Restored Vegetation Outcomes in Wetland Mitigation Banks Across Minnesota

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Abstract

Wetlands are one of the world's most important ecosystems, yet they continue to be degraded by urban and rural development. The Minnesota Wetland Banking Program exists as a convenient pathway to replace wetlands that have been destroyed. While the program has been offered since 1994, there has been no assessment of the long-term outcomes of wetland banking projects. Vegetation monitoring occurs for 5 years post-restoration, but even then these sites are ecologically young and conclusions made about the achievement of vegetation restoration goals may be premature.

This study aimed to evaluate vegetation outcomes in wetlands restored 8-11 years ago, and to compare these outcomes across four seeding zone types. The results indicate that the emergent zone had the lowest native species richness and highest invasive species cover. In all seeding zones, the number of seeded species present was often quite low even when native richness is high. This study also identified which seeded species and guilds persisted over time and which were consistently absent. This type of data can inform future seed mix adjustments, thereby improving the success and cost-effectiveness of wetland vegetation restoration efforts. Across all study sites, invasive narrow-leaved cattails and reed canary grass were pervasive and seem to be increasing in cover over time. Certain species such as rice cutgrass and tussock-forming sedges may compete effectively with invasives. This study highlights the necessity of long-term management to combat the ongoing expansion of invasive species and to promote the persistence of desired native species.

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I. Introduction

A. Wetland Benefits & Functions

The US EPA defines wetlands as "areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season." This includes swamps, marshes, bogs, fens, and other similar areas. Wetlands are high value ecosystems due to their provision of essential functions. Wetland habitats offer food, water, shelter, and breeding grounds for numerous fish and bird species. In Minnesota, some of the rarest plant species and most unique plant communities are found exclusively in wetlands (Coffin & Pfannmuller, 1988). Wetlands also provide many hydrologic functions. Wetlands mitigate floods by spreading water out over a large area and temporarily storing it, thereby reducing flow velocity and flood peaks. Additionally, wetlands play a role in aquifer recharge as well as water quality improvement. By slowing and storing water, wetlands allow suspended sediments to settle out. They are also effective at removing nutrients (i.e. total phosphorus, inorganic nitrogen), chloride, pesticides, sulfur, and heavy metals via biological and chemical processes (United States Geological Survey, 1996).

B. History of Wetlands in the U.S.

Despite the many benefits of wetland ecosystems, they were historically regarded as a nuisance; they were areas that bred diseases, impeded travel and settlement, and hindered agricultural production (Dahl and Allord 1997). Therefore, the draining, clearing, and plowing of wetlands became common practice during European settlement. Once drained, these areas proved to be productive cropland. In the 1780's, the contiguous 48 states contained 221 million acres of wetlands (Dahl, 1990). Over a period of 200 years, an estimated 53% of the original wetlands in the contiguous US were lost due primarily to drainage and conversion to agriculture. Wetlands were also lost due to intense logging and modified by levees, dams, and other flood-control/water-diversion projects (Dahl and Allord 1997). Wetland loss in Minnesota during this time period is estimated at 42%, falling well below the national average (Dahl, 1990).

In the late 1970s to early 1980s, people began to recognize the value and functions of wetlands, and the need to protect them. The Clean Water Act of 1972 set up a regulatory program under which a permit is required to drain, damage, or destroy a jurisdictional wetland. Additionally, the Emergency Wetlands Resources Act of 1986 (Public Law 99-645) was enacted to promote the conservation of wetlands in the US (Dahl, 2000). The result of these policies was a substantial decrease in the rate of wetland loss. In the 1980s and 1990s the average annual net loss of wetlands was only 58,500 acres, compared to 458,000 acres annually in the 1950s-1970s.

C. Wetland Restoration

Given the undeniable benefits of wetlands, coupled with their long history of destruction, there is a clear need to restore wetland ecosystems. The US EPA defines wetland restoration as "the return of a wetland and its functions to a close approximation of its original condition as it existed prior to disturbance on a former or degraded wetland site." Wetland restoration aims to restore lost biodiversity and/or functions such as water filtration and flood attenuation.

1. Restoration Process

In the *Practical Guidelines for Wetland Prairie Restoration*, Kruger et. al describe the six general steps that are involved in any wetland restoration. First, a site is selected based off its ability to support a healthy wetland ecosystem. Factors that go into the site selection process include the presence of hydric soils and suitable wetland hydrology, the size and historic condition of the site, and the connectivity of the site to other natural spaces. Second, a thorough site analysis must take place that evaluates the site's land use history, soils, geomorphology, wildlife, vegetation, and hydrology. A wetland delineation will also typically take place. Third is the planning and design process, during which proposed actions and restoration goals are defined. A timeline, plan map, and monitoring plan will also be established. This phase is when baseline monitoring and permitting occur.

The project finally breaks ground during the fourth step of site preparation. Wetland restorations typically require earthwork and hydrological modifications such as breaking tile lines, ditch removal, berm construction, etc. The site will also need to be treated multiple times to remove invasive species and their associated seed bank. The removal of invasive species can take more than one year to complete, particularly reed canary grass which has extensive rhizomes and prolific seed production (Wenzel & Shaw, 2012). Fifth, a native plant community needs to be established, which will occur over a two to three-year period. Often, wetlands will be broadcast or drill seeded with a mixture of native species (see Seed Mix Design below), and supplemental seedlings called plugs may also be planted. Depending on the success of establishment, select areas within the restoration site may need to be re-seeded in the following years. Lastly, a wetland restoration requires long-term management activities and monitoring in order to achieve restoration goals (Krueger, Bois, Kaye, & Steeck, 2014).

2. Seed Mix Design

A key aspect of wetland restoration is establishing native vegetation communities that are diverse and resilient. Vegetation establishment is usually achieved through the use of either standard or customized seed mixes. Standard seed mixes typically have lower diversity than site-specific seed mixes (MacDonagh & Hallyn, 2010). There are a few key principles that go into the design of any seed mix. First, seed mixes must be designed to match the target plant communities, soils, and hydrologic conditions of the restoration site. Second, plant species must be carefully selected to fulfill a diverse range of community functions. Typically, mixes are built off a few core species that are common, reliable, and readily available, with additional species added in to improve performance and diversity. The mix should include all guilds (warm and cool season grasses, sedges, rushes, forbs, etc.) that would be found in a natural plant community, as well as early, mid, and late successional species. The mix should also benefit pollinators by including at least three spring, summer, and fall blooming species. Lastly, seed mixes should be designed based on seeds per square foot, and individual species should be present at a high enough rate to ensure that they are able to establish on site (Minnesota Board of Water and Soil Resources, 2019). The number of seeds per square foot is based on factors including the size and purity of the seed and the germination rate of the species.

The composition of a seed mix can affect the vegetative outcomes of a restoration project in a variety of ways. Firstly, increasing the richness of the seed mix has been shown to result in greater planted species richness (Larson et al., 2011). Greater species richness within sites tends to increase the stability of ecosystem properties, and decrease exotic species invasion (Hooper et al., 2005). Seed mix composition can also influence guild cover, for example, perennial forb cover has been found to increase with higher seed mix richness (Larson et al., 2011). Considering the influence of the seed mix on the outcomes of restoration, there is a need to evaluate the performance of seed mixes using a variety of vegetation metrics, and to track changes in these metrics over time.

It is important to note that there are substantial costs associated with vegetation establishment. The Minnesota Department of Transportation estimates the total cost of wetland replacement is $600 to $106,000 per acre for rural areas, with around $200-$1,000 per acre attributed to the cost of the seed mixes. The cost of individual species varies based on supply and demand, with the more common species having lower seed costs. Given the financial investment of restoring native vegetation via seed mixes, it is imperative to regularly evaluate the success of seeding and adjust the composition of the mixes as needed.

D. Wetland Mitigation Banking

1. Background

In the state of Minnesota, wetlands are regulated through two primary wetland protection programs: the federal Clean Water Act (implemented by the US Army Corps of Engineers) and the Minnesota Wetland Conservation Act (implemented by the Local Government Units with oversight from the Minnesota Board of Water and Soil Resources). Under these programs, wetlands may be legally impacted, but their loss must be compensated for by the restoration, creation, or enhancement of other wetlands. This compensation for permitted wetland loss is referred to as mitigation. In theory, mitigation should result in "no net loss" of wetlands, as the area and function of impacted wetlands are replaced by other restored or created wetlands. Wetland mitigation can be achieved in one of two ways. First, the individual impacting a wetland can complete a project-specific replacement. This is when the individual impacting a wetland mitigates that impact by restoring or creating a wetland themselves. Often, the individual does not have the time or desire to undertake project-specific replacement. The second option is for the individual to mitigate their impact via Wetland Banking, through which they purchase approved “credits” from a third party that previously restored, enhanced, or created a wetland to fulfill their mitigation requirement.

The Minnesota Wetland Banking Program exists as a convenient pathway to wetland replacement. An individual, landowner, or entity (bank sponsor) restores or creates a wetland with oversight from the Minnesota Board of Water and Soil Resources (BWSR) and the US Army Corps of Engineers (USACE). Upon approval from BWSR, the Local Government Unit (LGU), and USACE, the bank sponsor receive credits. Credits are a representation of the function and value of a wetland in the Wetland Banking Program. The Bank Sponsor receives credits based on the acreage and quality of the wetland. Once credits are approved for deposit, BWSR deposits the credits into a wetland bank account. While BWSR is responsible for managing the transactions, the account holder retains ownership of the credits and can sell them to an individual that needs to replace an impacted wetland. The price of the credits is negotiated between the credit seller and the credit buyer. In 2018 the average cost per credit ranged from $18,583.20 to $82,449.92 depending on location within the state (i.e. the major drainage basin). Once an agreement is reached and approved by the LGU and USACE, BWSR processes the credit withdrawal. It is important to note a withdrawal can only be made if credits are available, thereby ensuring "no net loss" and preventing Minnesota from going into wetland debt. As of November 2018, there are approximately 42,000 acres in the wetland bank, and 154 accounts actively selling credits.

2. Monitoring Outcomes

As with many wetland mitigation programs across the country, Minnesota's Wetland Banking Program and federal rule requires restorations to be monitored for the first 5 years. Sites are monitored to determine if they meet a given set of "performance standards", which are established before the restoration and can be unique to each site. In Minnesota, performance standards typically relate to both vegetation and hydrology measurements, with an emphasis on vegetation. Common vegetation standards are related to richness and dominance of native hydrophytes and limits of non-native/invasive species and are typically negotiated in the bank plan approval process between the bank sponsor and the regulatory authorities (BWSR and the USACE). After 5 years, a determination is made about project performance and if the restoration is complete.

There are two main concerns regarding wetland bank monitoring. First, it has been suggested that current monitoring standards have been chosen for speed and cost-efficiency, not to reflect ecological processes, and therefore may be inadequate (Spieles, 2005). Second, wetlands are still ecologically young during the 5-year monitoring period, so conclusions made about the achievement of restoration goals may be premature (Kentula, 2000). It has been proposed that the true success of a wetland cannot be measured until 15-20 years post-restoration (Mitsch & Wilson, 1996). Unfortunately, there are few data available beyond the first 5 years, so we have an incomplete picture of the succession and long-term outcomes of restored wetland banks (Spieles, Coneybeer, & Horn, 2006). For this reason, several studies call for longer-term performance measures or extended monitoring periods (Spieles et al., 2006; Stefanik & Mitsch, 2012).

E. Research Objectives

There is a discrepancy between initial effort and follow-through when it comes to wetland restorations. With multiple wetland protection programs in place, over 42,000 acres in the wetland bank, and up to $1,000 per acre spent to seed native vegetation, it is evident that the state of Minnesota views wetland restoration as a priority. However, the current monitoring standards may not be enough to evaluate the true outcomes of wetland restoration projects, leaving questions about the long-term success and cost-effectiveness of restoration efforts. Within this context, the present study has three main objectives:

1. Evaluate the long-term vegetation outcomes of restored wetlands.

In the context of this study, "long-term" is defined as restorations around 10-years old. Vegetative outcomes are measured in terms of native species richness, percent of seeded species present, native species cover, and invasive species cover. These metrics are compared between four primary seeding zones: emergent wetland, wet meadow, wet prairie, and mesic prairie. The goal is to determine if the success of vegetation establishment varies between seeding zones, or simply depends on site-specific factors. This information will contribute to the limited body of knowledge on long-term outcomes of wetland bank restorations.

2. Identify the most successful species and guilds.

Within each of the seeding zones of interest, this study will identify the most successful species and guilds in terms of presence and cover. Guilds are groups of species with similar life-form, phenology, and ecology (Kindscher & Wells, 1995). Species that are rare or never present will also be identified. This information will help inform seed mix adjustments, thereby improving the success and cost-effectiveness of the standard state seed mixes.

3. Determine which species and guilds are resilient to invasion.

One of the main goals of restoration is to establish plant communities that can compete with invasive species. Seed mixes are therefore designed to maximize the resiliency of the resulting vegetation communities. This study will identify which species and guilds persist in highly invaded areas, and which species and guilds thrive without the pressure of invasives. Understanding species response to invasion and adapting restoration practices accordingly can improve the long-term resiliency of these wetland communities.

II. Methods

A. Study Seed Mixes

This study focuses on four standard state mixes that were designed for use in wetland mitigation: BWSR W1, W2, W3, and U3. Each of these seed mixes corresponds with a seeding zone – emergent wetland, wet meadow, wet prairie, and mesic prairie, respectively. These four standard mixes were commonly used in wetland bank restorations from around 2002 to 2009. A description of each of the mixes and corresponding seeding zones is provided below. A complete list of species included in each of the seed mixes can be found in Appendix A.

1. W1 – Emergent Wetland

In terms of richness, the W1 emergent wetland seed mix is comprised primarily of sedges (*Carex spp.*) and rushes (*Scirpus spp.*), as well as a handful of grasses (e.g. American slough grass) and forbs (e.g. Northern water plantain, broad-leaved arrowhead). The mix contains a total of 22 species that are characteristic of a shallow march community. Shallow marshes have soils that are saturated or inundated by up to 6 inches of standing water throughout most of the growing season. The W1 mix is typically used in a 6 to 10-foot band along the edge of the open water in the wetland fringe. This band is broadcast seeded by hand after water levels have stabilized, avoiding areas of open water as the seeds will float. The W1 mix contains 166 seeds per square foot and the recommended seeding rate is 8 pure live seed (PLS) lbs/sq ft.

2. W2 – Wet Meadow

Wet meadows, also called fresh meadows, have saturated soils but are without standing water for most of the growing season. The W2 wet meadow mix contains 33 species including forbs such as giant goldenrod and boneset, grasses such as fowl bluegrass and Virginia wildrye, and several *Carex* and *Scirpus* species. The number of grass species in the mix is equal to the number of sedge/rush species. The W2 mix contains 200 seeds per square foot and the recommended seeding rate is 8 PLS lbs/sq ft.

3. W3 – Wet Prairie

Wet prairies are similar to wet meadows but are dominated by grasses and forbs associated with prairies such as big bluestem, switchgrass, blazingstar, and sawtooth sunflower. The W3 wet prairie mix is therefore comprised of a mixture of tallgrass prairie grass and forb species, as well as a handful of sedge and rush species. The W3 mix contains 36 species total and 200 seeds per square foot. The recommended seeding rate is 10 PLS lbs/sq ft.

4. U3 – Mesic Prairie

Mesic prairies, also called tallgrass prairies, occur on rich, moist, well-drained soils. This mix is used in the upland area of the wetland basin, approximately 1-1.5 feet above pool elevation. The U3 mesic prairie mix contains 30 species including a diversity of native grasses (e.g. big bluestem, Canadian wildrye) and forbs (golden Alexanders, butterfly milkweed). A cover crop such as oats or winter rye is typically also included. The mix contains 48 seeds per square foot and can be either drill or broadcast seeded at a recommended rate of 15 PLS lbs/sq ft.

Table 1. Estimated costs of standard state seed mixes.*

	Cost per acre
W1 – Emergent Wetland	$1,180.00
W2 – Wet Meadow	$850.00
W3 – Wet Prairie	$785.00
U3 – Mesic Prairie	$310.00**

*Prices estimated based on seed mix composition prior to 2009. Prices vary in response to current markets.
**Includes oats as a cover crop.

B. Study Sites

Wetland bank sites were selected based on three criteria: 1) age, 2) seed mixes used, and 3) availability of seeding maps. As the main goal of this study was to evaluate long-term vegetation outcomes, the focus was restorations that were completed by, or prior to, 2011. The earliest restoration occurred in 2006, and the majority happened over the years 2009-2010. Sites were selected that used at least two of the standard state seed mixes described above (W1, W2, W3, U3). The factor that constrained site selection the most was the availability of good seeding maps. In order to randomly locate sampling plots within each seeding zone, detailed seeding zone maps that could be georeferenced in ArcGIS were needed.

All factors considered, 9 wetland bank sites met the criteria. They are located across Southern/Central Minnesota, as shown in Figure 1. A brief description of each site is provided below. All information on the wetland bank sites including age, seed mixes used, seeding zone maps, project goals, restoration methods, and management history was obtained from files stored at the Minnesota Board of Water and Soil Resources (BWSR) office in St. Paul, MN. For a summary of the seeding zones that were present and surveyed at each site, see Table 2.

1. Deinken

This site is in Morton, Minnesota and restoration began in 2006. It has a total area of 20.5 acres including 11.7 acres of wetland and 8.8 acres of upland buffer. Of these acres, 2.25 acres had been partially drained for farmland, and the rest of the basin was completely drained. Methods to restore hydrology included constructing two earthen dikes, an emergency spillway, and a culvert. There is also a small drainage pipe that outlets into the wetland. Vegetation was restored by seeding the shallow marsh fringe, wet/sedge meadow zone, and upland prairie. Management activities included periodic mowing and spot spraying for Canada thistle, as well as a prescribed burn in 2010 and chopping cottonwood saplings in 2011.

2. Drummer

This site is in Mankato, MN and restoration began in 2010. It has a total area of 55.6 restored acres including 41.10 acres of wetland and 14.50 acres of native upland buffer. Part of the property was in row crops, and part was enrolled in the Conservation Reserve Program (CRP) from 1986 to 2008. Hydrology was restored by filling the ditch, removing 100-feet of tile line, and constructing a berm and outlet structure on the east side of the basin. Vegetation was restored by seeding the upland, transition, and wetland zones, and by deep water planting of live tubers. Management activities included monthly mowing during the growing seasons of 2011-2013, and regular cutting/spraying of reed canary grass.

3. Elfering

This site is in Stewart, MN and restoration began in 2009. It has a total area of 152.8-acres including approximately 60 acres of wetlands (9 basins) and 93 acres of upland grassland buffer. The land was previously row cropped. Hydrology was restored by blocking tile lines and constructing earthen embankments with outlet structures. Vegetation was restored by seeding the shallow marsh, wet prairie, and upland zones, and by planting pre-emergent plant starts. Management efforts included mowing, herbicide application, re-seeding in 2012, and a prescribed burn in 2013.

4. Engstrom

This is site is in Dayton, MN and restoration was conducted by Stantec in 2009. It has a total area of 24.7 acres including 15.4 acres of wetland and 9.3 acres of upland. The land was previously row cropped and partially drained. Methods to restore hydrology included creating a fixed outlet spillway, removing and blocking tile line, constructing a berm, and a control structure. Management history includes mowing, cattail wicking and cutting, spot spraying of reed canary grass and thistle, supplemental seeding, and sapling control of Siberian elm.

5. Krohn

This site is just north of Madelia, MN and restoration began in 2009. It has a total area of 50.1 acres, including 29.8 acres of wetland and 13.8 acres of upland. 15.5 acres on the site were farmed wetlands, while remaining area was drained by tiling and tile intakes. Hydrology was restored by breaking and re-routing tiles, and constructing an embankment with an inline water control structure as an outlet. The site still has a subsurface tile feeding into it. Vegetative restoration was conducted through seeding and planting of emergent vegetation. Management activities included supplemental seeding, herbicide application, mowing, and removal of reed canary seed heads.

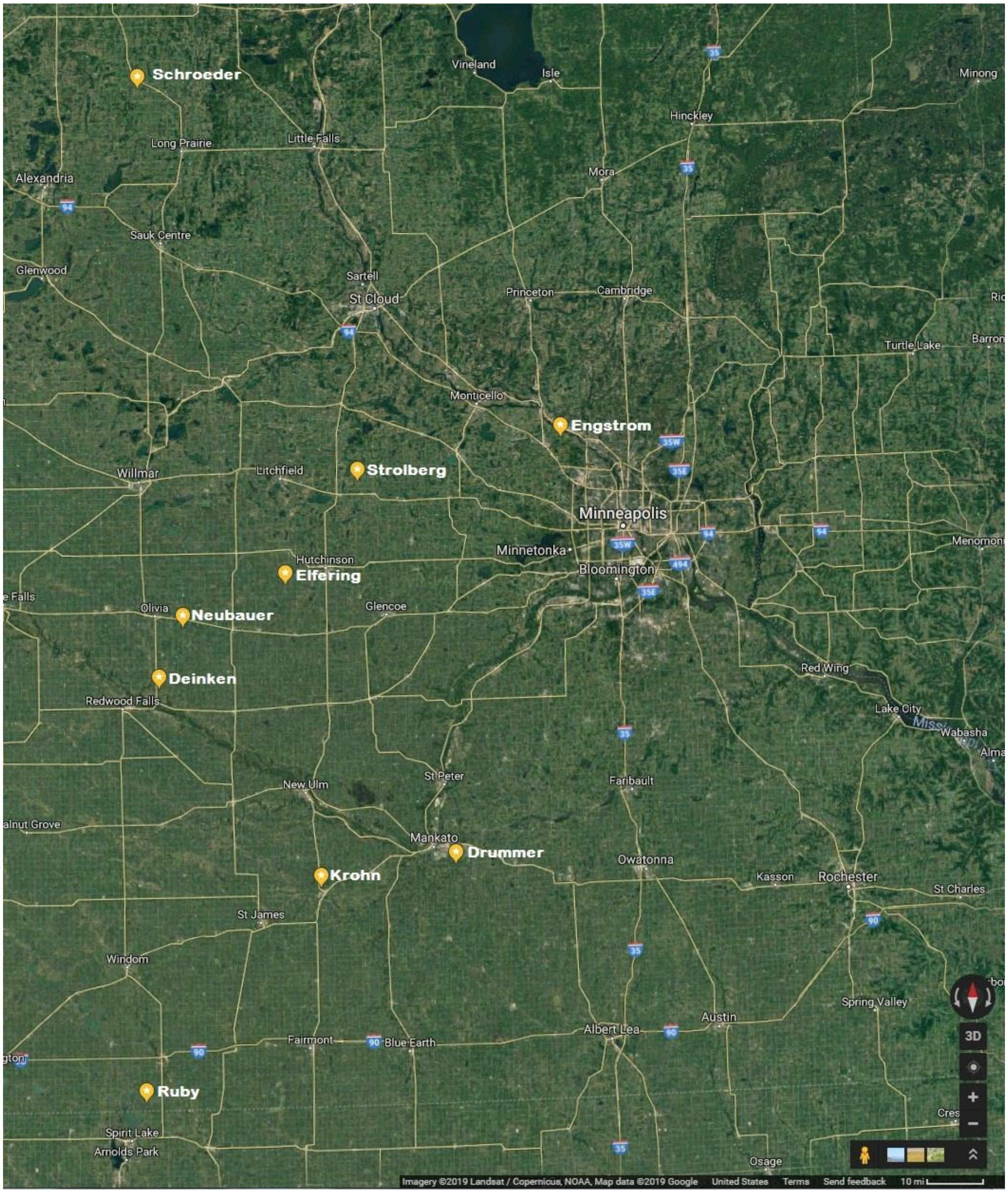

Figure 1. Locations of the 9 wetland bank sites surveyed in this study.

6. Neubauer

This site is located in Bird Island, MN and restoration began in 2007. It has a total area of 57.3 acres. The entire site had been previously drained and cropped. Hydrology was restored via three tile breaks and construction of earthen embankments. Native vegetation was seeded along the fringe of the shallow marsh area, in the wet meadow zone, and in adjacent uplands. Plugs were planted in portions of the shallow marsh with standing water. Management included clipping the upland, spot spraying thistle, and a prescribed burn in 2010.

7. Ruby

This site is in Jackson County, MN near the Iowa border, north of Spirit Lake. Restoration began in 2009. The total area is 72.7 acres, including 39.4 acres of wetland (3 basins) and 33.3 acres of upland. The land was previously in soybean production. Methods to restore hydrology included removing, rerouting, and capping drain tile, and constructing berm structures. Native vegetation was seeded in the shallow marsh, wet meadow, and upland buffer areas. Management activities involved cutting woody plants and spraying Canada thistle and reed canary grass as needed.

8. Schroeder

This is site is in Eagle Bend, MN and the restoration was conducted in 2011 by Stantec. The total area is around 21.9 acres, including 20 acres of wetland and just under 2 acres of upland. The site was consistently farmed for 20 years, and then in CRP starting in 2001. Hydrologic restoration included the construction of a spillway and an earthen berm. Native vegetation was seeded in the emergent zone, wet meadow, and upland buffer zones. Management history includes mowing, spraying for reed canary grass, and a prescribed burn in 2013.

9. Strolberg

This site is near Cokato, MN and the restoration began in 2009. It has a total area of 143.7 acres including 54 acres of wetlands in 10 basins. The area was previously partially cropped. Hydrology was restored through tile blocks and construction of earthen embankments with outlet structures. Native vegetation has been restored in both uplands and wetlands. Management activities included spot spraying and mowing reed canary and thistle, and a prescribed burn in 2010.

Table 2. Summary of the seeding zones present at each study site.

	W1	W2	W3	U3
Deinken	x	x		
Drummer	x		x	x
Elfering	x		x	x
Engstrom	x	x	x	
Krohn		x	x	x
Neubauer	x	x		x
Ruby	x		x	x
Schroeder	x	x		
Strolberg	x	x		x
Total number of sites	**8**	**6**	**5**	**6**
Total number of plots	**80**	**60**	**50**	**60**

C. Vegetation Surveys

Vegetation surveys were completed during June–August 2017. At each site, both a plot-based survey and a timed meander were conducted.

1. Plot-based Surveys

Before visiting the sites, ArcGIS ArcMap version 10.4.1 was used to georeference the PDFs of the seeding zone maps and randomly place vegetation plots with no knowledge of on-site conditions. Ten plots were placed in each of the seeding zones (W1, W2, W3, U3), for a total of 20-40 plots per wetland bank, depending on the number of seed mixes used at each site (see Table 2). Maps of the survey plots can be found in Appendix B. The georeferenced PDFs with the plot locations were uploaded to the mobile app Avenza Maps. Once on-site, this app was used to navigate to the predetermined plot locations.

At each location, a 1-m^2 quadrat constructed from PVC pipe was laid down, which served as the frame for the vegetation survey. All the species that were rooted within the plot were recorded, as well as an ocular estimate of the aerial cover of each species. These measures were always recorded by the same two people, and were not repeated, so subjectivity of the ocular cover estimates is not a concern. Bare ground cover was negligible in the plots, but there were some areas of unvegetated open water in the W1 seeding zone. Data from the plot-based surveys were used in the analyses of native cover, invasive cover, plot-level native richness, and guild cover, as well as in the rankings of the most common species.

2. Timed Meanders

In addition to the plot-based vegetation survey, a timed meander was also performed. The goal of the timed meander was to gather a better estimate of the total species richness, as some species may not have been recorded in the plots. The base meander time was calculated according to the MPCA Rapid Floristic Quality Assessment Manual, as follows: 30 minutes for the first seeding zone + 20 minutes for each additional seeding zone. We traversed the site back and forth, crossing into and out of the different seeding zones, with no designated pattern. As we walked, we recorded every species we saw, including species that occurred both within and outside of our plots. We meandered and recorded species until our predetermined amount of time was up, or no more than three new species were found within the last 5-minutes.

D. Statistical Analyses

All statistical tests were conducted in SPSS version 24. Prior to statistical testing, all the data were subjected to an outlier test, a Shapiro-Wilk test for normality, and a Levene's test for homogeneity of variances.

1. Seeding Zone Comparison

Species were categorized as native, non-native, or invasive using the USDA PLANTS Database. Non-native species are introduced by humans, but do not displace native species. Native species richness was calculated at both the plot and site level. Plot level native richness is the number of native species per $1m^2$ plot. Richness values were averaged across the 10 plots in a given seeding zone at a given site. Zone-level native richness is defined as the total number of species within each seeding zone on a given site. This number was determined by compiling a list of all species that were recorded in the plots as well as during the timed meander, with each species counted only once per site. This resulted in one site-level richness value per seeding zone per site.

Using the full species list compiled for the site-level species richness analysis, each species was marked as seeded or not seeded. This designation was determined using the species list for each seed mix found on BWSR's website. As the seed mixes are standard, we can assume that the same species were planted at each site. The total number of seeded species present was counted for each seeding zone. To standardize this measure, the count of seeded species present was converted to a percent by dividing by the total number of species included in each of the seed mixes (W1 – 22, W2 – 33, W3 – 36, U3 – 30).

For the native cover and invasive cover analyses, the ocular estimates of cover for each species were converted to relative cover so that the total plant cover within each plot sums to 100. As with plot-level richness, native cover and invasive cover were averaged across the 10 plots in each seeding zone at each site.

Average plot-level richness, zone-level richness, percent of planted species present, native cover, and invasive cover were compared across the four seeding zones using a one-way analysis of variance (ANOVA). A one-way ANOVA is used to test whether there are statistically significant differences between the means of three or more groups. ANOVA assumptions include independence of observations, an approximately normal distribution, and homogeneity of variances. The one-way ANOVA is robust to violations of these assumptions, meaning the Type I error rate (chance of a false positive) is little affected when the assumptions are not met. Accordingly, an ANOVA was used even in the infrequent instances when there were slight violations to the normality assumption. In the analyses, the groups are the four seeding zones. Seeding zone means were compared using a one-way ANOVA of site means. This approach prevents pseudoreplication, which would occur if each plot were treated as an independent measure. An alpha level of 0.05 was used to determine statistical significance. When the ANOVA produced a significant result, a Gabriel post-hoc test was conducted to discern which means were statistically different from one another.

The Gabriel post-hoc test is a pairwise comparison test that uses the Studentized maximum modulus. It is appropriate when the data are assumed to have equal variance and the group sizes are unequal. It is generally more powerful than Hochberg's GT2, but should be used when group sizes are only slightly unequal, as is the case in my data where n ranges from 5-8 (Andy Field, 2016).

2. Community Composition

To get an idea of community composition, the average relative cover across all sites was calculated for each species within each seeding zone. The species within each seeding zone were then ranked from highest to lowest average relative cover. Species within each seeding zone were also ranked based on frequency, which is the percentage of the surveyed plots that they occurred within. This metric was expressed as a percentage to facilitate comparisons across seeding zones with different numbers of plots. Lists of the top 10 most common species in each seeding zone for two different metrics were produced. More than 10 species were listed when there was a tie for 10^{th} place. Note that *Typha angustifolia* and *Typha x glauca* were combined, as both species exhibit invasive behavior and are difficult to distinguish in the field. They are hereafter referred to collectively as "narrow-leaved cattails" or "invasive cattails".

Additionally, native species were placed into the following guilds: warm season grass, cool season grass, sedge/rush, woody, and forb. Sedges and rushes were combined into one guild to ensure there were enough data points for statistical analysis. Native average relative cover was calculated for each of the five guilds within each seeding zone using the site means, as described in the previous section.

Within each seeding zone, mean native cover was compared across the five guilds using site means with either a one-way ANOVA (for normal data) or a Kruskal-Wallis test (for non-normal data). As described above, this approach prevents pseudoreplication. The Kruskal-Wallis test is the non-parametric equivalent of a one-way ANOVA and compares the mean rank of three or more groups. Although the one-way ANOVA is robust to violations of the normality assumption, a Kruskal-Wallis test was used here as a more conservative approach since the sample size is quite small. The default for Kruskal-Wallis in SPSS is a Dunn's post hoc test on each pair of groups. The Bonferroni adjustment is automatically made to the p-value to account for multiple tests being carried out (which increases the chance of a Type I error). An alpha level of 0.05 was used to determine statistical significance.

3. Species & Guild Resiliency

An evaluation of invasion resilience was conducted by dividing the plots into two categories: high and low invasive cover. "High" invasive cover plots were those with greater than 20% relative cover when all invasive species were combined, and "low" plots had less than 20% combined invasive cover. 20% is a common limit for vegetation standards on many wetland restorations. Using these two subsets of plots, the frequency and the average relative cover across all sites was calculated for each species within each seeding zone. A list of the top 10 species for each of these metrics generated for both the areas of high and low invasive cover within each seeding zone. More than 10 species were listed when there was a tie for 10th place.

Average native cover within each seeding zone was calculated for each of the five guilds (warm season grass, cool season grass, sedge/rush, woody, and forb) using the two subsets of plots. Again, the seeding zone mean was calculated using the means from individual sites. Group sizes were frequently smaller than the number of groups, so it was impossible to perform meaningful statistical tests on this subset of data. Instead, bar graphs are presented to provide a visual of the community composition by guild within areas of high and low invasive cover.

III. Results

A. Seeding Zone Comparison

1. Plot-Level Native Species Richness

Average plot-level native richness ranged across the sites from 0.5–5.6 in the W1 zone, 3.8–6.9 in the W2 zone, 4.6–6.8 in the W3 zone, and 2–8.6 in the U3 zone. This data can be found in Appendix C. A Shapiro-Wilk test showed that the data was not statistically different from a normal distribution ($p>0.05$). A Levene's test confirmed the equal variance assumption had been met ($p>0.05$). The ANOVA results indicate that average plot-level richness is not equal across the four seeding zones ($p = 0.009$). The post-hoc test revealed that the W1 seeding zone has significantly lower plot-level richness than the W3 and U3 seeding zones.

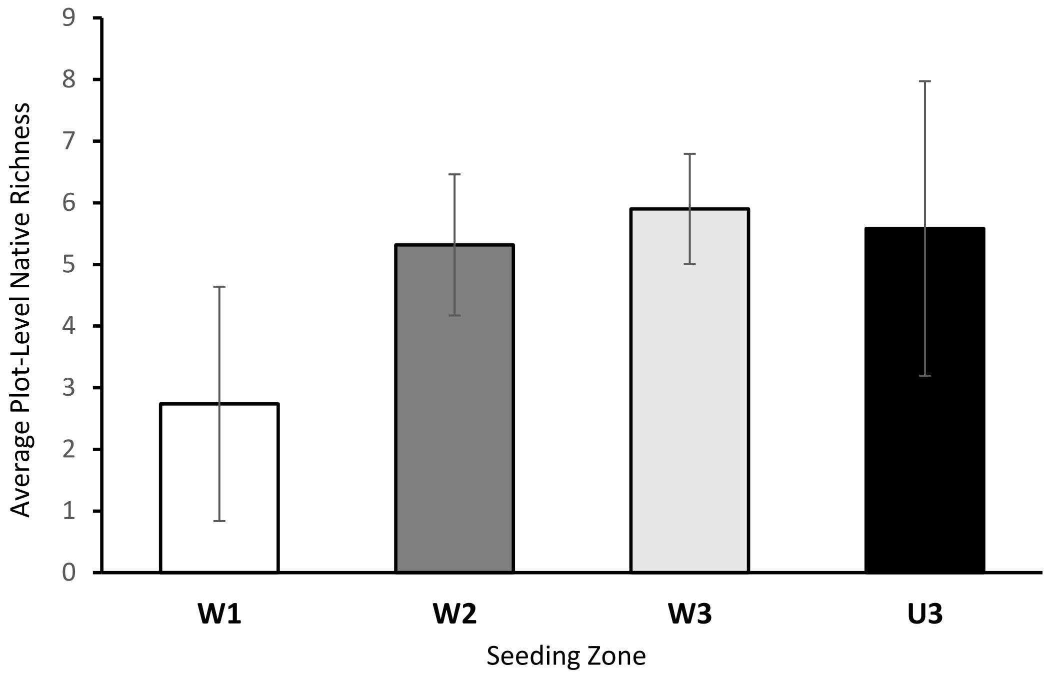

Figure 2. Average plot-level native richness compared across four seeding zones. Error bars represent one standard deviation. Plot-level richness was significantly lower in the W1 zone than in the W3 and U3 zone.

2. Zone-Level Native Species Richness

Average zone-level native richness ranged across the sites from 13–34 in the W1 zone, 32–64 in the W2 zone, 36–55 in the W3 zone, and 24–46 in the U3 zone. This data can be found in Appendix C. The Strolberg site had an unusually high zone-level richness (34) for the W1 mix and was confirmed to be an outlier but was not excluded from the analysis.

A Shapiro-Wilk test showed that the data was not statistically different from a normal distribution ($p>0.05$). A Levene's test confirmed the equal variance assumption had been met ($p>0.05$). The ANOVA results indicate that there is a statistically significant difference in average zone-level richness across the four seeding zones ($p = 0.000$). The post-hoc test revealed that the W1 seeding zone has significantly lower zone-level richness than the W2 and W3 seeding zones. Figure 3 shows the native richness of each seeding zone, and breaks the richness value down into seeded species (those included in the seed mix) and volunteer natives (those not originally seeded within that zone).

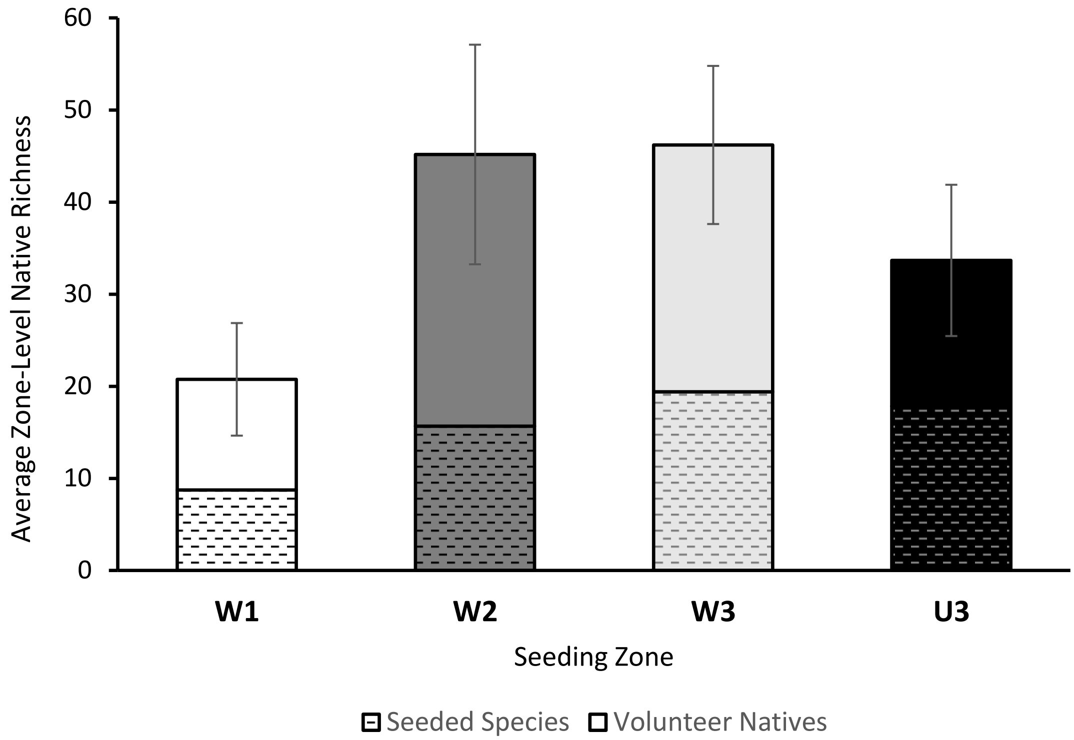

Figure 3. Average zone-level native richness compared across four seeding zones. Error bars represent one standard deviation. The number of seeded species in each zone is marked for reference. Zone-level richness was significantly lower in the W1 zone than in the W2 and W3 zone.

3. Percent of Seeded Species Present

The average percent of seeded species present ranged across the sites from 22.7–59.1% in the W1 zone, 36.3–66.7% in the W2 zone, 38.9–66.7% in the W3 zone, and 40–76.7% in the U3 zone. This data can be found in Appendix C. A Shapiro-Wilk test showed that the data meet the normality assumption ($p>0.05$). A Levene's test confirmed the equal variance assumption had also been met ($p>0.05$). According to the ANOVA, there is no statistically significant difference in the average percent of seeded species present across the four seeding zones ($p = 0.082$).

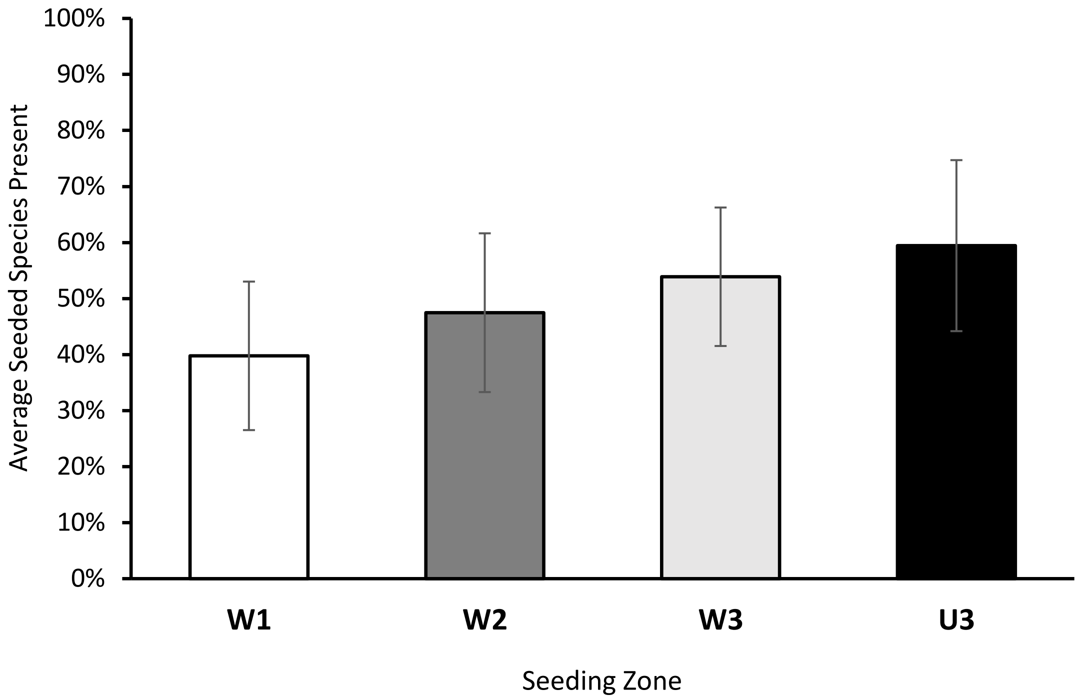

Figure 4. Average seeded species present across four seeding zones. Error bars represent one standard deviation. There were no statistically significant differences between the seeding zones.

4. Native Species Cover

The average relative native species cover ranged across the sites from 8.5–56.8% in the W1 zone, 35.7–78.3% in the W2 zone, 42.3–87.8% in the W3 zone, and 20.6–94.1% in the U3 zone. This data can be found in Appendix C. The Drummer site was an outlier for native species cover in the U3 seeding zone, with an average cover of 20.6% while the rest of the sites ranged from 88.1% to 94.1%. This can be explained by a high presence of Kentucky bluegrass which is categorized as a non-native species. It cannot be determined if this is an error in the data, so the site was not excluded from the analysis.

A Shapiro-Wilk test showed that the data was slightly statistically different from a normal distribution ($p = 0.048$). The p-value is very close to the significance level of 0.05 and therefore the ANOVA was still conducted. A Levene's test confirmed the equal variance assumption had been met ($p>0.05$). The ANOVA results indicate that there is a statistically significant difference in average native species cover across the four seeding zones ($p = 0.001$). The post-hoc test revealed that the W1 seeding zone has significantly lower native cover than the W3 and U3 seeding zones.

5. Invasive Species Cover

The average relative invasive species cover ranged across the sites from 28.8–60.1% in the W1 zone, 9.7–51.9% in the W2 zone, 1.2–44.2% in the W3 zone, and 2.4–13.2% in the U3 zone. This data can be found in Appendix C. A Shapiro-Wilk test showed that normality assumption had been met ($p>0.05$). A Levene's test revealed the data also met the equal variance assumption ($p>0.05$). According to the ANOVA, average invasive species cover was not equal across the four seeding zones ($p = 0.000$). The post-hoc test revealed the W1 zone had significantly higher invasive species cover than the W3 and U3 zones.

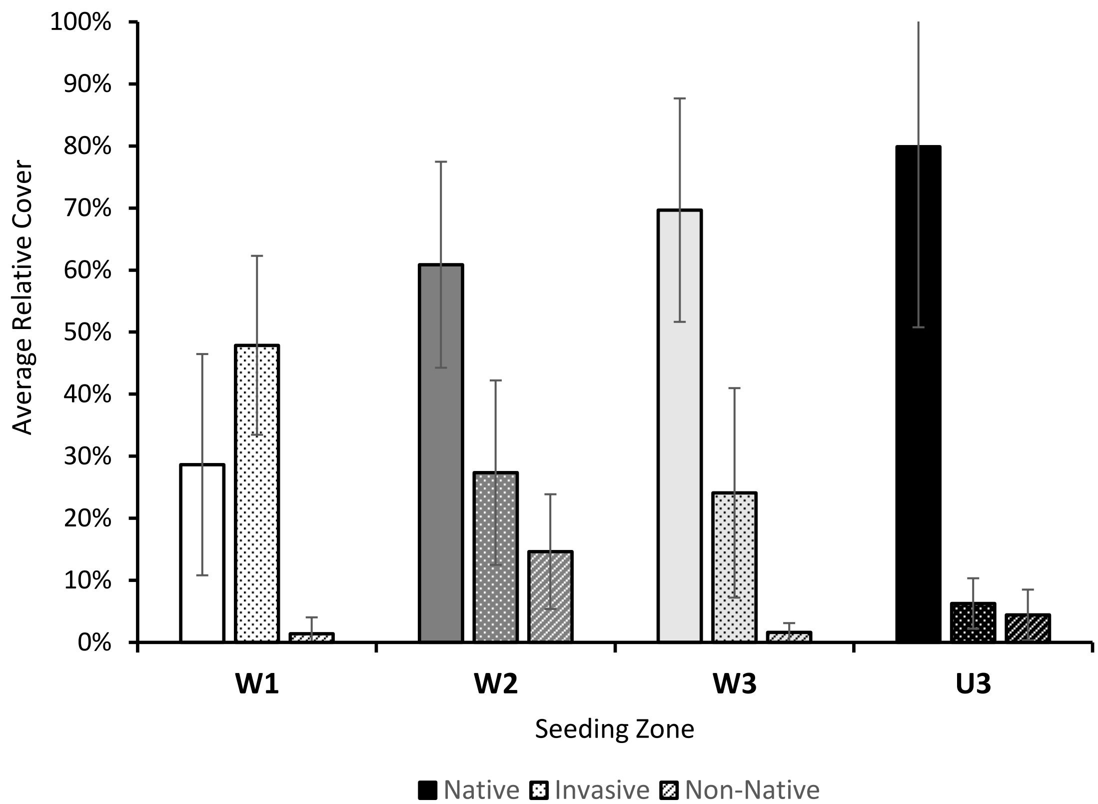

Figure 5. Average relative cover of native, invasive, and non-native species compared across four seeding zones. Error bars represent one standard deviation. Native cover was significantly lower, and invasive cover was significantly higher, in the W1 zone than in the W3 and U3 zone.

B. Community Composition

1. Emergent Wetland Zone

a) Most Common Species

The W1 zone was dominated by invasives, specifically narrow-leaved cattails and reed canary grass (*Phalaris arundinacea*), which occurred in more plots and had higher cover than any other species. Note that these cover estimates represent how much of the total seeding zone is covered by an individual species. The native species with the highest cover were several species of sedges and rushes, e.g. green bulrush (*Scirpus atrovirens*), river bulrush (*Bolboschoenus fluviatilis*), etc., as well as rice cutgrass (*Leersia oryzoides*). Note that duckweed, a small aquatic plant, had an average relative cover of around 22%.

Table 3. Top 10 species in the W1 seeding zone ranked by average relative cover.

W1 Emergent Wetland		
Species	**Common Name**	**Average Relative Cover**
*Typha angustifolia/x glauca**	Narrow-leaved cattails	33.9%
*Phalaris arundinacea**	Reed canary grass	13.8%
Scirpus atrovirens	Green bulrush	3.5%
Leersia oryzoides	Rice cutgrass	2.8%
Bolboschoenus fluviatilis	River bulrush	2.4%
Carex hystericina	Porcupine sedge	2.3%
Eleocharis palustris	Common spikerush	2.3%
Carex vulpinoidea	Fox sedge	1.5%
Carex lacustris	Lake sedge	1.3%
Glyceria grandis	American manna grass	1.1%

*Invasive species

Narrow-leaved cattails were found in over three-quarters of the plots. Softstem bulrush (*Schoenoplectus tabernaemontani*), swamp milkweed (*Asclepias incarnata*), and broadleaf arrowhead (*Sagittaria latifolia*) occurred in many of the plots but had low average cover. River bulrush (*Bolboschoenus fluviatilis*) and porcupine sedge (*Carex hystericina*) occurred infrequently but had high cover in the plots where they were present.

Table 4. Top 10 species in the W1 seeding zone ranked by frequency.

W1 Emergent Wetland		
Species	**Common Name**	**Frequency**
*Typha angustifolia/x glauca**	Narrow-leaved cattails	77.5%
*Phalaris arundinacea**	Reed canary grass	42.5%
Leersia oryzoides	Rice cutgrass	23.8%
Schoenoplectus tabernaemontani	Softstem bulrush	18.8%
Scirpus atrovirens	Green bulrush	16.3%
Asclepias incarnata	Swamp milkweed	13.8%
Eleocharis palustris	Common spikerush	13.8%
Poa palustris	Fowl bluegrass	12.5%
Sagittaria latifolia	Broadleaf arrowhead	12.5%
Carex vulpinoidea	Fox sedge	11.3%

*Invasive species

b) Uncommon or Absent Species

American slough grass (*Beckmannia syzigachne*) comprised 46% of the W1 seed mix but was not present in any of the quadrats. This is to be expected as it is an annual used as for cover while other natives get established. Giant bur-reed (*Sparganium eurycarpum*) comprised 10% of the mix, and was only seen during the timed meander. Blue-joint grass (*Calamagrostis canadensis*) and sweet flag (*Acorus calamus*) were other species included in the seed mix that did not appear in any of our W1 plots. Rattlesnake manna grass (*Glyceria canadensis*) was only seen on one site.

c) Guild Comparison

Looking at guilds, sedges/rushes had the highest average relative cover, followed by forbs and then cool-season grasses. A table showing cover values for the guilds can be found in Appendix D. A Shapiro-Wilk test showed that normality assumption was violated ($p<0.05$). A Levene's test revealed the data was also heteroscedastic ($p<0.05$). The Kruskal-Wallis test indicated that native species average relative cover was not equal across the five guilds ($p = 0.005$). The significance of this result was confirmed with a Welch's ANOVA (a test that does not assume equal variance). A post-hoc test revealed that sedge/rush cover was significantly higher than warm-season grass cover only. There were no other statistically significant differences between guilds.

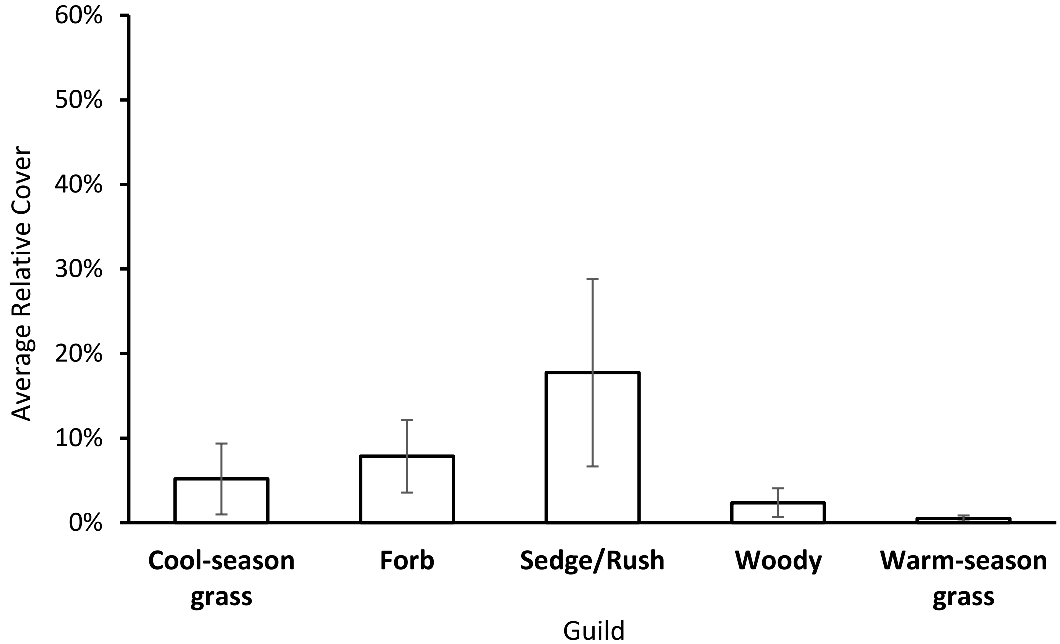

Figure 6. Native species average relative cover across five guilds in the W1 seeding zone. Error bars represent one standard deviation. Sedge/rush cover was significantly higher than warm season grass cover.

2. Wet Meadow Zone

a) Most Common Species

The W2 seeding zone had similar cover of native fowl bluegrass (*Poa palustris*) and invasive reed canary grass (*Phalaris arundinacea*). Invasive narrow-leaved cattails also had high cover. Other notable natives in terms of cover included fox sedge (*Carex vulpinoidea*) and green bulrush (*Scirpus atrovirens*).

Table 5. Top species in the W2 seeding zone ranked by average relative cover.

W2 Wet Meadow		
Species	**Common Name**	**Average Relative Cover**
*Phalaris arundinacea**	Reed canary grass	15.3%
Poa palustris	Fowl bluegrass	13.3%
*Typha angustifolia/x glauca**	Narrow-leaved cattails	9.5%
Carex vulpinoidea	Fox sedge	5.1%
Scirpus atrovirens	Green bulrush	4.3%
Symphyotrichum lanceolatum	Panicled aster	3.5%
Leersia oryzoides	Rice cutgrass	3.0%
Panicum virgatum	Switchgrass	2.5%
Zizia aurea	Golden Alexanders	1.8%
Helianthus grosseserratus	Sawtooth sunflower	1.6%
Equisetum arvense	Field horsetail	1.6%

*Invasive species

Fowl bluegrass (*Poa palustris*) was abundant throughout, occurring in over two-thirds of the plots. Rice cutgrass (*Leersia oryzoides*), switchgrass (*Panicum virgatum*), golden Alexanders (*Zizia aurea*), sawtooth sunflower (*Helianthus grosseserratus*) occurred infrequently but with high cover. Swamp milkweed (*Asclepias incarnata)*, awlfruit sedge (*Carex stipata)*, and purple-stemmed aster (*Symphyotrichum puniceum*) occurred in 20%+ of the plots but did not have high cover.

Table 6. Top 10 species in the W2 seeding zone ranked by frequency.

W2 Wet Meadow		
Species	**Common Name**	**Frequency**
Poa palustris	Fowl bluegrass	66.7%
*Phalaris arundinacea**	Reed canary grass	48.3%
Carex vulpinoidea	Fox sedge	35.0%
*Typha angustifolia/x glauca**	Narrow-leaved cattails	33.3%
Scirpus atrovirens	Green bulrush	26.7%
Asclepias incarnata	Swamp milkweed	25.0%
Symphyotrichum laeve	Smooth blue aster	23.3%
Carex stipata	Awlfruit sedge	20.0%
Symphyotrichum puniceum	Purple-stemmed aster	20.0%
Elymus virginicus	Virginia wildrye	16.7%

*Invasive species

b) Uncommon or Absent Species

The only species included in the W2 mix that were not found at any of our site surveys were Canada anemone (*Amenone canadensis*) and Joe-pye weed (*Eutrochium maculatum*). As with the W1 zone, American slough grass (*Beckmannia syzigachne*) and blue-joint grass (*Calamagrostis canadensis*) were only seen during the timed meander, not in the quadrats. Fringed brome (*Bromus ciliatus*), grass-leaved goldenrod (*Euthamia graminifolia*), fowl manna grass (*Glyceria striata*), blue-flag iris (*Iris versicolor*), great-blue lobelia (*Lobelia siphilitica*), and Culver's root (*Veronicastrum virginicum*) were also rarely seen.

c) Guild Comparison

Average relative cover was nearly even across native cool-season grasses, forbs, and sedges/rushes. A table showing cover values for the guilds can be found in Appendix D. A Shapiro-Wilk test showed that normality assumption was violated ($p<0.05$). A Levene's test met the homogeneous variance assumption ($p>0.05$). The Kruskal-Wallis test indicated that native species average relative cover was not equal across the five guilds ($p = 0.007$). The post-hoc test revealed that cool-season grass cover was significantly higher that woody cover. There were no other statistically significant differences between guilds.

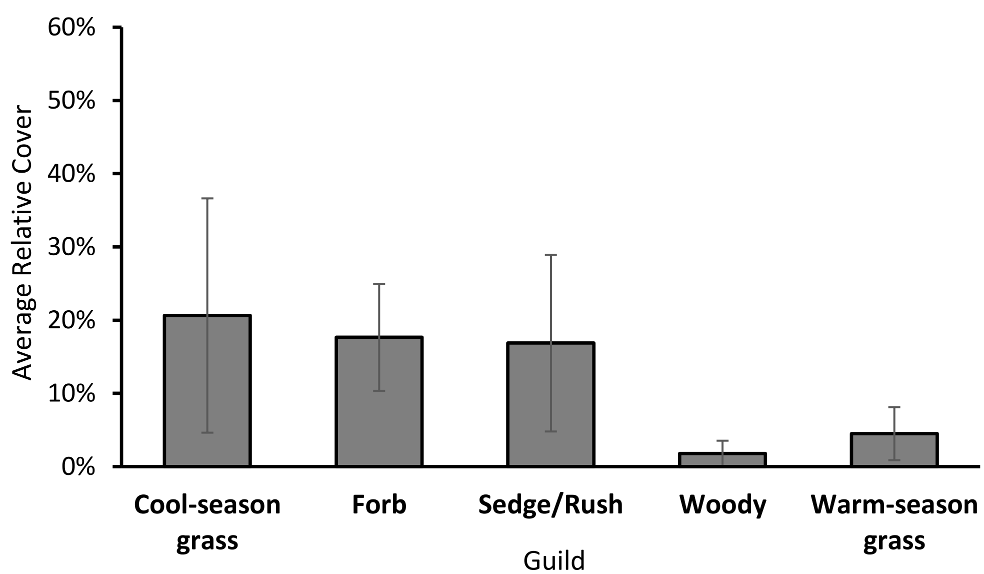

Figure 7. Native species average relative cover across five guilds in the W2 seeding zone. Error bars represent one standard deviation. Cool-season grass cover was significantly higher than woody cover.

3. Wet Prairie Zone

a) Most Common Species

Reed canary grass (*Phalaris arundinacea*) had the highest cover of any species, followed by fowl bluegrass (*Poa palustris*), switchgrass (*Panicum virgatum),* and big bluestem (*Andropogon gerardii*). Narrow-leaved cattails had substantially less cover in this zone than in the W1 and W2 zones.

Table 7. Top 10 species in the W3 seeding zone ranked by average relative cover.

W3 Wet Prairie		
Species	**Common Name**	**Average Relative Cover**
*Phalaris arundinacea**	Reed canary grass	17.0%
Poa palustris	Fowl bluegrass	7.9%
Panicum virgatum	Switchgrass	7.0%
Andropogon gerardii	Big bluestem	5.7%
Symphyotrichum laeve	Smooth blue aster	5.0%
*Typha angustifolia/x glauca**	Narrow-leaved cattails	4.3%
Zizia aurea	Golden Alexanders	4.2%
Leersia oryzoides	Rice cutgrass	4.1%
Spartina pectinata	Prairie cordgrass	3.8%
Scirpus atrovirens	Green bulrush	2.9%

*Invasive species

Fowl bluegrass (*Poa palustris*) was present in over 50% of the plots, more than any other species. Reed canary grass (*Phalaris arundinacea*) occurred in just under half of the plots. Desirable forbs for pollinators such as smooth blue aster (*Symphyotrichum laeve*), golden alexanders (*Zizia aurea*), swamp milkweed (*Asclepias incarnata*), and sawtooth sunflower were all common throughout (*Helianthus grosseserratus*), though swamp milkweed and sawtooth sunflower had low cover. Canada thistle (*Cirsium arvense*) was present in 22% of the plots but with low cover.

Table 8. Top 10 species in the W3 seeding zone ranked by frequency.

W3 Wet Prairie		
Species	**Common Name**	**Frequency**
Poa palustris	Fowl bluegrass	58.0%
*Phalaris arundinacea**	Reed canary grass	46.0%
Symphyotrichum laeve	Smooth blue aster	40.0%
*Typha angustifolia/x glauca**	Narrow-leaved cattails	36.0%
Zizia aurea	Golden Alexanders	34.0%
Panicum virgatum	Switchgrass	32.0%
Asclepias incarnata	Swamp milkweed	28.0%
Andropogon gerardii	Big bluestem	22.0%
*Cirsium arvense**	Canada thistle	22.0%
Helianthus grosseserratus	Sawtooth sunflower	22.0%
Leersia oryzoides	Rice cutgrass	22.0%
Scirpus atrovirens	Green bulrush	22.0%

*Invasive species

b) Uncommon or Absent Species

Most grasses seemed to be well-established, except for Indian grass (*Sorghastrum nutans*), blue-joint grass (*Calamagrostis canadensis*), and fringed brome (*Bromus ciliata*) which did not appear in any of the plots. Canada anemone (*Amenone canadensis*), grass-leaved goldenrod (*Euthamia graminifolia*), both Glyceria species, great-blue lobelia (*Lobelia siphilitica*), and Culver's root (*Veronicastrum virginicum*) were also rare. Blue-flag iris (*Iris versicolor*) was not seen on any of the sites.

c) Guild Comparison

Across guilds in the wet prairie zone, forbs had the highest average relative cover, followed by warm-season grasses, and then cool-season grasses. A table showing cover values for the guilds can be found in Appendix D. A Shapiro-Wilk test showed that the data was not statistically different from a normal distribution ($p>0.05$). A Levene's test confirmed the equal variance assumption had been met ($p>0.05$). The results of the one-way ANOVA indicate that there was no statistically significant difference in native species average relative cover across the five guilds ($p = 0.053$).

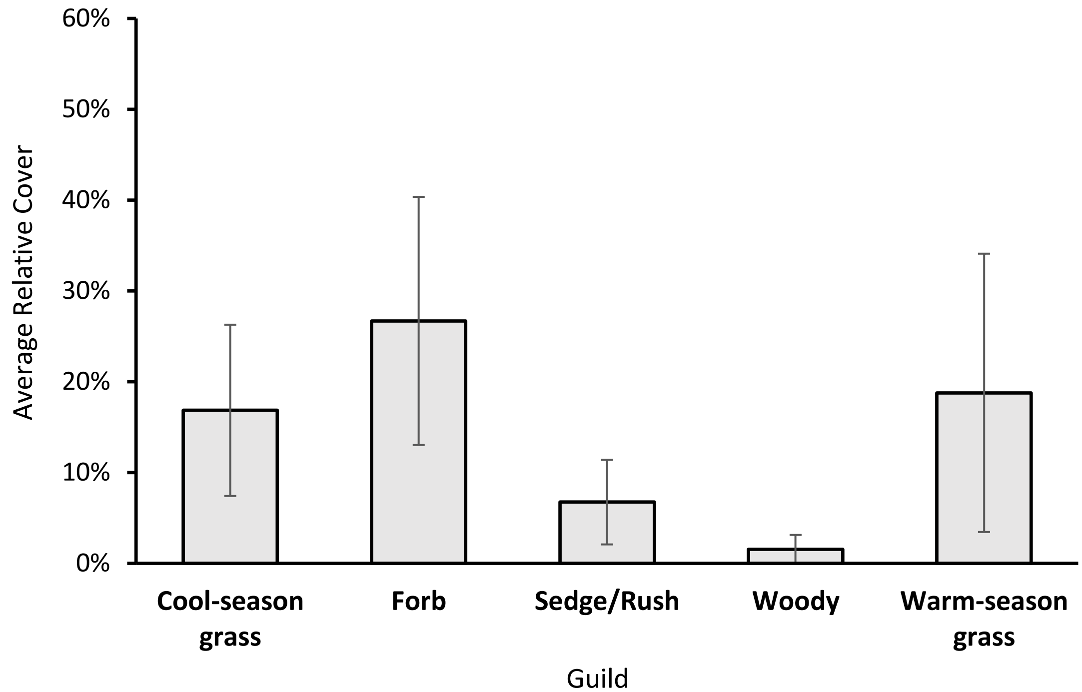

Figure 8. Native species average relative cover across five guilds in the W3 seeding zone. Error bars represent one standard deviation. There were no statistically significant differences among guilds.

4. Mesic Prairie Zone

a) Most Common Species

U3 was the only seeding zone with a native species (big bluestem) ranked highest in terms of relative cover. Other native grasses such as little bluestem (*Schizachyrium scoparium*), Canada wildrye (*Elymus canadensis*), and switchgrass (*Panicum virgatum*), and forbs including wild bergamot (*Monarda fistulosa*), golden Alexanders (*Zizia aurea*), and stiff goldenrod (*Solidago rigida*) also had high cover.

Table 9. Top 10 species in the U3 seeding zone ranked by average relative cover.

U3 Mesic Prairie		
Species	**Common Name**	**Average Relative Cover**
Andropogon gerardii	Big bluestem	22.0%
Poa pratensis	Kentucky bluegrass	10.6%
Schizachyrium scoparium	Little bluestem	10.0%
Monarda fistulosa	Wild bergamot	8.5%
Elymus canadensis	Canada wildrye	5.8%
Panicum virgatum	Switchgrass	4.5%
Poa palustris	Fowl bluegrass	3.7%
Solidago rigida	Stiff goldenrod	3.6%
*Cirsium arvense**	Canada thistle	3.5%
Zizia aurea	Golden Alexanders	3.5%

*Invasive species

Canada thistle (*Cirsium arvense*) proved to be a worrisome invasive, occurring in half of all plots, though its cover was low. Common dandelion (*Taraxacum officinale*) also appeared in nearly half the plots. Wild bergamot (*Monarda fistulosa*) and gray-headed cone flower (*Ratibida pinnata*) were common but did not have high average cover.

Table 10. Top 10 species in the U3 seeding zone ranked by frequency.

U3 Mesic Prairie		
Species	**Common Name**	**Frequency**
Andropogon gerardii	Big bluestem	71.7%
*Cirsium arvense**	Canada thistle	50.0%
Taraxacum officinale	Common dandelion	48.3%
Zizia aurea	Golden Alexanders	45.0%
Panicum virgatum	Switchgrass	38.3%
Schizachyrium scoparium	Little bluestem	35.0%
Solidago rigida	Stiff goldenrod	35.0%
Elymus canadensis	Canada wildrye	33.3%
Monarda fistulosa	Wild bergamot	28.3%
Ratibida pinnata	Gray-headed coneflower	25.0%

*Invasive species

b) Uncommon or Absent Species

All the grasses in the U3 zone were abundant, except for tall dropseed (*Sporobolus asper*), western wheat-grass (*Elytrigia smithii*), and green needlegrass (*Nassella* *viridula*). Of the forbs, partridge pea (*Chamaecrista fasciculata*) and showy penstemon (*Penstemon grandifloras*) were rare, and rough blazingstar (*Liatris aspera*) was not seen on any of the sites.

c) Guild Comparison

In the mesic prairie zone, the guild with the highest average relative cover was warm-season grasses, followed by forbs, then cool-season grasses. There was negligible cover of the sedge/rush and woody guilds. A table showing cover values for the guilds can be found in Appendix D. A Shapiro-Wilk test showed that the data was slightly statistically different from a normal distribution (p=0.047). A Levene's test confirmed the equal variance assumption had been met (p>0.05). The results of the one-way ANOVA indicate that there was no statistically significant difference in native species average relative cover across the five guilds (p = 0.092). This result was confirmed with the non-parametric Kruskal-Wallis test.

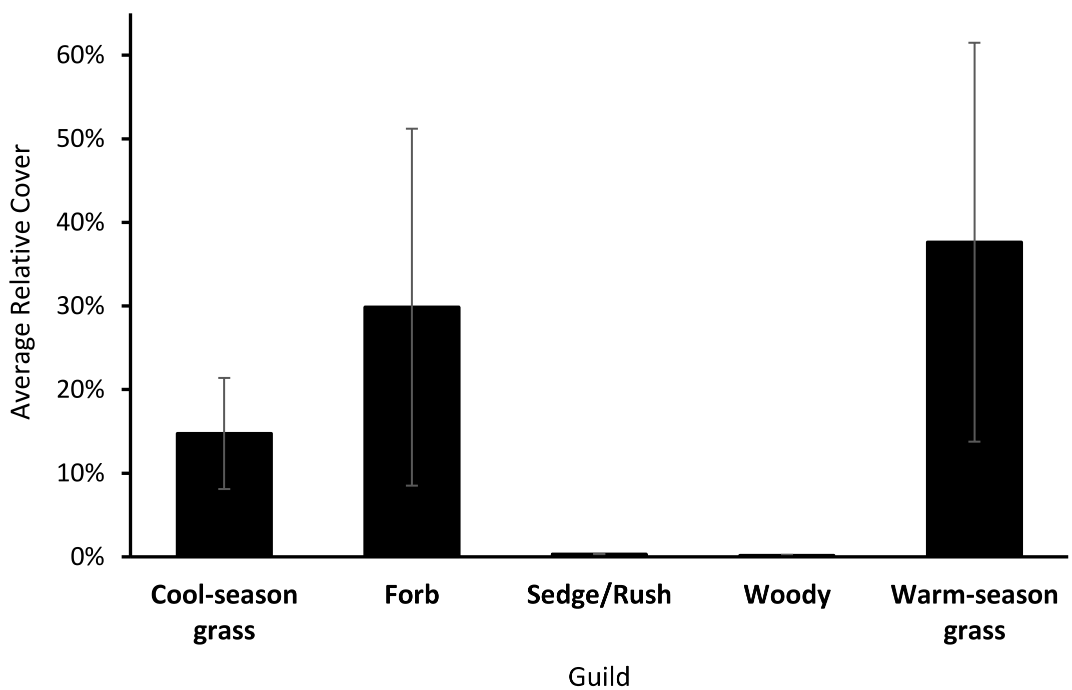

Figure 9. Native species average relative cover across five guilds in the U3 seeding zone. Error bars represent one standard deviation. There were no statistically significant differences among guilds.

C. Species & Guild Resiliency

1. Emergent Wetland Zone

a) High Invasion Areas

Across the eight sites, there were a total of 58 plots in the W1 seeding zone with >20% cover of invasive species. The primary invasive species in this subset of plots were narrow-leaved cattails, which occurred in 86.2% of the plots with an average relative cover of 42.8%, and reed canary grass, which occurred in 48.3% of the plots with an average relative cover of 16.3%. The native species with the highest cover in these plots was by far rice cutgrass, followed by porcupine sedge and green bulrush (Table 11). Note that, as above, these cover estimates represent how much of the total seeding zone is covered by an individual species.

Table 11. Top 10 native species by cover when invasive cover is greater than 20% in the W1 seeding zone.

W1 Emergent Wetland		
Species	**Common Name**	**Average Relative Cover**
Leersia oryzoides	Rice cutgrass	3.5%
Carex hystericina	Porcupine sedge	2.2%
Scirpus atrovirens	Green bulrush	2.2%
Bidens cernua	Nodding beggarticks	1.2%
Symphyotrichum laeve	Smooth blue aster	1.1%
Bolboschoenus fluviatilis	River bulrush	1.1%
Alisma triviale	Northern water plantain	0.8%
Eleocharis palustris	Common spikerush	0.7%
Glyceria grandis	American manna grass	0.6%
Sagittaria latifolia	Broadleaf arrowhead	0.6%

Rice cutgrass (*Leersia oryzoides*) also appeared with the greatest frequency in the highly invaded plots (Table 12). While softstem bulrush (*Schoenoplectus tabernaemontani*) was not one of the natives with the highest cover, it was the second most frequent native species. Swamp milkweed (*Asclepias incarnata*), fox sedge (*Carex vulpinoidea*), and water smartweed (*Persicaria amphibia*) also appeared in a high percentage of the plots but with low cover. Nodding beggarticks (*Bidens cernua*) and American manna grass (*Glyceria grandis*) had higher cover but occurred infrequently.

Table 12. Top native species by frequency when invasive cover is greater than 20% in the W1 seeding zone.

W1 Emergent Wetland		
Species	**Common Name**	**Frequency**
Leersia oryzoides	Rice cutgrass	24.1%
Schoenoplectus tabernaemontani	Softstem bulrush	17.2%
Sagittaria latifolia	Broadleaf arrowhead	13.8%
Alisma triviale	Northern water plantain	12.1%
Asclepias incarnata	Swamp milkweed	12.1%
Eleocharis palustris	Common spikerush	10.3%
Scirpus atrovirens	Green bulrush	10.3%
Carex hystericina	Porcupine sedge	8.6%
Carex vulpinoidea	Fox sedge	8.6%
Persicaria amphibia	Water smartweed	8.6%
Poa palustris	Fowl bluegrass	8.6%
Bolboschoenus fluviatilis	River bulrush	8.6%
Symphyotrichum laeve	Smooth blue aster	8.6%

b) Low Invasion Areas

There was a total of 18 plots in the W1 seeding zone with <20% cover of invasive species. In this subset of plots, narrow-leaved cattails occurred in 55.6% of the plots with an average of 3.6% cover, and reed canary grass occurred in 22.2% of the plots with an average of 1.5% cover. Interestingly, rice cutgrass (*Leersia oryzoides*) becomes dramatically less common in these areas of low invasion. Instead, the native species with the highest cover are green bulrush (*Scirpus atrovirens*), common spikerush (*Eleocharis palustris*), river bulrush (*Bolboschoenus fluviatilis*), and lake sedge (*Carex lacustris*) (Table 13). Common spikerush (*Eleocharis palustris*), fox sedge (*Carex vulpinoidea*), and fowl bluegrass (*Poa palustris*) are noticeably more abundant. Broadleaf cattail (*Typha latifolia*) also has higher cover in these areas where there is less invasion pressure from narrow-leaved cattails.

Table 13. Top 10 native species by cover when invasive cover is less than 20% in the W1 seeding zone.

W1 Emergent Wetland		
Species	**Common Name**	**Average Relative Cover**
Scirpus atrovirens	Green bulrush	8.3%
Eleocharis palustris	Common spikerush	8.0%
Bolboschoenus fluviatilis	River bulrush	7.4%
Carex lacustris	Lake sedge	5.6%
Carex vulpinoidea	Fox sedge	4.8%
Equisetum arvense	Field horsetail	3.3%
Carex hystericina	Porcupine sedge	3.1%
Glyceria grandis	American manna grass	3.0%
Typha latifolia	Broadleaf cattail	2.6%
Poa palustris	Fowl bluegrass	1.6%

Green bulrush (*Scirpus atrovirens*) and common spikerush (*Eleocharis palustris*) also appeared with the greatest frequency in these plots (Table 14). Forbs like swamp milkweed (*Asclepias incarnata*), Canada goldenrod (*Solidago canadensis*), and sawtooth sunflower (*Helianthus grosseserratus*) occurred frequently in the plots but did not have high cover. River bulrush (*Bolboschoenus fluviatilis*), lake sedge (*Carex lacustris*), and field horsetail (*Equisetum arvense*) occurred infrequently, but had high cover where they did occur.

Table 14. Top 10 native species by frequency when invasive cover is less than 20% in the W1 seeding zone.

W1 Emergent Wetland		
Species	**Common Name**	**Frequency**
Scirpus atrovirens	Green bulrush	38.9%
Eleocharis palustris	Common spikerush	27.8%
Leersia oryzoides	Rice cutgrass	27.8%
Poa palustris	Fowl bluegrass	27.8%
Asclepias incarnata	Swamp milkweed	22.2%
Carex vulpinoidea	Fox sedge	22.2%
Schoenoplectus tabernaemontani	Softstem bulrush	22.2%
Solidago canadensis	Canada goldenrod	22.2%
Carex stipata	Awlfruit sedge	16.7%
Helianthus grosseserratus	Sawtooth sunflower	16.7%
Panicum virgatum	Switchgrass	16.7%
Symphyotrichum puniceum	Purple-stemmed aster	16.7%
Typha latifolia	Broadleaf cattail	16.7%

c) Guild Comparison

The overall composition of guilds appears to be the same between areas of high and low invasive cover (Figure 10). In both areas, sedges/rushes have the highest cover, followed by forbs, then cool-season grasses. As one would expect, average native cover of sedges/rushes and forbs was higher when invasive cover was low. Oppositely, native cool-grass cover was slightly higher when invasive cover was high, due to high rice cutgrass cover. These results are not statistically significant. A table showing cover values for the guilds in areas of high and low invasive cover can be found in Appendix E.

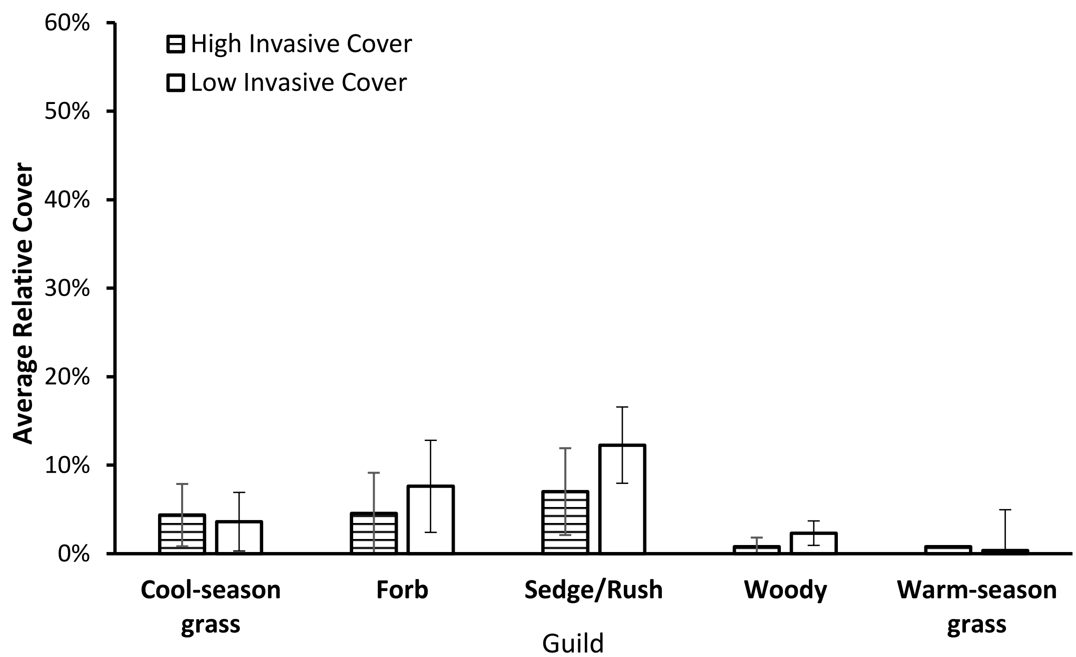

Figure 10. Native species average relative cover across five guilds in the W1 seeding zone, compared between areas of high and low invasive cover. Error bars represent one standard deviation.

2. Wet Meadow Zone

a) High Invasion Areas

Across the six sites, there were 27 plots total in the W2 seeding zone with >20% cover of invasive species. The primary invasive species in this subset of plots were reed canary grass, which occurred in 74.1% of the plots with an average relative cover of 42.8%, and narrow-leaved cattails, which occurred in 44.4% of the plots with an average relative cover of 13.9%. The native species with the highest cover in these plots was fowl bluegrass (*Poa palustris*), followed by fox sedge (*Carex vulpinoidea*) (Table 15).

Table 15. Top 10 native species by cover when invasive cover is greater than 20% in the W2 seeding zone.

W2 Wet Meadow		
Species	**Common Name**	**Average Relative Cover**
Poa palustris	Fowl bluegrass	6.1%
Carex vulpinoidea	Fox sedge	4.9%
Leersia oryzoides	Rice cutgrass	3.0%
Equisetum arvense	Field horsetail	2.3%
Scirpus atrovirens	Green bulrush	2.2%
Zizia aurea	Golden Alexanders	1.6%
Asclepias incarnata	Swamp milkweed	1.3%
Symphyotrichum lanceolatum	Panicled aster	1.3%
Elymus trachycaulus	Slender wheatgrass	1.2%
Carex stipata	Awlfruit sedge	1.2%

Fowl bluegrass (*Poa palustris*) was also the species that occurred with the greatest frequency, followed by swamp milkweed (*Asclepias incarnata*). Green bulrush (*Scirpus atrovirens*) occurred in a high percentage of the plots but had low cover. Virginia wildrye (*Elymus virginicus*), sawtooth sunflower (*Helianthus grosseserratus*), switchgrass (*Panicum virgatum*), and water smartweed (*Persicaria amphibia*) also had high frequency but did not appear in the top 10 species by cover.

Table 16. Top native species by frequency when invasive cover is greater than 20% in the W2 seeding zone.

W2 Wet Meadow		
Species	**Common Name**	**Frequency**
Poa palustris	Fowl bluegrass	48.1%
Asclepias incarnata	Swamp milkweed	33.3%
Carex vulpinoidea	Fox sedge	22.2%
Scirpus atrovirens	Green bulrush	22.2%
Symphyotrichum laeve	Smooth blue aster	22.2%
Equisetum arvense	Field horsetail	18.5%
Leersia oryzoides	Rice cutgrass	18.5%
Symphyotrichum puniceum	Purple-stemmed aster	18.5%
Sonchus arvensis	Perennial sow thistle	14.8%
Carex stipata	Awlfruit sedge	11.1%
Elymus virginicus	Virginia wildrye	11.1%
Helianthus grosseserratus	Sawtooth sunflower	11.1%
Panicum virgatum	Switchgrass	11.1%
Persicaria amphibia	Water smartweed	11.1%
Zizia aurea	Golden Alexanders	11.1%

b) Low Invasion Areas

There was a total of 31 plots in the W2 seeding zone with <20% cover of invasive species. In this subset of plots, reed canary grass occurred in 22.6% of the plots with an average of only 1.7% cover, and narrow-leaved cattails occurred in 19.3% of the plots with an average of 1.1% cover. Fowl bluegrass (*Poa palustris*) was by far the native species with the highest cover, covering 3 times more area than the next highest species, green bulrush (*Scirpus atrovirens*). Overall the composition of species in low invasion areas was quite different to that of high invasion areas, with switchgrass (*Panicum virgatum*), Canada wildrye (*Elymus canadensis*), bottlebrush sedge (*Carex comosa*), and sawtooth sunflower (*Helianthus grosseserratus*) replacing field horsetail (*Equisetum arvense*), golden Alexanders (*Zizia aurea*), and awlfruit sedge (*Carex stipata*).

Table 17. Top 10 native species by cover when invasive cover is less than 20% in the W2 seeding zone.

W2 Wet Meadow		
Species	**Common Name**	**Average Relative Cover**
Poa palustris	Fowl bluegrass	20.4%
Scirpus atrovirens	Green bulrush	6.3%
Symphyotrichum lanceolatum	Panicled aster	5.7%
Carex vulpinoidea	Fox sedge	4.1%
Panicum virgatum	Switchgrass	3.8%
Leersia oryzoides	Rice cutgrass	3.2%
Elymus canadensis	Canada wildrye	2.8%
Carex comosa	Bottlebrush sedge	2.5%
Helianthus grosseserratus	Sawtooth sunflower	2.3%
Elymus virginicus	Virginia wildrye	2.2%

Looking at frequency, the top three species, fowl bluegrass, fox sedge, and green bulrush) are the same as in the ranking by cover. Virginia wildrye and awlfruit sedge, as well as forbs like purple-stemmed aster, smooth blue aster, and swamp milkweed occur with great frequency but low cover. Grasses like rice cutgrass and Canada wildrye occur infrequently but with high cover.

Table 18. Top 10 native species by frequency when invasive cover is less than 20% in the W2 seeding zone.

W2 Wet Meadow		
Species	**Common Name**	**Frequency**
Poa palustris	Fowl bluegrass	87.1%
Carex vulpinoidea	Fox sedge	45.2%
Scirpus atrovirens	Green bulrush	32.3%
Carex stipata	Awlfruit sedge	29.0%
Symphyotrichum laeve	Smooth blue aster	25.8%
Elymus virginicus	Virginia wildrye	22.6%
Symphyotrichum puniceum	Purple-stemmed aster	22.6%
Asclepias incarnata	Swamp milkweed	19.4%
Panicum virgatum	Switchgrass	19.4%
Symphyotrichum lanceolatum	Panicled aster	19.4%

c) Guild Composition

In low invasion areas, all guilds have higher average cover than they do in areas of high invasive cover. In areas of low invasive cover, cool-season grasses have the highest relative cover, followed by forbs, then sedges/rushes. The average cover of cool-season grasses, forbs, and sedges/rushes is nearly equal in areas of high invasive cover. These results are not statistically significant. A table showing cover values for the guilds in areas of high and low invasive cover can be found in Appendix E.

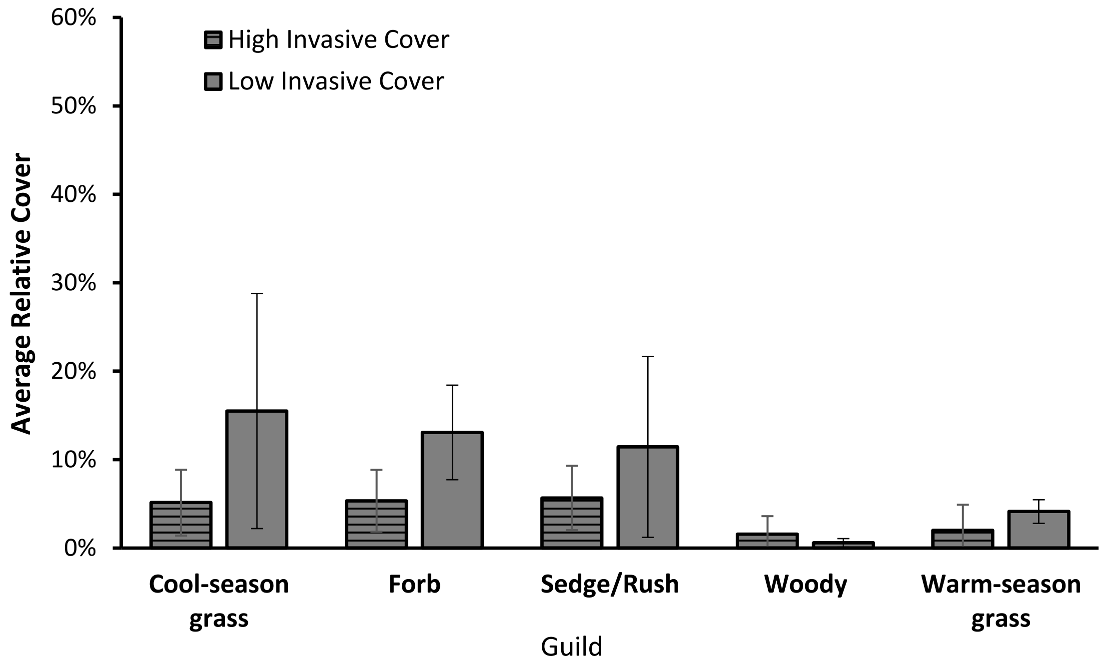

Figure 11. Native species average relative cover across five guilds in the W2 seeding zone, compared between areas of high and low invasive cover. Error bars represent one standard deviation.

3. Wet Prairie Zone

a) High Invasion Areas

In the W3 seeding zone, there were 19 plots total across the 5 sites with >20% cover of invasive species. The primary invasive species in this subset of plots were reed canary grass, which occurred in 78.9% of the plots with an average relative cover of 37.5%, and narrow-leaved cattails, which occurred in 57.9% of the plots with an average relative cover of 8.7%. The native species with the highest cover in these plots was fowl bluegrass (*Poa palustris*), followed by smooth blue aster (*Symphyotrichum laeve*), and rice cutgrass (*Leersia oryzoides*) (Table 19).

Table 19. Top 10 native species by cover when invasive cover is greater than 20% in the W3 seeding zone.

W3 Wet Prairie		
Species	**Common Name**	**Average Relative Cover**
Poa palustris	Fowl bluegrass	7.2%
Symphyotrichum laeve	Smooth blue aster	6.2%
Leersia oryzoides	Rice cutgrass	4.6%
Helenium autumnale	Common sneezeweed	3.3%
Eupatorium perfoliatum	Common boneset	3.0%
Spartina pectinata	Prairie cordgrass	3.0%
Scirpus atrovirens	Green bulrush	2.5%
Bolboschoenus fluviatilis	River bulrush	2.3%
Symphyotrichum puniceum	Purple-stemmed aster	2.1%
Zizia aurea	Golden Alexanders	2.0%

The most frequent native species in this subset of plots were nearly identical to those with the highest cover, suggesting that these species have high cover wherever they occur. The one exception was swamp milkweed (*Asclepias incarnata*) which occurred with high frequency but had low average cover.

Table 20. Top native species by frequency when invasive cover is greater than 20% in the W3 seeding zone.

W3 Wet Prairie		
Species	**Common Name**	**Abundance**
Poa palustris	Fowl bluegrass	52.6%
Symphyotrichum laeve	Smooth blue aster	42.1%
Leersia oryzoides	Rice cutgrass	31.6%
Helianthus grosseserratus	Sawtooth sunflower	26.3%
Spartina pectinata	Prairie cordgrass	26.3%
Symphyotrichum puniceum	Purple-stemmed aster	26.3%
Asclepias incarnata	Swamp milkweed	21.1%
Eupatorium perfoliatum	Common boneset	21.1%
Helenium autumnale	Common sneezeweed	21.1%
Scirpus atrovirens	Green bulrush	21.1%
Zizia aurea	Golden Alexanders	21.1%

b) Low Invasion Areas

There was a total of 29 plots in the W3 seeding zone with <20% cover of invasive species. In this subset of plots, invasive Canada thistle (*Cirsium arvense*) occurred in

31% of the plots with 1% average cover, and both narrow-leaved cattails and reed canary grass occurred in 24.1% of the plots with an average of 1.8% and 1.2% cover, respectively. Native cover in these plots was dominated by grasses. While fowl bluegrass (*Poa palustris*) was common in areas of high and low invasion, switchgrass (*Panicum virgatum*), big bluestem (*Panicum virgatum*), Virginia wildrye (*Elymus virginicus*), and little bluestem (*Schizachyrium scoparium*) had high cover only in areas of low invasive cover.

Table 21. Top 10 native abundant species by cover when invasive cover is less than 20% in the W3 zone.

W3 Wet Prairie		
Species	**Common Name**	**Average Relative Cover**
Panicum virgatum	Switchgrass	12.1%
Andropogon gerardii	Big bluestem	8.8%
Poa palustris	Fowl bluegrass	8.8%
Zizia aurea	Golden Alexanders	6.0%
Spartina pectinata	Prairie cordgrass	4.6%
Symphyotrichum laeve	Smooth blue aster	4.6%
Leersia oryzoides	Rice cutgrass	4.0%
Elymus virginicus	Virginia wildrye	3.9%
Schizachyrium scoparium	Little bluestem	3.8%
Scirpus atrovirens	Green bulrush	3.4%

Native species with the highest frequency were like those with the highest cover. The main differences were swamp milkweed (*Asclepias incarnata*) and rice cutgrass (*Leersia oryzoides*), which were frequent but had low cover where they occurred. While Virginia wildrye (*Elymus virginicus*) had higher cover, Canada wildrye (*Elymus canadensis*) was more frequent. Compared to the high invasion plots, big bluestem (*Andropogon gerardii*) and Canada wildrye were much more frequent (*Elymus canadensis*).

Table 22. Top 10 native species by frequency when invasive cover is less than 20% in the W3 seeding zone.

W3 Wet Prairie		
Species	**Common Name**	**Frequency**
Poa palustris	Fowl bluegrass	65.5%
Panicum virgatum	Switchgrass	51.7%
Zizia aurea	Golden Alexanders	44.8%
Symphyotrichum laeve	Smooth blue aster	41.4%
Andropogon gerardii	Big bluestem	34.5%
Asclepias incarnata	Swamp milkweed	34.5%
Scirpus atrovirens	Green bulrush	24.1%
Elymus canadensis	Canada wildrye	20.7%
Helianthus grosseserratus	Sawtooth sunflower	17.2%
Leersia oryzoides	Rice cutgrass	17.2%

c) Guild Comparison

Again, native species cover was higher across all guilds when invasive cover was low, except for woody species. Warm-season grass cover was dramatically higher in areas of low invasion than in highly invaded areas. Native forb cover was higher than other guilds in areas of high invasion. These results are not statistically significant. A table showing cover values for the guilds in areas of high and low invasive cover can be found in Appendix E.

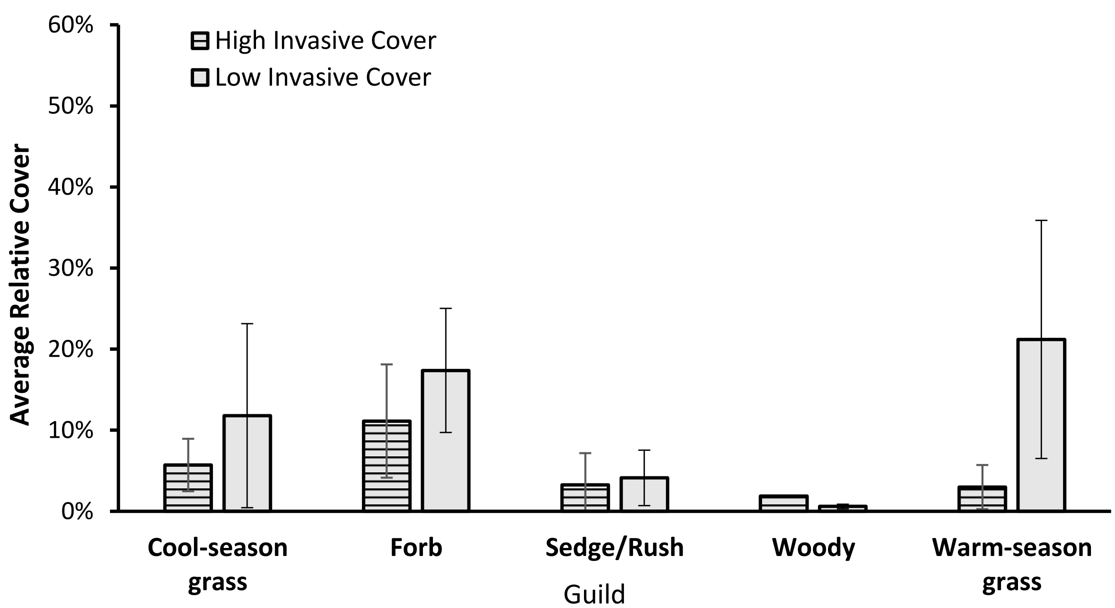

Figure 12. Native species average relative cover across five guilds in the W3 seeding zone, compared between areas of high and low invasive cover. Error bars represent one standard deviation.

4. Mesic Prairie Zone

a) High Invasion Areas

Across all six sites, there were only 5 plots with >20% invasive cover with the U3 seeding zone. The results presented below are not particularly meaningful, as the lists contain all the species found within this small subset of plots. Therefore, they should be interpreted with caution. The invasive species of concern in these plots is Canada thistle (*Cirsium arvense*), which occurred with a frequency of 100% and an average relative cover of 23.5%. Big bluestem (*Andropogon gerardii*) was the dominant native species in this subset of plots. Canada wildrye (*Elymus canadensis*), little bluestem (*Schizachyrium scoparium*), and partridge pea (*Chamaecrista fasciculata*) also had high cover.

Table 23. Top 10 native species by cover when invasive cover is greater than 20% in the U3 seeding zone.

U3 Mesic Prairie		
Species	**Common Name**	**Average Relative Cover**
Andropogon gerardii	Big bluestem	30.5%
Elymus canadensis	Canada wildrye	12.1%
Schizachyrium scoparium	Little bluestem	11.0%
Chamaecrista fasciculata	Partridge pea	9.8%
Solidago rigida	Stiff goldenrod	4.0%
Panicum virgatum	Switchgrass	2.9%
Zizia aurea	Golden Alexanders	2.2%
Heliopsis helianthoides	Smooth oxeye	1.6%
Poa palustris	Fowl bluegrass	1.0%
Desmodium canadense	Showy tick-trefoil	0.7%

As seen in Table 24, big bluestem (*Andropogon gerardii*) occurred in all five of the plots with >20% invasive cover. Other grasses including Canada wildrye (*Elymus canadensis*), switchgrass (*Panicum virgatum*), and little bluestem (*Schizachyrium scoparium*), also occurred in a large percentage of the plots. Stiff goldenrod (*Solidago rigida*) and Golden Alexanders (*Zizia aurea*) were the most frequent forbs.

Table 24. Top 10 native species by frequency when invasive cover is greater than 20% in the U3 zone.

U3 Mesic Prairie		
Species	**Common Name**	**Frequency**
Andropogon gerardii	Big bluestem	100.0%
Elymus canadensis	Canada wildrye	40.0%
Panicum virgatum	Switchgrass	40.0%
Schizachyrium scoparium	Little bluestem	40.0%
Solidago rigida	Stiff goldenrod	40.0%
Zizia aurea	Golden Alexanders	40.0%
Chamaecrista fasciculata	Partridge pea	20.0%
Desmodium canadense	Showy tick-trefoil	20.0%
Heliopsis helianthoides	Smooth oxeye	20.0%
Poa palustris	Fowl bluegrass	20.0%
Ratibida pinnata	Grey-headed coneflower	20.0%
Sonchus arvensis	Perennial sow thistle	20.0%

b) Low Invasion Areas

There was a total of 51 plots in the U3 seeding zone with <20% cover of invasive species. In this subset of plots, invasive Canada thistle (*Cirsium arvense*) occurred in about half (49%) of the plots with 1.8% average cover. As in the highly invaded areas, big bluestem (*Andropogon gerardii*) was the native with the highest cover. Little bluestem (*Schizachyrium scoparium*) covered the same amount of area as it did in the high invasive plots. Partridge pea (*Chamaecrista fasciculata*) did not appear in this subset of plots, but wild bergamot (*Monarda fistulosa*), which did not appear in the high invasion plots, had high cover.

Table 25. *Top 10 native species by cover when invasive cover is less than 20% in the U3 seeding zone.*

U3 Mesic Prairie		
Species	**Common Name**	**Average Relative Cover**
Andropogon gerardii	Big bluestem	22.4%
Schizachyrium scoparium	Little bluestem	10.7%
Monarda fistulosa	Wild bergamot	9.0%
Elymus canadensis	Canada wildrye	5.7%
Panicum virgatum	Switchgrass	4.3%
Poa palustris	Fowl bluegrass	4.2%
Solidago rigida	Stiff goldenrod	3.8%
Zizia aurea	Golden Alexanders	3.8%
Desmodium canadense	Showy tick-trefoil	3.2%
Pascopyrum smithii	Western wheatgrass	2.0%

Big bluestem (*Andropogon gerardii*) was also the native that occurred most frequently in low invasion areas, occurring in nearly three quarters of the plots. Golden Alexanders (*Zizia aurea*) occurred with high frequency. Grey-headed coneflower were frequently found in the plots but had low relative cover (*Ratibida pinnata*). The composition of species in these low invasion plots was like that of the highly invaded plots.

Table 26. *Top 10 native species by frequency when invasive cover is less than 20% in the U3 seeding zone.*

U3 Mesic Prairie		
Species	**Common Name**	**Frequency**
Andropogon gerardii	Big bluestem	72.5%
Zizia aurea	Golden Alexanders	47.1%
Panicum virgatum	Switchgrass	37.3%
Schizachyrium scoparium	Little bluestem	37.3%
Elymus canadensis	Canada wildrye	35.3%
Solidago rigida	Stiff goldenrod	35.3%
Monarda fistulosa	Wild bergamot	31.4%
Pascopyrum smithii	Western wheatgrass	27.5%
Ratibida pinnata	Grey-headed coneflower	25.5%
Poa palustris	Fowl bluegrass	23.5%

c) Guild Composition

As expected, native cover was substantially higher across all guilds in the low invasion plots. The presence of invasives does not seem to affect the relative proportions of each guild; in both high and low invasion plots warm-season grasses have the highest cover, followed by forbs, and then cool-season grasses. These results are not statistically significant. A table showing cover values for the guilds in areas of high and low invasive cover can be found in Appendix E.

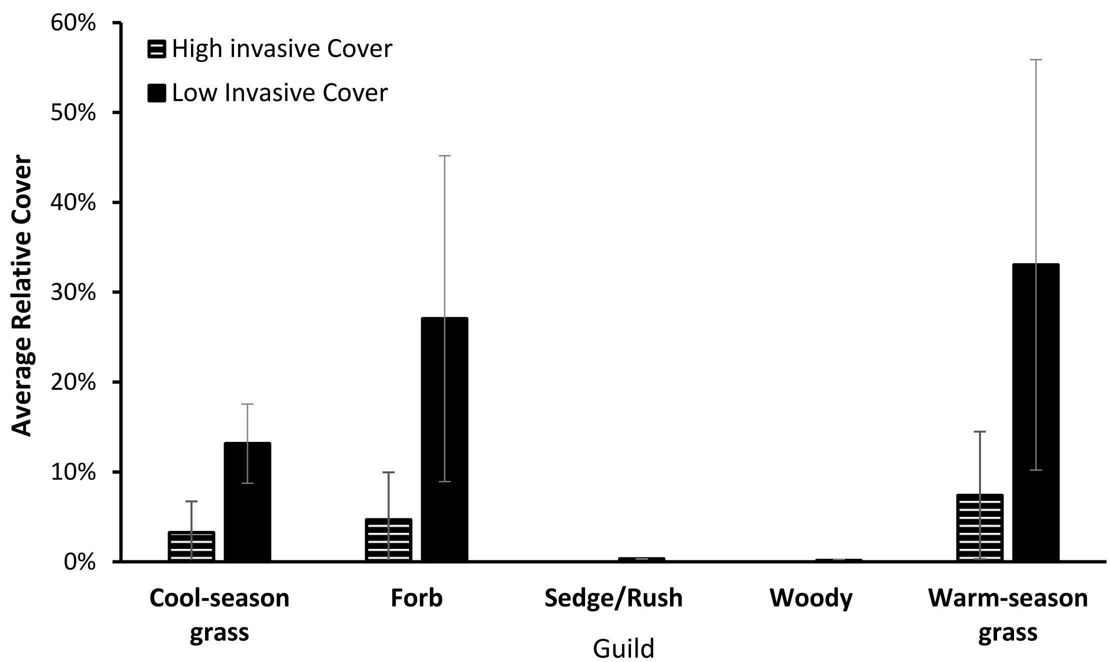

Figure 13. Native species average relative cover across five guilds in the U3 seeding zone, compared between areas of high and low invasive cover. Error bars represent one standard deviation.

IV. Discussion

A. Seeding Zone Performance

1. Emergent Wetland (W1)

a) Successes

While the outcomes of the W1 seeding zone were disappointing overall, there were a few positives. The difference between the average percent of seeded species present in the W1 zone and the other seeding zones was not statically significant. Swamp milkweed, an important species for pollinators, was present in around 14% of the 80 plots. Even in areas of greater than 20% invasive species cover, forbs like broadleaf arrowhead, northern water plantain, and swamp milkweed still occurred frequently.

b) Challenges

The W1 seeding zone had lower plot- and zone-level native species richness, lower native species cover, and higher invasive species cover than all other seeding zones. Average native cover was only around 30%, and average zone-level native richness was about 21. It is worthwhile to note that there were only 22 species included in the seed mix; however, only 40% of these seeded species are showing up on average.

The emergent wetland/shallow marsh zone presents a series of challenges when it comes to establishing native vegetation. Fluctuating water levels can make it difficult for seeded species to establish, as most wetland seed will float. It is therefore common to plant live plugs along the edge of the water with the hope that they will spread inwards. Waterfowl and muskrats may present a problem if they graze on young plants. This zone of a wetland is also the most difficult to access and maneuver within, and therefore is the most challenging area on which to implement management activities. These factors may all contribute to poorer native establishment in the W1 seeding zone.

The main issue in this zone is invasive narrow-leaved cattail species. Combined, *Typha angustifolia* and *Typha x glauca* were truly dominant in the emergent zone, occurring over three-quarters of the plots and covering over one-third of the total area. *Typha angustifolia* was introduced to the Atlantic coast from Europe and spread inland through ditches. As its range increased in size, it began hybridizing with native broadleaf cattail to form *Typha x glauca.* These narrow-leaved cattails are colonial species that invade wetlands and form monocultures, with *T. glauca* often being even more aggressive than its parent species. They reproduce both via seed and rhizomes, spreading quickly underground to form large patches. Both species are particularly problematic in disturbed areas, taking over native communities where there are changes in hydrology or fertility. This puts restored wetlands, which are often close to roads, formerly row cropped, and hydrologically altered, at a high risk of invasion.

Many management strategies have been developed to control invasive cattails. While they are resistant to moderate grazing, intense grazing during the period where the flower spikes are emerging can eliminate invasive cattails. Other mechanical controls like cutting or disking can slow shoot formation and damage the rhizomes but must be combined with high springtime water levels. This "cut and flood" method can be very effective but is most appropriate for wetlands with water control structures. Chemical control with herbicides such as glyphosate or imazapyr is also an option, and boom or wick applications can be used to control the application and prevent drift (SEWISC 2019).

Based on the monitoring reports from the study sites, there seems to be greater emphasis on managing reed canary grass and Canada thistle than invasive cattails. Often, cattails are not listed as a species to control in the bank plans. In fact, they are considered an expected component of depressional wetlands, especially given the site stressors associated with wetland mitigation banks. Only one site (Engstrom) specifically mentioned the wicking and cutting of cattails in the management history. Engstrom's average invasive species cover in the W1 zone was 31%, compared to the overall W1 average of around 48%. Note that in Minnesota, the statewide average for non-native cover in shallow marsh communities is 50% (Bourdaghs et al., 2015), which indicates that these restored wetlands are no better or worse than the average Minnesota wetland.

c) Future Directions

Many of the changes that were made to the W1 seed mix in 2009 align well with alterations I would recommend based on the long-term outcomes seen in this seeding zone. A list of species in the updated state seed mixes can be found in Appendix F. Blue-joint grass, which was never seen on site, was removed from the mix. *Glyceria grandis,* which was found to be the more successful of the two *Glyceria* species, remained in the mix while *Glyceria canadensis* was removed. Hardstem bulrush, which was rarely seen in the vegetation surveys was also removed. Porcupine sedge was not included in the updated mix because it was believed to be more of a wet meadow species, and less important for the emergent zone. I would suggest adding porcupine sedge back into the mix, as it was found to be one of the native species with the highest cover in these older wetland bank sites.

Other species that did not seem to persist well over time were sweet flag and giant bur reed. In the 2009 update, the amount of sweet flag included in the mix was increased from 0.4 to 0.67 seeds per square foot, which may help improve its on-site presence. No changes were made to giant bur reed which remained at about 1 seed/sq ft. If this species is desirable, it might be worthwhile to increase the number of giant bur reed seeds in the mix, especially since it is inexpensive compared to some of the other emergent wetland species. Plugs could also be considered for those species that did not establish well from seed.

The cost of the modified W1 seed mix (now named 34-181) remains over $1,000 per acre. The emergent seed mix is by far the most expensive of the mixes used in wetland mitigation and is shown in the present study to be the least successful. With invasive species making up 50% of the vegetative cover in the zone and only 40% of seeded species persisting over time, I think serious consideration needs to be given to whether seeding this zone is worth it. If cattails are considered an expected component of the W1 zone and are not managed, seeding this zone does not seem like a cost-effective choice. More emphasis needs to be placed on long-term management of cattails, or else they are guaranteed to outcompete the seeded natives and dominate these wetland bank restorations.

Another option would be to have tighter restrictions around when the emergent zone is seeded and when it is not. Invasive cattails are particularly competitive and dominant in wetlands with high nutrient inputs and/or stabilized water levels (Boers & Zedler, 2008). Therefore, a protocol could be developed to assess the site conditions both before any restoration actions are begun and before seeding. Important characteristics to consider would be soil nutrients, climatic factors, water level control structures, and hydrologic inputs to the ecosystem, with an emphasis on better understanding the watershed as a whole and its role in the invasibility of the wetland ecosystem. Once these conditions are understood, a decision could be made about whether the risk of invasion is too high to warrant the seeding of the W1 zone.

Given that the W1 mix is seeded in narrow 6-foot band, there is a lot of edge space for interior cattails to invade. BWSR is testing a pilot “deep marsh” mix that may prove to be successful in these fringe areas typically dominated by cattails. The deep marsh mix would be seeded in addition to the W1 mix, thereby widening the band. It contains only 6 species and therefore may be a cost-effective way to stabilize the deep and shallow marsh areas of restored wetlands. There has also been some discussion about seeding W2 farther in towards the W1 zone. I think that the practice of seeding the W2 mix a bit farther down, coupled with not seeding the areas with consistent standing water, could be an effective alternative to seeding the W1 mix.

2. Wet Meadow (W2) & Wet Prairie (W3)

a) Successes

The composition of the W2 and W3 seed mixes is very similar, with W3 having more grass species (big bluestem, switchgrass, Indian grass, prairie cordgrass) and W2 having more sedges/rushes (bottlebrush sedge, slender rush, river bulrush). It is possible that the stronger presence of warm-season grasses in the W3 zone gives the community a slight advantage; however, both the wet meadow and wet prairie zones performed well over the long term, particularly in terms of native richness.

In the W2 zone, cover of the different guilds, i.e. cool-season grasses, forbs, and sedge/rushes was well balanced, even when invasive species cover was high. Additionally, many important pollinator species were present, with swamp milkweed occurring in 25% of the plots. The W3 zone had high forb cover, comprised mostly of wildflowers, including in areas of high invasive cover. Therefore, this zone plays an important role in terms of pollinator habitat.

b) Challenges

The wet meadow has the second lowest seeded species presence (around 50%) and native cover (just over 60%) of the four seeding zones. All the vegetative success metrics (i.e. native cover, native richness, invasive cover, seeded species present) were slightly better in the W3 zone than in the W2 zone, though the differences were not statistically significant. The wet meadow zone appears to be more susceptible to cattail invasion, but the cover of reed canary grass is similar in both zones. Reed canary grass had higher cover than any other species in both zones. Across Minnesota, 35% of the total cover of wet meadows is comprised of non-native species (Bourdaghs et al., 2015). This study estimates non-native cover in the wet meadow zone to be around 40%, putting these restored sites slightly above the statewide average. This is to be expected given that the study sites are in south/central Minnesota, while the 35% estimate includes high-quality sites in the northeastern part of the state.

Wet meadows and wet prairies are particularly prone to invasion by reed canary grass, as was the case in this study. Reed canary grass provides a significant challenge for wetland restorations because it has large rhizomes and can be very difficult to remove once established. If reed canary grass is present at a site prior to restoration, serious thought must be given to whether the restoration can be successful from a vegetative perspective; water storage and other hydrology-related goals may still be achieved. The project will require thorough site preparation, which may include scraping the top 8 inches of the soil to remove the rhizomes. A common management sequence includes summer mowing, fall glyphosate application, and spring burning, followed by additional herbicide application as needed (Wenzel & Shaw, 2012).

Research into how to best prevent reed canary invasion is ongoing. It has been suggested that cover crops are not an effective strategy to prevent the establishment of reed canary grass. On the contrary, they may inhibit the growth of native species, allowing reed canary to become established (Iannone & Galatowitsch, 2008). One study found that using imazapyr herbicide was superior to glyphosate at reducing the relative importance values of reed canary grass, and that earlier applications are more effective (Mozdzer, Hutto, Clarke, & Field, 2008).

While most of the study sites indicate some form of reed canary grass control in the management histories, it is unclear what actions are taken after the 5-year monitoring period, if any. There are no standard long-term management requirements for wetland mitigation banks. This study shows that reed canary grass is an issue even in older mitigation sites where native vegetation is well-established and diverse, and therefore long-term maintenance is a necessity.

c) Future Directions

Fowl bluegrass was the dominant native species in these two zones, occurring in two-thirds of the W2 plots and 58% of the W3 plots. This species is extremely successful over time but may be outcompeting some of the other natives. In the 2009 updates to the mixes, fowl bluegrass was reduced dramatically from 86.7 seeds per square foot to 16.5 seeds/sq ft in the W2 mix, and from 78 to 9.6 seeds/sq ft in the W3 mix. This adjustment should allow other native grasses to fill in. Blue-joint grass, which was patchy in our surveys, was also decreased in the mixes from 8.2 to 5 seeds/sq ft in the W2 mix and from 10.3 to 4 seeds/sq ft in the W3 mix, which I think will be detrimental to its establishment.

Canada anemone, which was not seen in any of our wet meadow surveys, and blue-flag iris, which was only see on one site, were removed from the new W2 mix (now 34-271). I believe these were a cost-effective decisions. No significant changes were made to *Euthamia graminifolia*, *Lobelia siphilitica*, or *Veronicastrum virginicum*. Any future seed mix adjustment should consider increasing the quantity of these forbs to better promote establishment and long-term persistence or removing these species to improve the cost-effectiveness of the mix. Interestingly, river bulrush and softstem bulrush were removed from the mix and replaced with *Carex scoparia* and *Carex stipata*. River bulrush and softstem bulrush had very low cover on-site, so hopefully this adjustment will increase native cover in the W2 zone. Joe-pye weed was increased slightly in the update from 0.6 to 0.75 seeds/sq ft, but it is unclear if this is enough to increase its presence in the zone.

In the wet prairie zone, fringed brome and Indian grass were not seen in any of our survey plots. When the W3 seed mix was updated to 34-262 (see Appendix F), fringed brome was increased from 1.8 to 6.08 seeds/sq ft, which could improve its establishment. Indian grass, however, was decreased slightly in the new seed mix, perhaps because it is considered more of an upland species. Blue-flag iris was not seen on any site seeded with the W3 mix, and blue flag iris was wisely removed from the mix in the update. I would recommend that any future seed mix adjustments either remove Canada anemone, grass-leaved goldenrod, great-blue lobelia, and Culver's root to improve cost-effectiveness, or increase the number of seeds included in the mix to ensure that these species are showing up and persisting over the long-term. Plugs could also be considered for those species that did not establish well from seed.

Overall, there is high native richness within these two zones and only a few minor changes to the seed mixes are suggested to improve cost-effectiveness. The main concern for these zones moving forward is ensuring that plans are in place to control reed canary grass, and that adaptive management continues into the future. Reed canary grass is a threat to wet meadows and wet prairies that will persist indefinitely.

3. Mesic Prairie (U3)

a) Successes

The mesic prairie zone had the highest percent of seeded species present, the highest native cover, and the lowest invasive cover of any of the seeding zones. All sites but one had around 90% native cover, and only 5 of the 60 surveyed plots had invasive cover higher than 20%. This is because invasive cattails and reed canary grass simply aren’t as much of a risk in this drier upland area. Native grasses were abundant, especially warm-season species, as were forbs. In general, the restoration and management techniques used in this zone seem to be highly effective across sites. Upland prairie restoration is an older science and with fewer stressors than wetland restoration, so it is not surprising that this zone had better outcomes over time.

b) Challenges

It is concerning that Canada thistle was present in half of the survey plots. Canada thistle can be hard to control as it had an aggressive root system that gives rise to new shoots as it spreads (Gover, Johnson, & Sellmer, 2007). It also spreads by wind dispersal, with each plant containing up to 10,000 seeds. Eliminating Canada thistle requires treatments in both the spring and fall over multiple seasons. In late spring, when the thistle is about to bloom, the top growth should be removed via clipping, mowing, or herbicide application. Even more important is the fall treatment, when an herbicide like aminopyralid or glyphosate will cause the most damage to the root system (Gover et al., 2007). Thistle will typically be spot-sprayed, but in cases where thistle cover is dense and native forbs are not present, broadcast spraying is an option. Most of the sites describe actions taken to control Canada thistle including clipping and spot spraying. It is unclear if these management actions continued beyond the 5-year monitoring timeframe, but there is a clear need for continued control efforts.

The mesic prairie zone consistently had lower native species richness than the wet meadow or wet prairie zones. While the U3 mix had slightly fewer species than the W2 and W3 mixes, there was no significant difference in the percent of planted species present. It does appear as though the W2 and W3 zones are better at recruiting volunteer natives. In addition, the W2 and W3 zones border both the W1 and U3 zones, so species from the emergent and mesic prairie zones can overlap into this "middle ground" and establish, increasing diversity. The lower richness in the U3 zone could also be explained by the dominance of warm-season grass species. The mesic prairie zone has fewer species with higher cover that might outcompete other natives, while the W2 and W3 zones have more low-cover species. This is not necessarily a bad thing, as the high native cover seems to be preventing invasion, but it is a consideration if the restoration goal is high diversity.

c) Future Directions

Certain grasses including tall dropseed, western wheat grass, and green needle grass were rare across the surveyed sites. In the 2009 update (see Appendix F), tall dropseed was removed from the mix, which this study confirms was a cost-effective decision. No changes were made to the quantity of western wheat grass or green needle grass included in the U3 (now 35-541) mix. If these species are desired on site, perhaps big bluestem (which was very abundant) could be reduced in the mix, and these two species increased. Of the forbs that did not persist over time, only showy penstemon was removed from the 35-541 mix. *Liatris aspera* and *Chamaecrista fasciculata* remain in the update mix with no change. I would suggest that these species be reconsidered; if they are desired, their quantity in the mix should potentially be increased, if they are not necessary, they should be removed to lower the cost of the mix. Plugs could also be considered for those species that did not establish well from seed.

The continued success of the mesic prairie zone in restored wetland bank sites depends on the diligent management of Canada thistle. Present in half of all survey plots, and with a vigorously creeping root system, this invasive could quickly get out of control. To prevent the reversal of successful native vegetation, land managers need to understand that multiple treatments must occur over multiple seasons. There is no end date to the management of these restoration sites.

4. Caveats

There are always limitations when it comes to vegetation surveys. The 1-m^2 quadrats provide an estimate of zone-level cover that is imperfect. Due to the random placement of the plots, the rarer and/or patchy species may not be well-represented, if at all, in the cover estimates. The timed meanders serve as a sort of quality control for the plot-level data, to ensure that these sparser species are recorded. However, due to the random nature of the meander and the large size of some of the sites, there is always the chance that some species were missed. The Rapid FQA protocol was closely followed to minimize the number of missed species during the timed meander. Additionally, some of the vegetation surveys were conducted in June and early July when many aster species and grasses are not at their peak. The absence of flowers occasionally made plant identification challenging.

There is also some level of uncertainty associated with the location of the seeding zones. The seeding maps were used to place the plots, but this assumes that the seeding took place precisely within that delineated area. If there was overlap in the seeding, plots located near the edge of a seeding zone may have been seeded with two seed mixes. This study also assumed that there were no major substitutions to the seed mixes for the specific restoration sites, though at least one site planted plugs in the emergent zone. This study also did not differentiate between areas that were seeded once versus those that were re-seeded. These are all factors that should be considered when assessing the data presented in this study.

B. Long-Term Restoration Outcomes

1. Community Composition

It is important for wetland ecosystems to contain a balance of guilds, as each group plays a particular role in the community. It has been found that ecosystem processes are more consistently associated with functional composition and the number of guilds than with species richness (Díaz & Cabido, 2001). Examples of some of the benefits provided by the guilds evaluated in this study are provided below.

The main role of forbs in wetlands is to provide benefits to pollinators and other wildlife, while also increasing diversity and enhancing aesthetic. Forbs in the legume family also provide the important function of nitrogen fixation. Sedges and rushes tend to have shallow, spreading roots that bind the soil. This makes them important for trapping sediment and controlling erosion, which in turn reduces nutrient runoff into nearby waterbodies. The root system also helps to oxygenate the water and soil, which is important for nutrient transformation. Sedges have been observed to recycle nutrients faster than other plants (Damman & French, 1987). When planted in dense stands, native sedges can function to exclude invasive species (Mishra, Tripathi, Tripathi, & Chauhan, 2015). A mix of cool- and warm-season grasses is desirable because their growth peaks at different points during the year. Cool-season grass grow most quickly in the spring and fall and can establish rapidly. Warm-season grasses have the highest rate of growth in the summer. While warm-season grasses are slow to establish, they use water and nutrients efficiently and are drought tolerant. A plant community with a strong presence of both cool- and warm-season grasses should therefore be more resilient to climatic variation, and better able to compete with invasive species.

Native cover in the emergent wetland zone was dominated by sedges and rushes. This is to be expected given that they made up the highest proportion of the seed mix and given the hydrology of the zone. It is possible that increasing the presence of cool-season grasses in this zone may improve its resiliency to invasion. The wet meadow zone was the most balanced of any seeding zone in terms of guild representation, with native cool-season grasses, forbs, and sedges/rushes having approximately equal cover. In theory, this balanced composition indicates that the zone is providing a diverse suite of ecosystem services, though invasive cover was quite high in this zone. The wet prairie zone had more forbs and fewer sedge/rushes, and a nice balance of cool- and warm-season grasses. The differences in guild composition between the wet meadow and wet prairie can largely be explained by the composition of the seed mix, as the W3 mix is more geared toward prairie species. While the cover of warm season grasses in the mesic prairie appeared to be far higher than the cover of cool-season grasses, this imbalance did not seem to result in greater invasive cover.

2. Resiliency

There are two ways to interpret the resiliency data. First, the native species that are present in areas of low invasion are the most robust as they are preventing invasion. From this perspective, the most resilient species are as follows: W1 – green bulrush and common spikerush, W2 – fowl bluegrass and green bulrush, W3 – switchgrass, fowl bluegrass, and big bluestem, U3 – big bluestem and little bluestem. Observationally, it seems as though green bulrush competes well with invasive cattails and fowl bluegrass competes well with reed canary grass. In both the W3 and U3 zones, warm-season grass cover is very high in low-invasion areas, which may suggest this guild is robust to invasion by reed canary, a cool-season grass.

Alternatively, it could be argued that the aforementioned species can only thrive in areas of low invasive cover and are present simply because the invasives haven't reached that area yet. In this second interpretation, the species that can persist in high invasion areas are the most resilient. In other words, invasive species are present, but these natives are holding their own. From this perspective, the most robust species are as follows: W1 – rice cutgrass, W2 – fowl bluegrass and fox sedge, W3 – fowl bluegrass and smooth blue aster, U3 – big bluestem and Canada wildrye. It is interesting that in the W1 zone rice cut grass is dramatically more abundant in high-invasion plots, perhaps due to its ability to coexist with reed canary grass (USDA NRCS). In the W2 zone, cool-season grass cover is much high in the highly invaded plots, suggesting that these species can compete with reed canary grass. It should also be noted that some of the species discussed above, such as big bluestem, are the most abundant species in the seeding zone overall, regardless of whether invasive cover is low or high.

The Wisconsin DNR lists the following species as potentially being able to compete with reed canary: prairie cord grass (*Spartina pectinata*), rice cutgrass (*Leersia oryzoides*), blue-joint grass (*Calamagrostis canadensis*), and fowl manna grass (*Glyceria striata*), and in wetter areas, lake sedge (*Carex lacustris*), wool-grass (*Scirpus cyperinus*), river bulrush (*Bolboschoenus fluviatilis*), and soft-stem bulrush (*Schoenoplectus tabernaemontani*). It has been suggested that when it comes to invasive cattails, cespatose sedges that form clumps, such as porcupine sedge (*Carex hystericina*), may be the most resistant (Larkin, Freyman, Lishawa, Geddes, & Tuchman, 2011). The present study provides additional data supporting that rice cutgrass, river bulrush, and porcupine sedge may play an important role in preventing invasion and presents two additional species that exhibit promising resilience - fowl bluegrass and green bulrush.

3. Comparison to 5-Year Conclusions

As this study is interested in long-term vegetation changes, the following is a discussion of how the results from the present study compare to the final monitoring report from each of the mitigation banking sites. The monitoring reports were obtained from the Board of Water and Soil Resources. When performance standards were listed in the report, it is noted whether the 2017 site-conditions continue to meet these criteria. This discussion is meant to provide a rough idea of some changes that appear to have occurred on these sites but must be interpreted with caution due to the lack of consistency in monitoring methods and surveyors. It is also important to note that the monitoring reports summarize by community, while this study summarizes by seeding zone. If there were cattails in the W2 zone, the annual report would categorize it as shallow marsh (previously referred to as the emergent zone), while the present study would consider it wet meadow. This could further contribute to discrepancies between the two data sets.

a) Deinken

In 2011, the estimated relative native cover was 64% in the shallow marsh and 99% in the wet meadow. In our 2017 surveys, we estimate that native cover was 52% in the W1 zone and only 60% in the W2 zone. In 2011, reed canary grass cover was estimated at only 2% in the wet meadow zone, but it has become dramatically more abundant in recent years. In 2011, the shallow marsh did not meet the performance standard of >4 native species with <5% invasive cover, but the wet meadow did meet the standard of >10 native species and <5% invasive cover. In 2017, neither zone met the performance standards.

b) Drummer

In 2015, 17 of the seeded species were present in the shallow marsh zone, 15 in the wet prairie zone, and 12 in the mesic prairie zone. In our 2017 surveys, only 6 of the seeded species were confirmed in the W1 zone, 14 in the W3 zone, and again 12 in the U3 zone. The dramatic difference in the number of seeded species seen in the W1 zone between the two years may be explained by the time of year the surveys were conducted. In 2015, the estimated cover of narrow-leaf cattail was only 5% in the shallow marsh, while our 2017 survey suggests it was closer to 26%. Increased invasive cover may have caused the decline in seeded species presence. There were no formal performance standards set for this site.

c) Elfering

In 2013, average native cover was estimated at 63% in the shallow marsh zone, 71% in the wet prairie, and 92% in the mesic prairie. In our 2017 survey, these numbers were 35%, 68%, and 94% in the three zones respectively. While native cover appears to have remained relatively constant over time in the wet prairie and mesic prairie zones, it seems to have decreased significantly in the shallow marsh (W1 zone). This change can be attributed to a substantial increase in reed canary grass cover in the W1 zone. Invasive cattail cover looks constant over time. In 2013, all zones met the performance standards (>4 natives and <10% invasive cover in the shallow marsh; >10 natives and <10% invasive cover in the wet and mesic prairies). In 2017, only the mesic prairie continued to meet performance standards.

d) Engstrom

The 2014 monitoring report is not as detailed for Engstrom as for some of the other sites. The estimated native cover in the wetland areas is somewhere around 54% on average. I assume that this considers the W1, W2, and W3 zones together. The best estimate for a comparable value in 2017 is about 40%. Invasive cattails and reed canary grass were problematic in 2014, and the issue seems to be worsening over time. There are no clear performance standards described for this site.

e) Krohn

In 2015, native cover was estimated at 90% in the wet meadow zone, 85% in the wet prairie zone, and 92% in the mesic prairie. In our 2017 survey, these measures were 64%, 88%, and 91% in the three zones respectively. Native cover has remained constant in the W3 and U3 zones. In the 2015 report there was no mention of invasive cattails or reed canary grass in the wet meadow, while in 2017, invasive cattail cover was around 14% and reed canary grass cover was 6% in the W2 zone. In 2015, the shallow marsh did not meet the performance standard of 8 native species with 75% cover, but the wet meadow did meet the standard of 12 native species with

90% cover. In 2017, neither zone met the performance standards, due largely to cattail encroachment into the W2 zone.

f) Neubauer

In 2012, 19 native species were seen in the shallow marsh; this number was 22 in 2017 (no change). There was a note that the shallow marsh was largely dominated by narrow-leaved cattails, which held true in our 2017 surveys. In 2012, native cover was estimated at 95% in the wet meadow and 90% in the mesic prairie; in 2017, native cover was around 78% in W2 and 88% in U3. Cover of invasive cattails, reed canary grass, and especially Canada thistle increased in the wet meadow zone over time. The shallow marsh and wet meadow did not meet performance standards in 2012 or 2017 standards (>4 natives and <5% invasive cover in the shallow marsh; 10+ natives and <5% invasive cover in the wet meadow).

g) Ruby

In 2014, 25 of the seeded species in the U3 zone were recorded; this number was 21 in 2017. In 2014, Canada thistle in the U3 zone was reported to have 2.8% cover; this increased to 7.5% in 2017. Narrow-leaved cattail had 11.2% cover in the W3 zone in 2014 and around 7.2% in 2017. In the emergent zone, narrow-leaved cattails were estimated to have 42% cover in 2014 and 57% cover in 2017. Overall, invasive cover seems to be increasing over time in the emergent wetland and mesic prairie zones.

h) Schroeder

Narrow-leaved cattail cover in the emergent zone was estimated at 25% in 2015 and 39% in 2017. Native cover was estimated at 80% wet meadow zone in 2015, but at only 49% in 2017. This large change is at least partly explained by the increase in invasive cattail cover in the zone from <5% to around 20%. The cover of reed canary grass more than doubled in the emergent zone over time but remained constant in the wet meadow. The monitoring report is somewhat vague and there are no performance standards described for this restoration.

i) Strolberg

In 2013, native cover was estimated at 65% in the shallow marsh, 90% in the wet meadow, and 99% in the mesic prairie. By 2017, native cover had decreased to 57%, 78%, and 94% in the three zones, respectively. Over time, reed canary grass cover seems to have increased substantially in the W1 and W2 zones. In 2013, the shallow marsh did not meet the performance standard of 8 native species with 75% cover, but the wet meadow did meet the standard of 12 native species with 90% cover. In 2017, neither zone met these performance standards.

A positive theme across sites is that native cover seems to remain constant over time in the mesic prairie (U3) zone. Native species richness does not decline in any of the seeding zones, although there is sometimes a decrease in the number of seeded species present. A negative trend is that invasive cover appears to consistently increase over time in both the emergent (W1) and wet meadow (W2) zones. The increase in invasive cover in the wet meadow zone is often dramatic. Again, there is some uncertainty in these conclusions due to the differing surveying methods between the two years.

4. Influential Factors

While this study largely focused on the role of seed mixes and vegetation communities on the long-term outcomes of restored wetlands, there are numerous other factors that can affect the success of a restoration project. These factors were outside the scope of the present study, but past research can provide some insight into why some of the study sites may have had poorer outcomes across all seeding zones, or why certain sites were more susceptible to invasion. A 2016 study that evaluated 78 restoration plans and surveys 59 projects sites in Minnesota concluded that there were four main predictors of restoration success: 1) starting condition of the site, 2) the type of system being restored, 3) the internal capacity of the restoration team, and 4) if the restoration team wrote the plan (Galatowitsch & Bohnen, 2016).

a) Environmental Conditions

Restorations of highly altered sites are less likely to result in successful outcomes (Galatowitsch & Bohnen, 2016). Unlike remnant natural areas, where the only restoration activity may be removing invasive species, highly disturbed sites will need to be seeded. Historically, all the sites surveyed in this study were fully or partially row cropped, a severe disturbance that makes the restorations riskier. Sites that were previously farmed have altered hydrology, increased inputs of nutrients, and high anthropogenic disturbance, and each of these factors increase their invasibility (Ehrenfeld, 2000). Future research could evaluate hydrologic inputs and nutrient availability in the soil to help explain why certain sites had higher invasive cover over the long term.

The type of ecosystem also plays a role in determining restoration success. For example, it is more challenging to reestablish forest communities than wetlands or prairies (Minnesota Board of Water and Soil Resources, 2019). In this study, the emergent wetland ecosystem was less successful across all metrics than the mesic prairie community. This may indicate that regardless of all other factors (land-use history, management, etc.) the ecosystem type itself will largely determine long-term restoration outcomes.

b) Restoration Techniques

There are countless factors related to the restoration itself that may affect the success of a restoration project including site preparation to remove invasives, seedbed preparation, the use of cover crops, seeding method (i.e. drill or broadcast seeding), timing of seeding/plant installation, and more. While the quality of the project's restoration plan doesn't seem to affect outcomes, who wrote the plan does matter. Restorations guided by plans written by the restoration team itself and not a contractor are more likely to be successful (Galatowitsch & Bohnen, 2016). Additionally, restoration teams that lack expertise or sufficient staff are more likely to execute low-quality restorations, regardless of the use of a contractor (Galatowitsch & Bohnen, 2016). Future research could look for trends in the relationship between vegetative outcomes and restoration techniques.

c) Management

A critical component to the long-term success of wetland restorations is management. Without consistent intensive management, particularly in the first 5 years post-restoration, these sites can quickly become overrun by invasive species. The management techniques (e.g. clipping, mowing, herbicide application, burning), combinations, timing, and frequency varied between the study sites, all of which could have contributed to the overall outcome of the restorations. The presence of invasive species on these restoration sites is still a pressing threat, and a commitment to ongoing management is necessary to ensure the long-term success of these projects. Unfortunately, management activities can be time consuming, labor-intensive, and costly, and therefore ongoing management often depends on the availability of funding.

This study shows that invasive species cover can continue to expand even in relatively mature, established wetland restoration sites. I therefore argue that if there is no funding for long-term management, the upfront costs of seeding vegetation may not be worth it. Without management, the sites are likely to become dominated by invasive species over time, and therefore it may be more cost-effective to restore wetland hydrology but let the sites revegetate naturally. More research is needed to evaluate whether seeding significantly improves the overall composition, diversity, and resiliency of restored vegetation communities compared to natural recolonization. With that said, the present study is still relatively short-term ecologically speaking, and it’s possible that over the next decade the sites may reach more of an equilibrium.

C. Conclusions

Overall, the emergent zone had poorer long-term outcomes than the other seeding zones across all vegetation metrics. Serious consideration should be given to changing the seeding strategy for this zone or discontinuing seeding all together. Native species richness generally exceeds performance standards in all seeding zones, but the number of seeded species present is often quite low. Narrow-leaved cattails and reed canary grass were pervasive across all sites and seem to be increasing in cover over time. Certain species such as rice cutgrass and tussock-forming sedges may compete effectively with invasive cattails and/or reed canary grass. Long-term management is needed to combat the ongoing expansion of invasive species and promote the persistence of desired native species. Additional research on site-specific restoration and management approaches, as well as abiotic conditions, may further elucidate what factors have the most influence on long-term restoration outcomes.

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Appendix A. State Seed Mixes

	Mixture W1 (Native Emergent/Wetland Fringe)					
	Common Name	**Botanical Name**	**Indicator Status**	**Seeds/oz**	**Seeds/ft²**	**% of Mix**
Grasses	Slough grass, American	*Beckmannia syzigachne*	*OBL*	50,000	67.6	46.0
	Blue-joint grass	*Calamagrostis canadensis*	*OBL*	280,000	8.2	1.0
	Manna grass, rattlesnake	*Glyceria canadensis*	*OBL*	74,000	4.3	2.0
	Manna grass, reed	*Glyceria grandis*	*OBL*	80,000	4.7	2.0
	Cut-grass, rice	*Leersia oryzoides*	*OBL*	34,000	2.0	2.0
Other Graminoids	Sedge, bottlebrush	*Carex comosa*	*OBL*	30,000	1.8	2.0
	Sedge, porcupine	*Carex hystericina*	*OBL*	30,000	3.5	4.0
	Sedge, lake	*Carex lacustris*	*OBL*	32,000	0.5	0.5
	Sedge, tussock	*Carex stricta*	*OBL*	53,000	0.8	0.5
	Sedge, fox	*Carex vulpinoidea*	*OBL*	100,000	14.7	5.0
	Spike-rush, creeping	*Eleocharis acicularis*	*OBL*	70,000	2.1	1.0
	Spike-rush, great	*Eleocharis palustris*	*OBL*	51,000	1.5	1.0
	Rush, common	*Juncus effusus*	*OBL*	1,000,000	29.4	1.0
	Bulrush, hard-stem	*Scirpus acutus*	*OBL*	20,000	1.2	2.0
	Bulrush, river	*Scripus fluviatilis*	*OBL*	4,300	0.3	2.0
	Bulrush, soft-stem	*Scirpus validus*	*OBL*	31,000	1.8	2.0
	Bur-reed, giant	*Sparganium eurycarpum*	*OBL*	500	0.1	10.0
Forbs	Sweet flag	*Acorus calamus*	*OBL*	6,600	0.4	2.0
	Plantain, large flowered-water	*Alisma triviale*	*OBL*	66,000	7.8	4.0
	Milkweed, marsh	*Asclepias incarnata*	*OBL*	4,800	0.6	4.0
	Joe-pye weed	*Eupatorium maculatum*	*OBL*	95,000	5.6	2.0
	Arrowhead, broad-leaved	*Sagittaria latifolia*	*OBL*	61,000	7.2	4.0
					Total:	**100.0**
Recommended Rate: 8.0 (PLS lbs/acre)						
Summaries						
Mix Seeds Per Square Foot		**Mix Seeds Per Square Yard**		**Mix Seeds Per Acre**		
166		1,493		7,226,240		
% by wt. Grasses		**% by wt. Other Graminoids**		**% by wt. Forbs**		
53.0		21.0		26.0		
% by Seed Count Grasses		**% by Seed Count Other Graminoids**		**% by Seed Count Forbs**		
52.0		35.0		13.0		

Source: Minnesota Board of Water and Soil Resources

Mixture W2 (Native Sedge/Wet Meadow)						
	Common Name	**Botanical Name**	**Indicator Status**	**Seeds/oz.**	**Seeds/ft^2**	**% of Mix**
Grasses	Slough grass, American	*Beckmannia syzigachne*	*OBL*	50,000	36.7	25.0
	Brome, fringed	*Bromus ciliata*	*FACW*	10,000	1.5	5.0
	Blue-joint grass	*Calamagrostis canadensis*	*OBL*	280,000	8.2	1.0
	Wild-rye, Virginia	*Elymus virginicus*	*FACW-*	4,200	3.1	25.0
	Manna grass, reed	*Glyceria grandis*	*OBL*	80,000	2.4	1.0
	Manna grass, fowl	*Glyceria striata*	*OBL*	160,000	4.7	1.0
	Bluegrass, fowl	*Poa palustris*	*FACW+*	118,000	86.7	25.0
Other Graminoids	Sedge, bottlebrush	*Carex comosa*	*OBL*	30,000	0.9	1.0
	Sedge, tussock	*Carex stricta*	*OBL*	53,000	0.8	0.5
	Sedge, fox	*Carex vulpinoidea*	*OBL*	100,000	5.9	2.0
	Rush, slender	*Juncus tenuis*	*FAC*	1,000,000	8.8	0.3
	Bulrush, green	*Scirpus atrovirens*	*OBL*	460,000	13.5	1.0
	Wool grass	*Scirpus cyperinus*	*OBL*	1,700,000	5.0	0.1
	Bulrush, river	*Scirpus fluviatilis*	*OBL*	4,300	0.1	0.4
	Bulrush, soft-stem	*Scirpus validus*	*OBL*	31,000	1.5	1.6
Forbs	Anemone, Canada	*Anemone canadensis*	*FACW*	8,000	0.1	0.6
	Milkweed, marsh	*Asclepias incarnata*	*OBL*	4,800	0.1	1.0
	Aster, swamp	*Aster puniceus*	*OBL*	80,000	0.5	0.2
	Aster, flat-topped	*Aster umbellatus*	*FACW*	67,000	0.8	0.4
	Joe-pye weed	*Eupatorium maculatum*	*OBL*	95,000	0.6	0.2
	Boneset	*Eupatorium perfoliatum*	*FACW+*	160,000	0.9	0.2
	Goldenrod, grass-leaved	*Euthamia graminifolia*	*FACW-*	350,000	1.0	0.1
	Sneezeweed	*Helenium autumnale*	*FACW+*	130,000	0.8	0.2
	Sunflower, serrated	*Helianthus grosseserratus*	*FACW-*	15,000	0.2	0.4
	Iris, blue-flag	*Iris versicolor*	*OBL*	1,300	0.18	4.6
	Blazingstar, meadow	*Liatris ligulistylis*	*FACU+*	10,000	0.2	0.6
	Lobelia, great-blue	*Lobelia siphilitica*	*FACW+*	500,000	2.9	0.2
	Monkey flower	*Mimulus ringens*	*OBL*	2,300,000	6.8	0.1
	Mint, mountain	*Pycnanthemum virginianum*	*FACW+*	220,000	1.3	0.2
	Goldenrod, giant	*Solidago gigantea*	*FACW*	80,000	0.5	0.2
	Vervain, blue	*Verbena hastata*	*FACW+*	93,000	1.1	0.4
	Ironweed	*Veronia fasciculata*	*FACW*	24,000	0.3	0.4
	Culver's root	*Veronicastrum virginicum*	*FAC*	800,000	2.4	0.1
					Total:	**100.0**
Recommended Rate: 8.0 (PLS lbs/acre)						

Summaries		
Mix Seeds Per Square Foot	**Mix Seeds Per Square Yard**	**Mix Seeds Per Acre**
200	1,802	8,719,360
% by wt. Grasses	**% by wt. Other Graminoids**	**% by wt. Forbs**
83.0	7.0	10.0
% by Seed Count Grasses	**% by Seed Count Other Graminoids**	**% by Seed Count Forbs**
72.0	18.0	10.0

Source: Minnesota Board of Water and Soil Resources

Mixture W3 (Native Wet Prairie)						
	Common Name	**Botanical Name**	**Indicator Status**	**Seeds/oz.**	**Seeds/ft²**	**% of Mix**
Grasses	Bluestem, big	*Andropogon gerardi*	*FAC-*	10,000	2.2	6.0
	Slough grass, American	*Beckmannia syzigachne*	*OBL*	50,000	44.1	24.0
	Brome, fringed	*Bromus ciliata*	*FACW*	10,000	1.8	5.0
	Blue-joint grass	*Calamagrostis canadensis*	*OBL*	280,000	10.3	1.0
	Wild-rye, Virginia	*Elymus virginicus*	*FACW-*	4,200	3.1	20.0
	Manna grass, reed	*Glyceria grandis*	*OBL*	80,000	2.9	1.0
	Manna grass, fowl	*Glyceria striata*	*OBL*	160,000	5.9	1.0
	Switchgrass	*Panicum virgatum*	*FAC+*	14,000	1.0	2.0
	Bluegrass, fowl	*Poa palustris*	*FACW+*	118,000	78.0	18.0
	Indian grass	*Sorghastrum nutans*	*FACU+*	12,000	2.6	6.0
	Cord grass, prairie	*Spartina pectinata*	*FACW+*	6,600	1.2	5.0
Other Graminoids	Sedge, tussock	*Carex stricta*	*OBL*	53,000	0.6	0.3
	Sedge, fox	*Carex vulpinoidea*	*OBL*	100,000	3.7	1.0
	Bulrush, green	*Scirpus atrovirens*	*OBL*	460,000	10.1	0.6
	Wool grass	*Scirpus cyperinus*	*OBL*	1,700,000	6.2	0.1
	Bulrush, soft-stem	*Scirpus validus*	*OBL*	31,000	1.1	1.0
Forbs	Anemone, Canada	*Anemone canadensis*	*FACW*	8,000	0.12	0.4
	Milkweed, marsh	*Asclepias incarnata*	*OBL*	4,800	0.2	1.0
	Aster, swamp	*Aster puniceus*	*OBL*	80,000	0.6	0.2
	Aster, flat-topped	*Aster umbellatus*	*FACW*	67,000	0.7	0.3
	Tic-trefoil, showy	*Desmodium canadense*	*FAC-*	5,500	0.1	0.4
	Joe-pye weed	*Eupatorium maculatum*	*OBL*	95,000	1.4	0.4
	Boneset	*Eupatorium perfoliatum*	*FACW+*	160,000	1.2	0.2
	Goldenrod, grass-leaved	*Euthamia graminifolia*	*FACW-*	350,000	2.6	0.2
	Sneezeweed	*Helenium autumnale*	*FACW+*	130,000	1.91	0.4
	Sunflower, serrated	*Helianthus grossesserratus*	*FACW-*	15,000	0.3	0.6
	Iris, blue-flag	*Iris versicolor*	*OBL*	1,300	0.08	1.6
	Blazingstar, meadow	*Liatris ligulistylis*	*FACU+*	10,000	0.1	0.4
	Blazingstar, tall	*Liatris pycnostachya*	*FAC-*	11,000	0.2	0.4
	Lobelia, great blue	*Lobelia siphilitica*	*FACW+*	500,000	1.8	0.1
	Monkey flower	*Mimulus ringens*	*OBL*	2,300,000	8.4	0.1
	Mint, mountain	*Pycnanthemum virginianum*	*FACW+*	220,000	1.6	0.2
	Vervain, blue	*Verbena hastata*	*FACW+*	93,000	1.4	0.4
	Ironweed	*Veronia fasciculata*	*FACW*	24,000	0.2	0.2
	Culver's root	*Veronicastrum virgnicum*	*FAC*	800,000	2.9	0.1
	Alexander's, golden	*Zizia aurea*	*FAC+*	11,000	0.2	0.4
					Total:	**100.0**

Recommended Rate: 10.0 (PLS lbs/acre)

Summaries

Mix Seeds Per Square Foot	**Mix Seeds Per Square Yard**	**Mix Seeds Per Acre**
200	1,802	8,719,360
% by wt. Grasses	**% by wt. Other Graminoids**	**% by wt. Forbs**
83.0	7.0	10.0
% by Seed Count Grasses	**% by Seed Count Other Graminoids**	**% by Seed Count Forbs**
72.0	18.0	10.0

Source: Minnesota Board of Water and Soil Resources

Mixture U3 (Native SW MN Mesic Tall-grass Prairie)					
	Common Name	**Botanical Name**	**Seeds/oz.**	**Seeds/ft^2**	**% of Mix**
Grasses & Cover Crops*	Bluestem, big	*Andropogon gerardi*	10,000	3.3	6.0
	Oats or winter wheat*	*Avena sativa* or *Triticum aestivum*	800	1.4	32.0
	Grama, sideoats	*Bouteloua curtipendula*	6,000	2.0	6.0
	Wild-rye, Canadian	*Elymus canadensis*	5,200	1.7	6.0
	Wheat-grass, slender	*Elymus trachycaulus*	6,900	2.3	6.0
	Wheat-grass, western	*Elytrigia smithii*	6,000	1.3	4.0
	Rye-grass, annual*	*Lolium italicum*	20,000	8.8	8.0
	Switch grass	*Panicum virgatum*	14,000	0.8	1.0
	Bluestem, little	*Schizachyrium scoparium*	15,000	8.3	10.0
	Indian grass	*Sorghastrum nutans*	12,000	6.6	10.0
	Dropseed, tall	*Sporobolus asper*	30,000	1.7	1.0
	Needle grass, green	*Stipa viridula*	7,500	1.7	4.0
Forbs	Milkweed, butterfly	*Asclepias tuberosa*	4,000	0.1	0.4
	Aster, smooth-blue	*Aster laevis*	55,000	0.6	0.2
	Milkvetch, Canada	*Astragalus canadensis*	17,000	0.4	0.4
	Partridge pea	*Chamaecrista fasiculata*	2,700	0.1	0.4
	Prairie clover, white	*Dalea candidum*	19,000	0.2	0.2
	Prairie clover, purple	*Dalea purpureum*	18,000	0.4	0.4
	Tick-trefoil. showy	*Desmodium canadense*	5,500	0.1	0.4
	Coneflower, narrow-leaved	*Echinacea angustifolia*	7,000	0.2	0.4
	Sunflower, early	*Heliopsis helianthoides*	6,300	0.1	0.4
	Blazingstar, rough	*Liatris aspera*	16,000	0.2	0.2
	Blazingstar, tall	*Liatris pycnostachya*	11,000	0.1	0.2
	Bergamot, wild	*Monarda fistulosa*	70,000	0.8	0.2
	Penstemon, showy	*Penstemon grandiflorum*	14,000	0.2	0.2
	Coneflower, columnar	*Ratibida columnifera*	42,000	0.5	0.2
	Coneflower, grey-headed	*Ratibida pinnata*	30,000	0.7	0.4
	Black-eyed Susan	*Rudbeckia hirta*	92,000	2.0	0.4
	Goldenrod, stiff	*Solidago rigida*	41,000	0.5	0.2
	Vervain, blue	*Verbena hastata*	93,000	1.0	0.2
	Vervain, hoary	*Verbena stricta*	28,000	0.3	0.2
	Alexanders, golden	*Zizia aurea*	11,000	0.2	0.4
				Total:	**100.0**

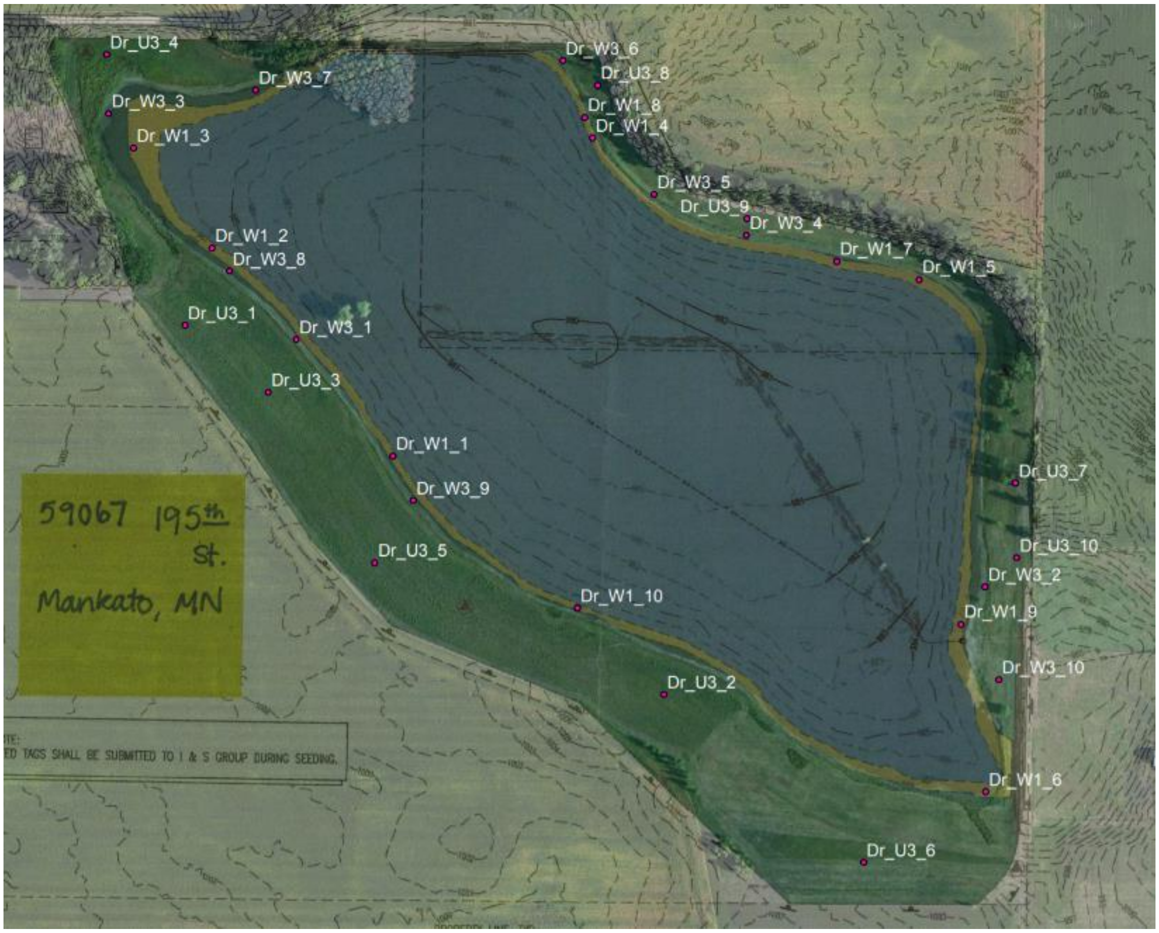
Recommended Rate: 15.0 (PLS lbs/acre)
***Note:** Oats are used in spring & summer and winter wheat in the fall.

Summaries		
Mix Seeds Per Square Foot	**Mix Seeds Per Square Yard**	**Mix Seeds Per Acre**
48	435	2,105,760
% by wt. Grasses	**% by wt. Cover Crop**	**% by wt. Forbs**
54.0	40.0	6.0
% by Seed Count Grasses	**% by Seed Count Cover Crop**	**% by Seed Count Forbs**
61.0	21.0	18.0

Source: Minnesota Board of Water and Soil Resources

Appendix B. Survey Plot Maps

Deinken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Dr_W3_5
Dr_U3_9
Dr_W3_4
Dr_W1_7
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Dr_W3_8
Dr_U3_1
Dr_W3_1
Dr_U3_3
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Dr_W3_9
Dr_U3_7
59067 195th St.
Mankato, MN
Dr_U3_5
Dr_U3_10
Dr_W3_2
Dr_W1_10
Dr_W1_9
Dr_W3_10
Dr_U3_2
ED TAGS SHALL BE SUBMITTED TO I & S GROUP DURING SEEDING.
Dr_W1_6
Dr_U3_6

Drummer


Wetland #1
El_U3_5
El_W1_9
Wetland #3
Wetland #4
El_W1_7
El_U3_10
El_U3_2
El_W1_1
El_U3_9
Wetland #2
El_W1_6
Wetland #6
El_U3_7
El_U3_8
El_U3_4
El_W1_2
El_W1_3
Wetland #7
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El_U3_3
Wetland #5
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Wetland #8
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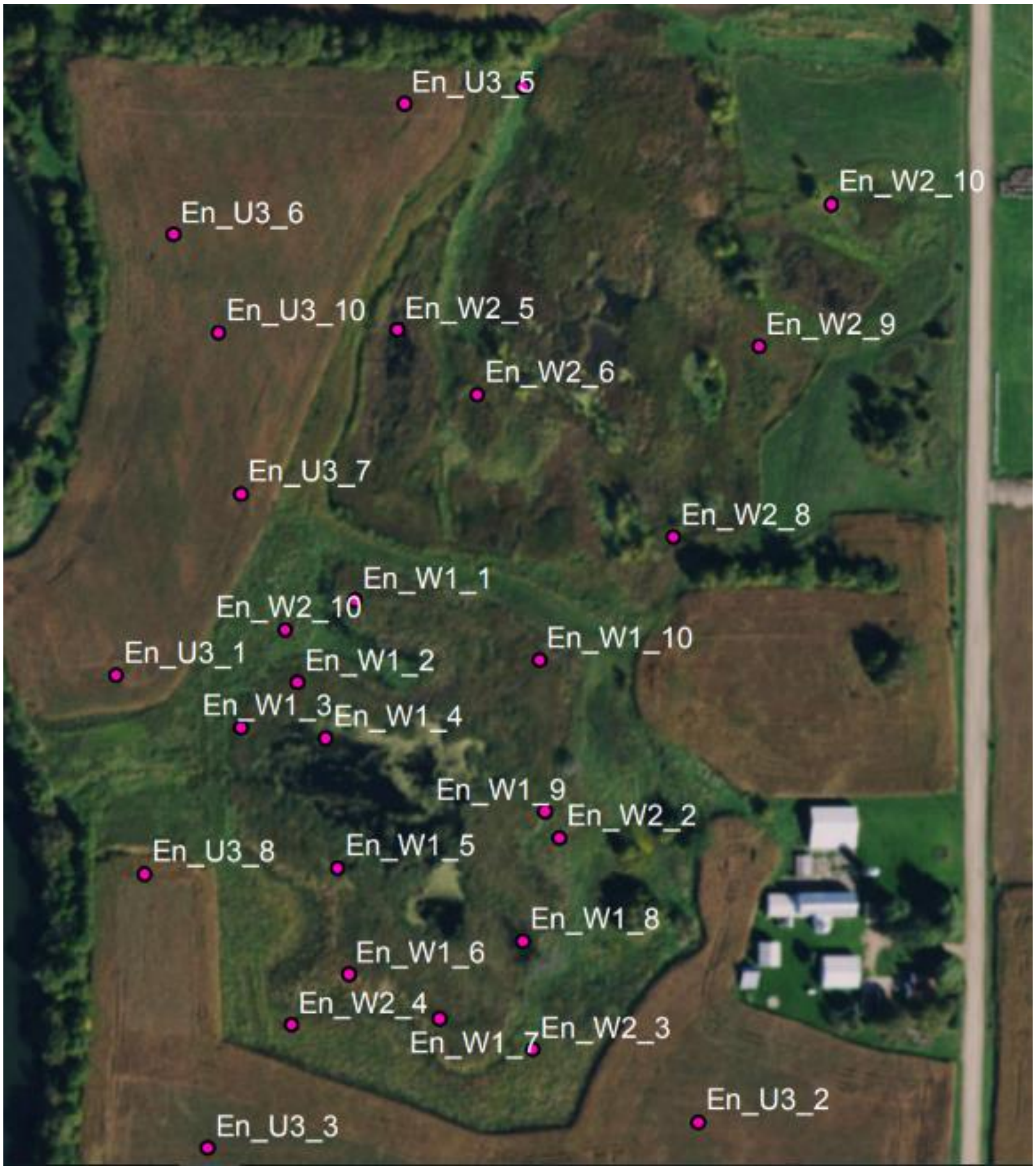
El_W1_10
Wetland #9

Elfering



En_U3_5
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En_U3_10
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En_W2_4
En_W1_7
En_W2_3
En_U3_2
En_U3_3

Engstrom


Kr_U3_1
Kr_U3_2
Kr_U3_3
Kr_W2_1
Kr_W2_3
Kr_W2_2
Kr_W2_5
Kr_W2_4
Kr_W2_7
Kr_W3_9
Kr_U3_4
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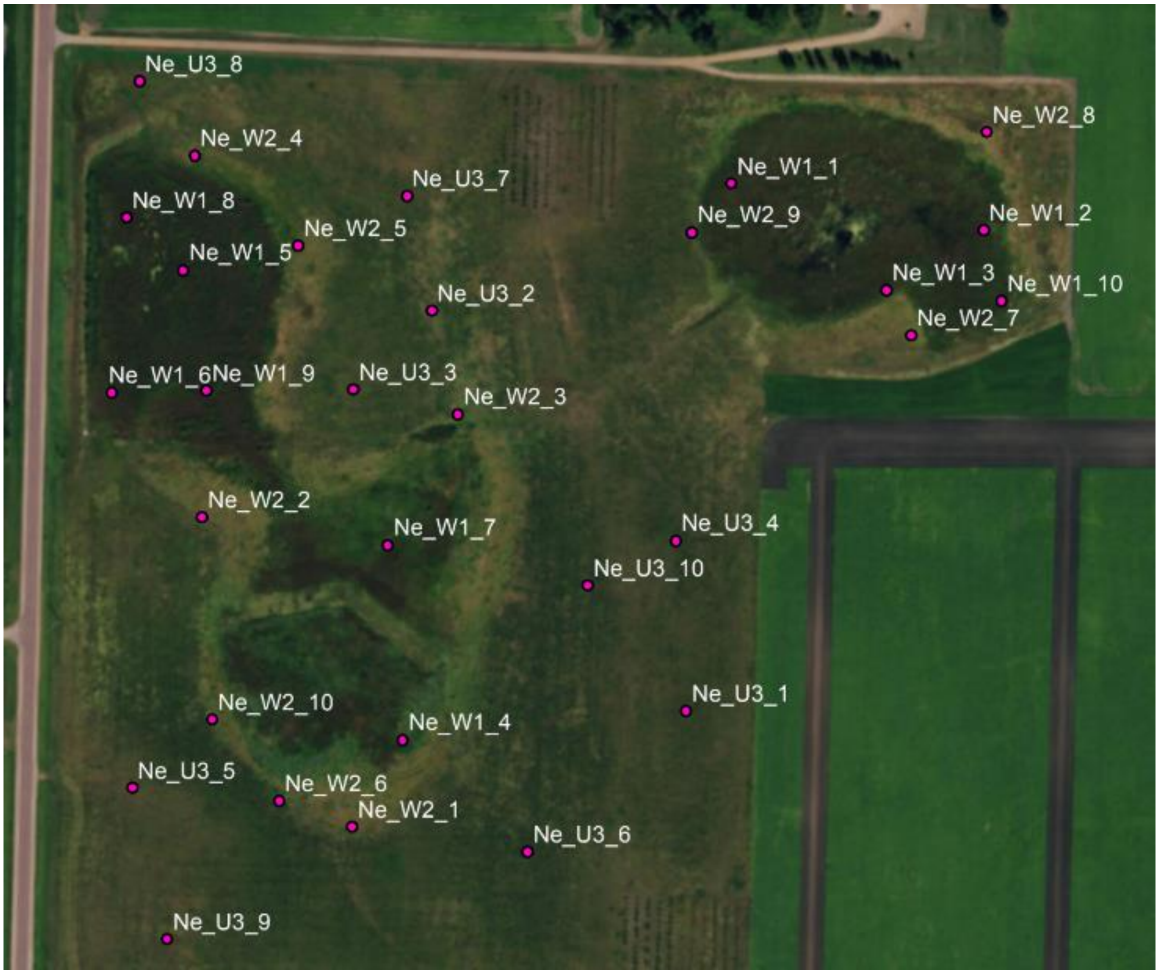
Krohn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Ne_W2_7
Ne_W1_6
Ne_W1_9
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Ne_U3_10
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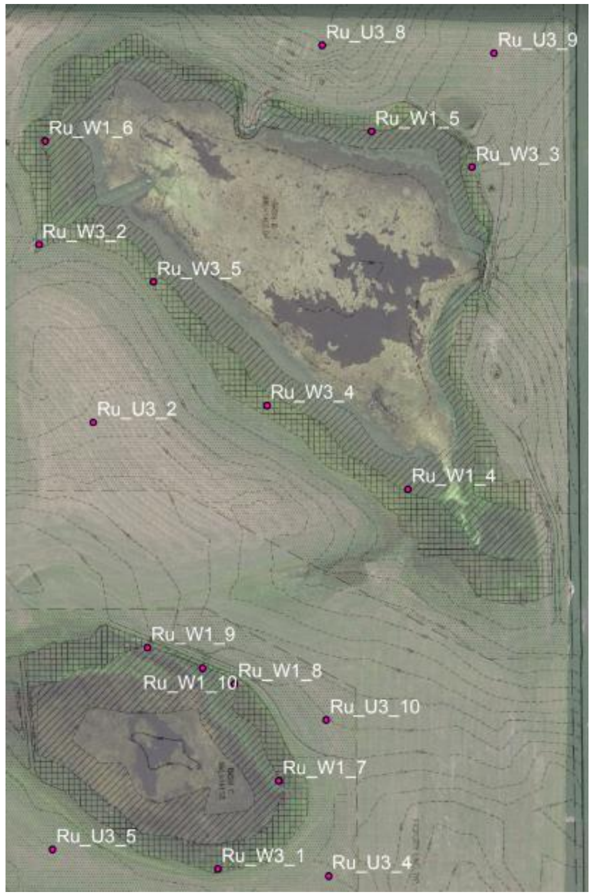
Neubauer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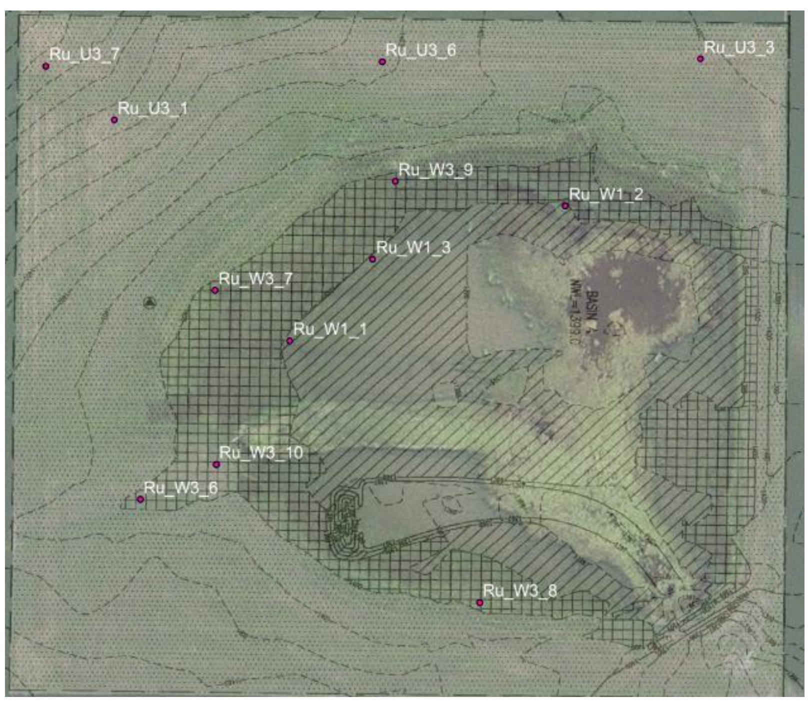
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Ru_W3_6
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Ruby


Sc_U1_8
Sc_W2_7
Sc_W2_2
Sc_U1_7
Sc_U1_3
Sc_W2_1
Sc_U1_10
Sc_U1_4
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Sc_W1_1
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Sc_U1_1
Sc_W1_8
Sc_W1_9
Sc_W1_10
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Sc_U1_9
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Sc_U1_2

Schroeder


Str_W1_10
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Str_W2_5
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LS B2
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Str_U3_5
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Str_W1_6
Str_W1_7
Str_U3_2
Str_U3_1
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Str_U3_9
Str_W2_10
Str_U3_8

Strolberg

Appendix C. Seeding Zone Comparison Data

Plot-Level Native Species Richness

Site	Zone	Avg Spp per Plot
Deinken	W1	5.6
Drummer	W1	0.5
Elfering	W1	2.4
Engstrom	W1	1.1
Neubauer	W1	1.2
Ruby	W1	3.3
Schroeder	W1	2.5
Strolberg	W1	5.3
Deinken	W2	5.9
Engstrom	W2	4.2
Ruby	W2	5.4
Neubauer	W2	3.8
Schroeder	W2	5.7
Strolberg	W2	6.9
Drummer	W3	4.6
Elfering	W3	6.8
Engstrom	W3	6.5
Krohn	W3	5.4
Ruby	W3	6.2
Drummer	U3	2
Elfering	U3	8.6
Krohn	U3	5.9
Neubauer	U3	3.9
Ruby	U3	7.5
Strolberg	U3	5.6

Zone	Avg Spp/Plot	Stdev
W1	2.7	1.9
W2	5.3	1.1
W3	5.9	0.9
U3	5.6	2.4

Zone-Level Native Species Richness

Site	Zone	Avg Zone Richness
Deinken	W1	22
Drummer	W1	18
Elfering	W1	21
Engstrom	W1	18
Neubauer	W1	22
Ruby	W1	18
Schroeder	W1	13
Strolberg	W1	34
Deinken	W2	37
Engstrom	W2	64
Krohn	W2	32
Neubauer	W2	38
Schroeder	W2	47
Strolberg	W2	53
Drummer	W3	55
Elfering	W3	47
Engstrom	W3	39
Krohn	W3	36
Ruby	W3	54
Drummer	U3	24
Elfering	U3	34
Krohn	U3	27
Neubauer	U3	31
Ruby	U3	46
Strolberg	U3	40

Zone	Avg Richness	Stdev
W1	20.8	6.1
W2	45.2	11.9
W3	46.2	8.6
U3	33.7	8.2

Percent of Seeded Species Present

Site	Zone	Avg % Present
Deinken	W1	36.4%
Drummer	W1	27.3%
Elfering	W1	45.5%
Engstrom	W1	22.7%
Neubauer	W1	50.0%
Ruby	W1	50.0%
Schroeder	W1	27.3%
Strolberg	W1	59.1%
Deinken	W2	36.4%
Engstrom	W2	63.6%
Krohn	W2	36.4%
Neubauer	W2	36.4%
Schroeder	W2	45.5%
Strolberg	W2	66.7%
Drummer	W3	38.9%
Elfering	W3	50.0%
Engstrom	W3	66.7%
Krohn	W3	47.2%
Ruby	W3	66.7%
Drummer	U3	40.0%
Elfering	U3	56.7%
Krohn	U3	43.3%
Neubauer	U3	76.7%
Ruby	U3	70.0%
Strolberg	U3	70.0%

Zone	Avg % Present	Stdev
W1	39.8%	13.3%
W2	47.5%	14.2%
W3	53.9%	12.4%
U3	59.4%	15.3%

Native Species Cover

Site	Zone	Avg Rel Cover Native
Deinken	W1	52.3%
Drummer	W1	8.5%
Elfering	W1	35.4%
Engstrom	W1	15.5%
Neubauer	W1	18.7%
Ruby	W1	24.8%
Schroeder	W1	17.2%
Strolberg	W1	56.8%
Deinken	W2	59.9%
Engstrom	W2	35.8%
Krohn	W2	64.4%
Neubauer	W2	78.4%
Schroeder	W2	48.9%
Strolberg	W2	77.8%
Drummer	W3	42.3%
Elfering	W3	67.7%
Engstrom	W3	66.6%
Krohn	W3	87.8%
Ruby	W3	84.0%
Drummer	U3	20.6%
Elfering	U3	94.1%
Krohn	U3	91.3%
Neubauer	U3	88.1%
Ruby	U3	91.5%
Strolberg	U3	93.7%

Zone	Avg Rel Cover Native	Stdev
W1	28.6%	17.8%
W2	60.9%	16.6%
W3	69.7%	18.0%
U3	79.9%	29.1%

Invasive Species Cover

Site	Zone	Avg Rel Cover Invasive
Deinken	W1	47.0%
Drummer	W1	28.8%
Elfering	W1	58.3%
Engstrom	W1	31.6%
Neubauer	W1	63.5%
Ruby	W1	68.1%
Schroeder	W1	45.7%
Strolberg	W1	40.1%
Deinken	W2	29.7%
Engstrom	W2	51.1%
Krohn	W2	21.2%
Neubauer	W2	9.7%
Schroeder	W2	35.8%
Strolberg	W2	16.6%
Drummer	W3	44.2%
Elfering	W3	29.6%
Engstrom	W3	32.2%
Krohn	W3	1.2%
Ruby	W3	13.2%
Drummer	U3	13.3%
Elfering	U3	2.5%
Krohn	U3	4.8%
Neubauer	U3	7.1%
Ruby	U3	7.5%
Strolberg	U3	2.4%

Zone	Avg Rel Cover Invasive	Stdev
W1	47.9%	14.4%
W2	27.4%	14.9%
W3	24.1%	16.9%
U3	6.3%	4.1%

Appendix D. Community Composition Data

W1 Zone Guild Comparison

Guild	Avg Rel Cover	Stdev
Cool-season grass	5.2%	4.2%
Forb	7.9%	4.3%
Sedge/Rush	17.7%	11.1%
Woody	2.4%	1.7%
Warm-season grass	0.5%	0.4%

W2 Zone Guild Comparison

Guild	Avg Rel Cover	Stdev
Cool-season grass	20.6%	16.0%
Forb	17.7%	7.3%
Sedge/Rush	16.9%	12.1%
Woody	1.8%	1.8%
Warm-season grass	4.5%	3.6%

W3 Zone Guild Comparison

Guild	Avg Rel Cover	Stdev
Cool-season grass	16.8%	9.4%
Forb	26.7%	13.7%
Sedge/Rush	6.7%	4.7%
Woody	1.5%	1.6%
Warm-season grass	18.8%	15.3%

U3 Zone Guild Comparison

Guild	Avg Rel Cover	Stdev
Cool-season grass	14.8%	6.6%
Forb	29.9%	21.3%
Sedge/Rush	0.3%	-
Woody	0.1%	0.1%
Warm-season grass	37.6%	23.9%

Appendix E. Guild Resiliency Data

W1 Zone Guild Comparison – High & Low Invasive Cover

Guild	Avg Rel Cover High Invasion	Stdev	Avg Rel Cover Low Invasion	Stdev
Cool-season grass	4.4%	3.5%	3.6%	2.9%
Forb	4.6%	4.6%	7.6%	3.5%
Sedge/Rush	7.0%	4.9%	12.3%	9.8%
Woody	0.8%	1.0%	2.3%	1.0%
Warm-season grass	0.8%	-	0.3%	0.4%

W2 Zone Guild Comparison – High & Low Invasive Cover

Guild	Avg Rel Cover High Invasion	Stdev	Avg Rel Cover Low Invasion	Stdev
Cool-season grass	5.1%	3.7%	15.5%	13.3%
Forb	5.3%	3.5%	13.1%	5.3%
Sedge/Rush	5.7%	3.6%	11.4%	10.2%
Woody	1.6%	2.0%	0.6%	0.5%
Warm-season grass	2.0%	2.9%	4.1%	1.3%

W3 Zone Guild Comparison – High & Low Invasive Cover

Guild	Avg Rel Cover High Invasion	Stdev	Avg Rel Cover Low Invasion	Stdev
Cool-season grass	5.7%	3.2%	11.8%	11.3%
Forb	11.1%	7.0%	17.4%	7.7%
Sedge/Rush	3.3%	3.9%	4.1%	3.4%
Woody	1.9%	-	0.6%	0.3%
Warm-season grass	3.0%	2.7%	21.2%	14.7%

U3 Zone Guild Comparison – High & Low Invasive Cover

Guild	Avg Rel Cover High Invasion	Stdev	Avg Rel Cover Low Invasion	Stdev
Cool-season grass	3.3%	3.5%	13.1%	4.4%
Forb	4.7%	5.3%	27.1%	18.1%
Sedge/Rush	-	-	0.3%	-
Woody	-	-	0.1%	0.1%

Appendix F. Updated State Seed Mixes

Formerly W1

Emergent Wetland

34-181

Common Name	Scientific Name	Rate (kg/ha)	Rate (lb/ac)	% of Mix (% by wt)	Seeds/ sq ft
American slough grass	*Beckmannia syzigachne*	0.78	0.70	14.07%	12.92
tall manna grass	*Glyceria grandis*	0.28	0.25	4.98%	6.40
rice cut grass	*Leersia oryzoides*	0.34	0.30	5.93%	3.70
	Total Grasses	**1.40**	**1.25**	**24.98%**	**23.02**
river bulrush	*Bolboschoenus fluviatilis*	0.85	0.76	15.20%	1.20
bristly sedge	*Carex comosa*	0.20	0.18	3.63%	2.00
lake sedge	*Carex lacustris*	0.07	0.06	1.19%	0.24
tussock sedge	*Carex stricta*	0.04	0.04	0.77%	0.75
least spikerush	*Eleocharis acicularis*	0.11	0.10	1.94%	2.50
marsh spikerush	*Eleocharis palustris*	0.11	0.10	2.03%	1.90
Torrey's rush	*Juncus torreyi*	0.04	0.04	0.85%	25.00
Three-square bulrush	*Schoenoplectus pungens*	0.26	0.23	4.54%	1.00
soft stem bulrush	*Schoenoplectus tabernaemontani*	0.49	0.44	8.78%	5.00
woolgrass	*Scirpus cyperinus*	0.06	0.05	1.02%	32.00
	Total Sedges and Rushes	**2.24**	**2.00**	**39.95%**	**71.59**
Sweet flag	*Acorus americanus*	0.31	0.28	5.53%	0.67
common water plantain	*Alisma triviale*	0.45	0.40	8.00%	9.70
marsh milkweed	*Asclepias incarnata*	0.31	0.28	5.67%	0.50
broad-leaved arrowhead	*Sagittaria latifolia*	0.34	0.30	6.07%	6.80
giant bur reed	*Sparganium eurycarpum*	0.55	0.49	9.80%	0.09
	Total Forbs	**1.96**	**1.75**	**35.07%**	**17.76**
	Totals:	**5.60**	**5.00**	**100.00%**	**112.37**
Purpose:	Emergent wetland restoration for use in wetland mitigation, shoreline restoration, wet stormwater ponds where emergent vegetation is desired.				
Planting Area:	Statewide				

Source: Minnesota Board of Water and Soil Resources

Formerly W2

34-271

Wet Meadow South and West

Common Name	Scientific Name	Rate (kg/ha)	Rate (lb/ac)	% of Mix (% by wt)	Seeds/ sq ft
fringed brome	*Bromus ciliatus*	1.23	1.10	9.18%	4.45
bluejoint	*Calamagrostis canadensis*	0.06	0.05	0.41%	5.00
Virginia wild rye	*Elymus virginicus*	1.12	1.00	8.37%	1.55
rice cut grass	*Leersia oryzoides*	0.28	0.25	2.07%	3.10
tall manna grass	*Glyceria grandis*	0.17	0.15	1.26%	3.90
fowl manna grass	*Glyceria striata*	0.11	0.10	0.83%	3.30
fowl bluegrass	*Poa palustris*	0.39	0.35	2.88%	16.50
	Total Grasses	**3.36**	**3.00**	**25.00%**	**37.80**
bristly sedge	*Carex comosa*	0.24	0.21	1.78%	2.36
pointed broom sedge	*Carex scoparia*	0.06	0.05	0.43%	1.60
awl-fruited sedge	*Carex stipata*	0.19	0.17	1.40%	2.10
tussock sedge	*Carex stricta*	0.03	0.03	0.21%	0.50
fox sedge	*Carex vulpinoidea*	0.16	0.14	1.13%	5.00
path rush	*Juncus tenuis*	0.04	0.04	0.34%	15.00
dark green bulrush	*Scirpus atrovirens*	0.20	0.18	1.48%	30.00
woolgrass	*Scirpus cyperinus*	0.09	0.08	0.67%	50.00
	Total Sedges and Rushes	**1.01**	**0.90**	**7.44%**	**106.56**
marsh milkweed	*Asclepias incarnata*	0.27	0.24	2.03%	0.43
common boneset	*Eupatorium perfoliatum*	0.02	0.02	0.18%	1.30
grass-leaved goldenrod	*Euthamia graminifolia*	0.01	0.01	0.06%	1.00
spotted Joe pye weed	*Eutrochium maculatum*	0.02	0.02	0.18%	0.75
autumn sneezeweed	*Helenium autumnale*	0.03	0.03	0.23%	1.30
sawtooth sunflower	*Helianthus grosseserratus*	0.04	0.04	0.30%	0.20
great lobelia	*Lobelia siphilitica*	0.02	0.02	0.13%	2.90
blue monkey flower	*Mimulus ringens*	0.01	0.01	0.07%	6.80
Virginia mountain mint	*Pycnanthemum virginianum*	0.07	0.06	0.53%	5.10
giant goldenrod	*Solidago gigantea*	0.02	0.02	0.14%	1.50
eastern panicled aster	*Symphyotrichum lanceolatum*	0.03	0.03	0.22%	1.50
red-stemmed aster	*Symphyotrichum puniceum*	0.19	0.17	1.42%	5.00
tall meadow-rue	*Thalictrum dasycarpum*	0.01	0.01	0.12%	0.11
blue vervain	*Verbena hastata*	0.15	0.13	1.12%	4.61
bunched ironweed	*Vernonia fasciculata*	0.03	0.03	0.28%	0.30
Culver's root	*Veronicastrum virginicum*	0.01	0.01	0.12%	4.20
golden alexanders	*Zizia aurea*	0.28	0.25	2.06%	1.00
	Total Forbs	**1.23**	**1.10**	**9.19%**	**38.00**
Oats	*Avena sativa*	7.85	7.00	58.37%	3.12
	Total Cover Crop	**7.85**	**7.00**	**58.37%**	**3.12**
	Totals:	**13.45**	**12.00**	**100.00%**	**185.48**
Purpose:	Wet meadow / Sedge meadow reconstruction for wetland mitigation or ecological restoration projects				
Planting Area:	Tallgrass Aspen Parklands, Prairie Parkland, and Eastern Broadleaf Forest Provinces. Mn/DOT Districts 2(west), 3B, 4, Metro, 6, 7 & 8.				

Source: Minnesota Board of Water and Soil Resources

Formerly W3

34-262

Wet Prairie

Common Name	Scientific Name	Rate (kg/ha)	Rate (lb/ac)	% of Mix (% by wt)	Seeds/ sq ft
big bluestem	*Andropogon gerardii*	1.12	1.00	6.89%	3.67
fringed brome	*Bromus ciliatus*	1.68	1.50	10.38%	6.08
bluejoint	*Calamagrostis canadensis*	0.04	0.04	0.27%	4.00
Virginia wild rye	*Elymus virginicus*	1.96	1.75	12.07%	2.70
tall manna grass	*Glyceria grandis*	0.17	0.15	1.02%	3.80
fowl manna grass	*Glyceria striata*	0.12	0.11	0.73%	3.50
switchgrass	*Panicum virgatum*	0.84	0.75	5.16%	3.85
fowl bluegrass	*Poa palustris*	0.22	0.20	1.39%	9.60
Indian grass	*Sorghastrum nutans*	0.56	0.50	3.44%	2.20
prairie cordgrass	*Spartina pectinata*	0.56	0.50	3.41%	1.20
	Total Grasses	**7.29**	**6.50**	**44.76%**	**40.60**
wooly sedge	*Carex pellita*	0.06	0.05	0.32%	0.47
tussock sedge	*Carex stricta*	0.02	0.02	0.17%	0.48
fox sedge	*Carex vulpinoidea*	0.11	0.10	0.66%	3.50
dark green bulrush	*Scirpus atrovirens*	0.11	0.10	0.72%	17.74
woolgrass	*Scirpus cyperinus*	0.03	0.03	0.18%	16.00
	Total Sedges and Rushes	**0.34**	**0.30**	**2.05%**	**38.19**
Canada anemone	*Anemone canadensis*	0.03	0.03	0.21%	0.09
marsh milkweed	*Asclepias incarnata*	0.09	0.08	0.55%	0.14
Canada tick trefoil	*Desmodium canadense*	0.56	0.50	3.41%	1.00
flat-topped aster	*Doellingeria umbellata*	0.06	0.05	0.34%	1.20
common boneset	*Eupatorium perfoliatum*	0.03	0.03	0.23%	2.00
grass-leaved goldenrod	*Euthamia graminifolia*	0.02	0.02	0.11%	2.00
spotted Joe pye weed	*Eutrochium maculatum*	0.04	0.04	0.30%	1.50
autumn sneezeweed	*Helenium autumnale*	0.06	0.05	0.35%	2.39
sawtooth sunflower	*Helianthus grosseserratus*	0.06	0.05	0.38%	0.30
great blazing star	*Liatris pycnostachya*	0.02	0.02	0.17%	0.10
great lobelia	*Lobelia siphilitica*	0.01	0.01	0.05%	1.40
blue monkey flower	*Mimulus ringens*	0.01	0.01	0.05%	6.40
Virginia mountain mint	*Pycnanthemum virginianum*	0.09	0.08	0.55%	6.50
red-stemmed aster	*Symphyotrichum puniceum*	0.09	0.08	0.56%	2.40
blue vervain	*Verbena hastata*	0.17	0.15	1.06%	5.25
bunched ironweed	*Vernonia fasciculata*	0.03	0.03	0.23%	0.30
Culver's root	*Veronicastrum virginicum*	0.02	0.02	0.14%	6.00
golden alexanders	*Zizia aurea*	0.28	0.25	1.76%	1.03
	Total Forbs	**1.68**	**1.50**	**10.45%**	**40.00**
Oats	*Avena sativa*	6.95	6.20	42.74%	2.76
	Total Cover Crop	**6.95**	**6.20**	**42.74%**	**2.76**
	Totals:	**16.25**	**14.50**	**100.00%**	**121.55**
Purpose:	Wet prairie reconstruction for wetland mitigation or ecological restoration.				
Planting Area:	Tallgrass Aspen Parklands, Prairie Parkland, and Eastern Broadleaf Forest Provinces. Mn/DOT Districts 2(west), 3B, 4, Metro, 6, 7 & 8.				

Source: Minnesota Board of Water and Soil Resources

Formerly U3

Mesic Prairie Southwest

35-541

Common Name	Scientific Name	Rate (kg/ha)	Rate (lb/ac)	% of Mix (% by wt)	Seeds/ sq ft
big bluestem	*Andropogon gerardii*	1.01	0.90	7.49%	3.30
side-oats grama	*Bouteloua curtipendula*	1.01	0.90	7.49%	1.98
nodding wild rye	*Elymus canadensis*	1.01	0.90	7.46%	1.71
slender wheatgrass	*Elymus trachycaulus*	1.01	0.90	7.46%	2.27
green needle grass	*Nassella viridula*	0.49	0.44	3.67%	1.70
switchgrass	*Panicum virgatum*	0.18	0.16	1.30%	0.80
western wheatgrass	*Pascopyrum smithii*	0.56	0.50	4.15%	1.30
little bluestem	*Schizachyrium scoparium*	1.68	1.50	12.50%	8.27
Indian grass	*Sorghastrum nutans*	1.68	1.50	12.54%	6.63
	Total Grasses	**8.63**	**7.70**	**64.06%**	**27.96**
Canada milk vetch	*Astragalus canadensis*	0.07	0.06	0.53%	0.40
partridge pea	*Chamaecrista fasciculata*	0.11	0.10	0.84%	0.10
white prairie clover	*Dalea candida*	0.03	0.03	0.24%	0.20
purple prairie clover	*Dalea purpurea*	0.08	0.07	0.61%	0.40
Canada tick trefoil	*Desmodium canadense*	0.06	0.05	0.45%	0.11
narrow-leaved purple coneflower	*Echinacea angustifolia*	0.09	0.08	0.65%	0.20
ox-eye	*Heliopsis helianthoides*	0.07	0.06	0.50%	0.14
rough blazing star	*Liatris aspera*	0.03	0.03	0.28%	0.20
great blazing star	*Liatris pycnostachya*	0.02	0.02	0.21%	0.10
wild bergamot	*Monarda fistulosa*	0.04	0.04	0.29%	0.90
stiff goldenrod	*Oligoneuron rigidum*	0.03	0.03	0.28%	0.50
gray-headed coneflower	*Ratibida pinnata*	0.08	0.07	0.61%	0.80
black-eyed susan	*Rudbeckia hirta*	0.07	0.06	0.49%	2.00
smooth aster	*Symphyotrichum laeve*	0.03	0.03	0.25%	0.60
blue vervain	*Verbena hastata*	0.08	0.07	0.61%	2.50
hoary vervain	*Verbena stricta*	0.06	0.05	0.41%	0.50
golden alexanders	*Zizia aurea*	0.28	0.25	2.06%	1.00
	Total Forbs	**1.23**	**1.10**	**9.31%**	**10.65**
Oats	*Avena sativa*	3.59	3.20	26.63%	1.42
	Total Cover Crop	**3.59**	**3.20**	**26.63%**	**1.42**
	Totals:	**13.45**	**12.00**	**100.00%**	**40.03**
Purpose:	Regional mesic prairie reconstruction for wetland mitigation, ecological restoration, or conservation program plantings.				
Planting Area:	North-Central Glaciated Plains Section. Mn/DOT Districts 3A(southwest) 3B, 4(south), 7 & 8.				

Source: Minnesota Board of Water and Soil Resources