth blue aster
Astragalus canadensis	Canadian milkvetch
Dalea purpurea	Purple prairie clover
Desmodium canadense	Showy ticktrefoil
Heliopsis helianthoides	Smooth oxeye
Monarda fistulosa	Wild bergamot
Oligoneuron rigidum	Stiff goldenrod
Rudbeckia hirta	Blackeyed susan
Verbena stricta	Hoary verbena
Zizia aurea	Golden zizia

APPENDIX B. WILLIAMS SITE SEEDING REPORTS OF THE COMPOSITION OF SEEDING IN 2008 AND 2010

REPORT OF SEED ANALYSIS

Names and Addresses	Date Received	Date Completed	Date of Report	Test No.
Prairie Restoration 31922 128th Street Princeton , MN 55371 Acct. Num: 130 MS	2/4/2008	2/26/2008	6/6/2008	**13448**

SENDER'S INFORMATION *

Kind/Brand Name:	NATIVE HARVEST
Variety:	NATIVE HARVEST
Genus/Species:	MIXTURE-NATIVE
Lot Number:	TNCBS07 MESIC

*The information provided here is that of the sender and not of the laboratory.

Varietal purity guaranteed by labeler. The analysis report shown below is accurate only for the sample received at the laboratory. Whoever makes use of this information for labeling purposes is guaranteeing that the sample is representative of the seed lot from which it was drawn. The characters '--' mean the test is not complete or not reported and the letter 'N' means the test was not requested.

Purity Analysis (7.477 Grams Analyzed) / **Viability Analysis**

Pure Seed Component(s):		Germination %	Abn%	Germ Remarks	Dormant	Hard Seed %	Total Viable %	Number of Seeds	Days Tested	TFL %	TZ %
BLUESTEM-BIG (*ANDROPOGON GERARDII*)	38.99%	28	1	--	54	--	82	400	22	N	82
INDIANGRASS (*SORGHASTRUM NUTANS*)	4.08%	9	0	--	77	--	86	100	22	N	86

OTHER CROP SEED:	5.80%
INERT MATTER	48.00%
WEED SEED	3.13%

Comments: Other prairie species tz=50%

OTHER CROP SEED:

1	BLUEGRASS-KENTUCKY (*POA PRATENSIS*)	61/lb
23	BLUESTEM LITTLE (*SCHIZACHYRIUM SCOPARIUM*)	1395/lb
7	SWITCHGRASS (*PANICUM VIRGATUM*)	425/lb
32	WHEATGRASS-SLENDER (*ELYMUS TRACHYCAULUS*)	1941/lb
1	WHEATGRASS-WESTERN (*PASCOPYRUM SMITHII*)	61/lb
43	CORDGRASS-PRAIRIE (*SPARTINA PECTINATA*)	2609/lb
6	CLOVER-PRAIRIE (*DALEA SPP*)	364/lb
5	LEADPLANT (*AMORPHA CANESCENS*)	303/lb
1	DROPSEED-TALL (*SPOROBOLUS COMPOSITUS*)	61/lb
93	DROPSEED-PRAIRIE (*SPOROBOLUS HETEROLEPIS*)	5642/lb
1	BROMEGRASS (*BROMUS SPP*)	61/lb

INERT MATTER:

A 71.44 g sample was examined for weed seed classified as noxious in the 48 contiguous states (except for Undesirable Grass Seeds)

(3 Noxious weed seed species found. Number of species found must equal number of species listed below for an authentic report)

2	WILD ONION (*ALLIUM SPP*)	13/lb
936	WILD SUNFLOWER (*HELIANTHUS ANNUUS*)	5943/lb
1	CURLY DOCK (*RUMEX CRISPUS*)	6/lb

WEED SEED: 38 GAYFEATHER (*LIATRIS SPP*) 2305/lb 25 GOLDEN ALEXANDER (*ZIZIA AUREA*) 1517/lb 31 GOLDENROD (*SOLIDAGO SPP*) 1881/lb	**OTHER DETERMINATIONS:**

TEST CODE AND FEES: **Fee: $265.00**
Germination, Purity, TZ, USA Noxious

TO: Bob Huffman Fax:
CC:
Germination, Purity and Noxious Weed Examination tested in accordance with AOSA Rules.
GERM METHOD:
COMMENTS:

SGS MWSS is an accredited Member Laboratory (USML06) of the International Seed Testing Association (ISTA).

Page 1 of 1

REPORT OF SEED ANALYSIS

SGS 236 32nd Ave. Brookings, SD 57006

Names and Addresses	Date Received	Date Completed	Date of Report	Test No.
	2/12/2010	3/4/2010	4/26/2011	**221600**

Prairie Restoration
31922 128th Street
Princeton , MN 55371

over 4% of the purity are tested for germination
Acct. Num: 130 MS

SENDER'S INFORMATION *

Variety:	CLAY COUNTY MN NATIVE
Genus/Species:	MIXTURE-NATIVE
Lot Number:	TNCBLU09

***The information provided here is that of the sender and not of the laboratory.**

Varietal purity guaranteed by labeler. The analysis report shown below is accurate only for the sample received at the laboratory. Whoever makes use of this information for labeling purposes is guaranteeing that the sample is representative of the seed lot from which it was drawn. The characters '--' mean the test is not complete or not reported and the letter 'N' means the test was not requested.

Purity Analysis / **Viability Analysis**

(7.094 Grams Analyzed) Pure Seed Component(s):		Germination %	Abn%	Germ Remarks	Dormant	Hard Seed %	Total Viable %	Number of Seeds	Days Tested	TFL %	TZ %
BLUESTEM-BIG (*ANDROPOGON GERARDII*)	20.15%	8	1	--	70	--	78	400	19	N	78
INDIANGRASS (*SORGHASTRUM NUTANS*)	18.93%	4	1	--	86	--	90	400	19	N	90
LEADPLANT (*AMORPHA CANESCENS*)	8.15%	14	7	IR, DS	3	--	17	200	19	N	29
DROPSEED-PRAIRIE (*SPOROBOLUS HETEROLEPIS*)	5.36%	0	2	--	46	--	46	200	14	N	46

OTHER CROP SEED:	5.02%
INERT MATTER	41.29%
WEED SEED	1.10%

Comments: 48% t z in forbs

OTHER CROP SEED:

6	GRAMA-BLUE (*BOUTELOUA GRACILIS*)	384/lb
45	BLUESTEM LITTLE (*SCHIZACHYRIUM SCOPARIUM*)	2877/lb

A 71.73 g sample was examined for weed seed classified as noxious in the 48 contiguous states (except for Undesirable Grass Seeds)
(3 Noxious weed seed species found. Number of species found must equal number of species listed below for an authentic report)

3	BROMEGRASS-SMOOTH (*BROMUS INERMIS*)	192/lb
24	GRAMA-SIDEOATS (*BOUTELOUA CURTIPENDULA*)	1535/lb
36	SWITCHGRASS (*PANICUM VIRGATUM*)	2302/lb
4	WHEATGRASS-SLENDER (*ELYMUS TRACHYCAULUS*)	256/lb
2	CLOVER-SWEET (*MELILOTUS SPP*)	128/lb
16	GAYFEATHER (*LIATRIS SPP*)	1023/lb
35	CLOVER-PRAIRIE (*DALEA SPP*)	2238/lb
66	GOLDENROD (*SOLIDAGO SPP*)	4220/lb
2	BLUEJOINT (*CALAMAGROSTIS CANADENSIS*)	128/lb
5	BROME-KALM (*BROMUS KALMII*)	320/lb
7	MEADOW RUE (*THALICTRUM SPP*)	448/lb
14	GOLDEN ALEXANDERS (*ZIZIA SPP.*)	895/lb
1	DROPSEED-ROUGH (*SPOROBOLUS ASPER*)	64/lb
3	ONION, WILD (*ALLIUM SPP*)	19/lb
202	RAGWEED, COMMON (*AMBROSIA ARTEMISIIFOLIA*)	1277/lb
172	SUNFLOWER, WILD (*HELIANTHUS ANNUUS*)	1088/lb

INERT MATTER:

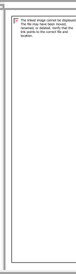
WEED SEED:

10	UNKNOWN (*UNKNOWN SEED*)	639/lb
1	IRONWEED (*VERNONIA SPP*)	64/lb
1	YELLOW FOXTAIL (*SETARIA PUMILA*)	64/lb
1	NIGHTFLOWERING CATCHFLY (*SILENE NOCTIFLORA*)	64/lb
4	DOGBANE (*APOCYNUM CANNABINUM*)	256/lb

OTHER DETERMINATIONS:

TEST CODE AND FEES: **Fee: $550.00**
Germination, Purity, TZ, USA Noxious

TO: Bob Huffman **Fax:**
CC:
Germination, Purity and Noxious Weed Examination tested in accordance with AOSA Rules.
GERM METHOD:
COMMENTS:



SGS Brookings is an accredited Member Laboratory (USML06) of the International Seed Testing Association (ISTA).

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APPENDIX C. COMPREHENSIVE PLANT SPECIES LIST OBSERVED AT THE BRANTNER SITE

Brantner Site Plant Species List

Scientific Name	**Common Name**
Achillea millefolium	Western yarrow
Agrostis gigantea	Redtop
Ambrosia artemisiifolia	Annual ragweed
Ambrosia trifida	Great ragweed
Andropogon gerardii	Big bluestem
Anemone canadensis	Canada anemone
Apocynum cannabinum	Indianhemp
Argentina anserina	Silverweed cinquefoil
Asclepias syriaca	Common milkweed
Astragalus canadensis	Canadian milkvetch
Bromus inermis	Smooth brome
Calamagrostis canadensis	Bluejoint
Carex aurea	Golden sedge
Carex brevior	Shortbeak sedge
Carex comosa	Longhair sedge
Carex duriuscula	Needleleaf sedge
Carex hystericina	Bottlebrush sedge
Carex pellita	Wooly sedge
Carex praegracilis	Clustered field sedge
Carex scoparia	Broom sedge
Carex vulpinoidea	Fox sedge
Cerastium arvense	Field chickweed
Cirsium vulgare	Bull thistle
Cornus sericea	Redosier dogwood
Dactylis glomerata	Orchardgrass
Desmodium canadense	Showy ticktrefoil
Eleocharis palustris	Common spikerush
Elymus canadensis	Canada wildrye
Elymus repens	Quackgrass
Equisetum arvense	Field horsetail
Equisetum hyemale	Scouringrush horsetail

Scientific Name	**Common Name**
Equisetum laevigatum	Smooth horsetail
Erigeron strigosus	Prairie fleabane
Eutrochium maculatum	Spotted joe pye weed
Euthamia graminifolia	Grass goldenrod
Eutrochium purpureum	Sweetscented joe pye weed
Eupatorium perfoliatum	Common boneset
Fraxinus pennsylvanica	Green ash
Galium trifidum	Threepetal bedstraw
Geum aleppicum	Yellow avens
Helianthus nuttallii	Nuttall's sunflower
Heliopsis helianthoides	Smooth ox eye
Juncus arcticus	Arctic rush
Juncus articulatus	Jointleaf rush
Juncus effusus	Common rush
Juncus tenuis	Poverty rush
Juncus torreyi	Torrey's rush
Lathyrus palustris	Marsh pea
Lobelia siphilitica	Great blue lobelia
Lycopus asper	Rough bugleweed
Medicago lupulina	Black medick
Melilotus officinalis	Sweetclover
Mentha arvensis	Wild mint
Monarda fistulosa	Wild bergamot
Monarda punctata	Spotted beebalm
Oenothera biennis	Common evening primrose
Packera paupercula	Balsam groundsel
Phalaris arundinacea	Reed canary grass
Phleum pratense	Timothy
Physalis virginiana	Virginia groundcherry
Cypridium parviflorum	Small yellow lady's slipper
Poa compressa	Canada bluegrass
Poa palustris	Fowl bluegrass
Poa pratensis	Kentucky bluegrass
Polygonum hirsutum	Hairy smartweed
Populus tremuloides	Quaking aspen
Potentilla argentea	Silver cinquefoil
Potentilla arguta	Tall cinquefoil
Rosa arkansana	Prairie rose

Scientific Name	**Common Name**
Rudbeckia hirta	Blackeyed susan
Rumex crispus	Curly dock
Salix bebbiana	Bebb willow
Salix interior	Sandbar willow
Salix eriocephala	Bayberry willow
Schedonorus pratensis	Meadow fescue
Schizachyrium scoparium	Little bluestem
Scirpus atrovirens	Green bulrush
Scirpus cyperinus	Woolgrass
Setaria viridis	Green bristlegrass
Silene latifolia	Bladder campion
Solidago canadensis	Canada goldenrod
Solidago gigantea	Giant goldenrod
Solidago rigida	Stiff golendrod
Sonchus arvensis	Field sowthistle
Sorghastrum nutans	Indiangrass
Spartina pectinata	Prairie cordgrass
Symphyotrichum ericoides	White heath aster
Symphyotrichum laeve	Smooth blue aster
Symphyotrichum lanceolatum	White panicle aster
Taraxacum officinale	Common dandelion
Teucrium canadense	Canada germander
Thalictrum dasycarpum	Purple meadow-rue
Trifolium pratense	Red clover
Urtica dioica	Stinging nettle
Verbena hastata	Swamp verbena
Verbena stricta	Hoary verbena
Vicia americana	American vetch
Viola nephrophylla	Northern bog violet
Zizia aptera	Meadow zizia
Zizia aurea	Golden zizia

APPENDIX D. COMPREHENSIVE PLANT SPECIES LIST OBSERVED AT THE WILLIAMS SITE

Williams Site Plant Species List

Scientific Name	Common Name
Agrostis gigantea	Redtop
Ambrosia artemisiifolia	Annual ragweed
Ambrosia psilostachya	Cuman ragweed
Amorpha nana	Dwarf false indigo
Andropogon gerardii	Big bluestem
Anemone canadensis	Canada anemone
Apocynum cannabinum	Indianhemp
Argentina anserina	Silverweed cinquefoil
Artemisia ludoviciana	White sage
Asclepias syriaca	Common milkweed
Bromus inermis	Smooth brome
Calamogrostis canadensis	Bluejoint
Carex blanda	Eastern woodland sedge
Carex brevior	Shortbeak sedge
Carex buxbaumii	Buxbaum's sedge
Carex crawei	Crawe's sedge
Carex pellita	Woolly sedge
Carex stricta	Upright sedge
Carex vulpinoidea	Fox Sedge
Cicuta maculata	Spotted water hemlock
Cirsium arvense	Canada Thistle
Cirsium vulgare	Bull thistle
Conyza canadensis	Canadian horseweed
Cornus sericea	Redosier dogwood
Eleocharis acicularis	Needle spikerush
Elymus repens	Quackgrass
Elymus trachycaulus	Slender wheatgrass
Elymus trachycaulus	Bearded wheatgrass
Epilobium ciliatum	Fringed willow herb
Equisetum arvense	Field horsetail
Equisetum laevigatum	Smooth horsetail

Scientific Name	Common Name
Eupatorium perfoliatum	Common boneset
Euphorbia esula	Leafy Spurge
Euthamia graminifolia	Grass goldenrod
Fragaria virginiana	Virginia strawberry
Galium boreale	Northern bedstraw
Geum aleppicum	Yellow avens
Helianthus maximiliani	Max sunflower
Helianthus nuttalli	Nuttall's sunflower
Heliopsis helianthoides	Smooth ox eye
Juncus arcticus	Arctic rush
Juncus dudleyi	Dudley's rush
Juncus torreyi	Torrey's rush
Lathyrus palustris	Marsh pea
Lobelia spicata	Palespike lobelia
Lotus corniculatus	Bird's-foot trefoil
Lycopus asper	Rough bugleweed
Lysimachia quadriflora	Fourflower yellow loosestrife
Medicago lupulina	Black medick
Melilotus officinalis	Sweetclover
Mentha arvensis	Wild mint
Muhlenbergia racemosa	Marsh muhly
Muhlenbergia richardsonis	Mat muhly
Oenothera biennis	Common evening primrose
Packera paupercula	Balsam groundsel
Panicum virgatum	Switchgrass
Persicaria amphibia	Smartweed
Persicaria amphibia	Water smartweed
Phalaris arundinacea	Reed canary grass
Phleum pratense	Timothy
Plantago major	Common plantian
Poa compressa	Canada bluegrass
Poa palustris	Fowl bluegrass
Poa pratensis	Kentucky bluegrass
Populus deltoides	Cottonwood
Populus tremuloides	Quaking aspen
Potentilla norvegica	Norwegian cinquefoil
Pycnanthemum virginianum	Virginia mountain mint
Ratibida columnifera	Upright prairie coneflower

Scientific Name	**Common Name**
Rhamnus cathartica	Common buckthorn
Rosa arkansana	Prairie rose
Rumex altissimus	Pale dock
Salix bebbiana	Bebb willow
Salix interior	Sandbar Willow
Salix eriocephala	Bayberry willow
Schizachyrium scoparium	Little Bluestem
Schoenoplectus acutus	Hardstem bulrush
Scirpus atrovirens	Green bulrush
Solidago canadensis	Canada goldenrod
Solidago gigantea	Giant goldenrod
Sonchus arvensis	Field sowthistle
Sorghastrum nutans	Indiangrass
Spartina pectinata	Prairie cordgrass
Spiraea alba	White meadowsweet
Spiranthes magnicamporum	Great Plains lady's tresses
Symphoricarpos occidentalis	Western snowberry
Symphyotrichum ericoides	White heath aster
Symphyotrichum lanceolatum	White panicle aster
Taraxacum officinale	Common dandelion
Teucrium canadense	Canada germander
Trifolium pratense	Red Clover
Typha angustifolia	Narrowleaf cattail
Typha glauca	Hybrid cattail
Verbena hastata	Swamp verbena
Zizia aptera	Meadow zizia
Zizia aurea	Golden zizia