A STUDY OF PRAIRIE RECONSTRUCTIONS IN THE EASTERN DAKOTAS

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

MASTER OF SCIENCE

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ABSTRACT

Two studies of reconstruction processes in the Northern Great Plains (NGP) are presented. The first study is a retrospective study on United States Fish and Wildlife Service (USFWS) managed lands seeded with a high diversity (>15 species) seed mix. Sites were grouped by available management history to find management tactics which may trend sites towards a more successful state. A large amount of variation was captured. Results showed uncontrollable factors may be driving the outcomes of these reconstructions. Attention should be paid to uncontrolled and landscape factors to drive management of each site. A second study investigates a possible method to establish specialized seed mixes. Precision Prairie Restoration (PPR) was used to establish five repetitions of six treatments. Early results are optimistic with several target species becoming established. Future sampling will be needed to determine success of this method.

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DEDICATION

I dedicate this project to my loving wife-to-be Rachel. No one has done more to help me along this path than you. Although you may have not always felt it, I appreciate everything you have done for me more than you could ever know.

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LIST OF ABBREVIATIONS

NGP..Northern Great Plains.

CRP ....Conservation Reserve Program.

USFWS ....United States Fish and Wildlife Service.

NMS..Nonmetric Multi-dimensional Scaling.

PERMANOVA ....Permutation Multivariate Analysis of Variance.

DF ....Degrees of Freedom.

SS ....Sums of Squares.

MS...Means of Squares.

NC ....Native Cover.

IC...Introduced Cover.

PPR ....Precision Prairie Reconstruction.

LIST OF APPENDIX TABLES

FORWARD

This dissertation will be split into three chapters. Chapter One will be a comprehensive literature review while Chapter Two and Chapter Three will be written as manuscripts to be submitted to a peer-reviewed journal. A comprehensive list of references for all three chapters will be listed at end of the dissertation before the appendix.

CHAPTER 1: LITERATURE REVIEW

Introduction

The tallgrass prairies of North America have been severely degraded and destroyed, leaving very little untouched prairie remaining (Samson et al. 2004). Across the Northern Great Plains (NGP), 75% of historic prairie has been destroyed since European settlement in search of agricultural and commercial gain**.** In this current state, it is essential to reconstruct and restore both converted and degraded prairies to maintain the ecological function they provide (Wilson 2002, McLachlan and Knispel 2005, Brudvig 2011). Reconstructions are fickle, and it can be difficult to achieve reliable and consistent results because of how many factors influence the success of a reconstruction (Bakker et al. 2003, Dickens and Suding 2013, Norland et al. 2015). Success is also difficult to define universally and will vary between each reconstruction (Allison 2002). With multiple complex variables determining the success of reconstructions, it can be difficult to predict the outcome of grassland reconstructions (Norland et al. 2015). It is important to remember reconstructions are never finished (Allison 2002). Reconstructions change on a yearly basis and need varying management every year to prevent introduced and undesired species from becoming dominant in the system. It is essential to keep detailed records of factors affecting each reconstruction as well as all management performed so future research can determine factors most influential in the success of reconstructions (Sutherland et al. 2004, Norland et al. 2015).

Restoration Vs Reconstruction

Restoration and reconstruction are two different methods to return a deteriorated system to a healthy native system (Smith 1981). Restoration is a process of assisting the recovery of a degraded system to a more desirable state. Management includes processes such as prescribed fire, grazing, and noxious weed control. These practices can reduce prevalence of introduced species and encourage competition from native species to restore dominance to the native species. In order to return these sites to a more historic trajectory, at least 20% of the grassland matrix needs to be composed of native species before other management can take place (Willson and Stubbendieck 2000). If the density of native species is too low, it can be difficult if not impossible to restore a system with management alone. Many managers may be tempted to "restart" the prairie by plowing the invaded system and starting fresh with native seed. A study by Grygiel et al. (2009) suggests this may not be necessary. Grygiel et al. suggest creating small disturbances within the invaded system to create a matrix of native species throughout the system. This can increase native species density past 20% and make restoration through management possible. They found disturbing 25% of a given system can yield the highest species richness. If restoration is not possible due to low native species rates, reconstruction may be necessary (Smith 1981). Reconstruction is the process of restarting a prairie system. A reconstruction is the practice of adding a mixture of native propagules (>10 species) to a system that has been cultivated or heavily disturbed by human intervention (Norland et al. 2018). The current system will be eliminated through herbicide, fire or mechanical measures such as tillage. Input of new seed is used to guide the reconstruction towards native dominance. After a site is reseeded, management is important to restore the system to a stable native dominated system.

Management of Reconstructions

Prairie reconstruction is an intensive process and should be managed closely in order to influence success of the reconstruction (Rowe 2010). There are a wide array of practices performed by managers which can influence the success of a reconstruction. Practices generally occurs post seeding, but there are a few practices performed before seeding in efforts to influence the outcome of the reconstruction. Prairies with low diversity or heavily invaded by noxious weeds will sometimes be converted to row crop for several years before reconstruction occurs. This practice creates a “clean slate” for the reconstruction (Stehlow et al. 2017). A monoculture row crop will be relatively weed free after a few years of farming creating less of a chance for the reconstruction to be dominated by introduced weeds. Modern agricultural crops resistant to glyphosate are used to eliminate weed growth in the site. Certain row crops such as soybeans also creates a smooth surface to seed on for the reconstruction. Generally, post seeding management includes burning, grazing, and mowing, with some cases of herbicide application to control introduced species; these practices increase the occurrence of native species and increasing the competitiveness of native species (Hartnett et al. 1996, Anderson 2006, Bahm et al. 2011). Post-seeding herbicide application can problematic because it kills native and introduced species and may have minimal effect on target species long-term (Bahm et al. 2011). Seed mix composition is crucial to the outcome of the reconstruction (Kirmer et al. 2012, Nemec et al. 2013, Norland et al. 2013, 2015). Using a strategically assembled seed mix it is possible to reduce the establishment of introduced species and reduce the chance of long-term failure of a reconstruction as well as improve the ecosystem function of the grassland.

Uncontrollable factors drive changes in reconstructions (Grman et al. 2013). Historical factors, landscape context, and physical site characteristics all play into the yearly composition of the reconstruction. These uncontrollable site-specific factors drive a large amount of variation in the outcomes of different reconstructions. Knowing these factors should help to guide the selection of management practices. Abiotic factors (such as loosening soil compaction or repairing modifications for water removal for example) may need to be amended or recreated before the site can be reconstructed (Brudvig 2011). Successful reconstruction may depend on reconstructing more than the plant communities. Communities of fauna such as grazers and pollinators may need to be restored as well. These communities all interact to influence the vegetative composition of the reconstruction. The size and the landscape context of reconstructions are important to managing the vegetative composition of the site. In order to foster interactions between the fauna and flora on a reconstruction, there must be enough suitable habitat for populations of wildlife to sustain themselves. This habitat can come from the reconstruction if it is large enough or it can come from other reconstructions in the nearby landscape. Surrounding landscape factors can also have detrimental effects on reconstructions. Introduced species can send propagules from the surrounding landscape and invade the reconstruction. Management of introduced species is essential to maintain the vegetative composition of a reconstruction.

Reintroduction of historic disturbance may also be essential to maintain the integrity of a reconstruction (Brudvig et al. 2007). Reintroduction of historic disturbance (flood regime, prescribed fire, grazing, etc.) favors the proclivity of native species adapted to this disturbance (Brudvig 2011). Species native to the NGP evolved with a suite of disturbances at a relatively regular interval. Returning this interval increases the competitiveness of native species, while decreasing the competitiveness of some introduced species (Brudvig et al. 2007, Bahm et al. 2011, Brudvig 2011).

Diversity

The prairie systems which characterize the NGP are well known for their bio-diversity (Barker and Whitman 1988). Many times, the diversity of grasslands can be negatively impacted by a list of factors ranging from changes in land use to changes in disturbance (Wilsey and Potvin 2000). The effects of loss of diversity are generally negative, while the benefits of increased diversity are generally positive (Grime 1998). Diversity in the NGP can be discussed in more detail than simply the floral communities populating the landscape, but also in the pollinators and other fauna utilizing the floral community. A diversity in the pollinator community is as essential as the diversity of the floral community (Wratten et al. 2012). The interwoven nature of the different systems composing the NGP deems it necessary for biodiversity to be maintained throughout all communities in the NGP. It is also essential to combat the forces which are detrimental to the functioning of a native prairie system such as changes in land use, habitat fragmentation and introduced species.

Proper vegetative composition is essential for the efficient functioning of a prairie system and the overall benefit to humans (Grime 1998, Christian and Wilson 1999, Kirmer et al. 2012, Craine et al. 2013). Grime (1998) sets forth to the task of describing the short and long-term effect of biodiversity in a grassland situation. Grime distinguishes between dominant, subordinate, and transient species. Dominant species are species which tend to be more frequent in the community, characterizing the typical state of the community. These species tend to make up are larger proportion of the biomass. Subordinates are species which occur paired with some species of dominants, but usually do not have more biomass than dominants even though they tend to be more numerous. Transients are not paired to another species and form a small percentage of the biomass of a community. They tend vary greatly in functional traits and number. Grime then continues to describe the "mass ratio" hypothesis. This hypothesis which states:

> "the relative importance of dominants, subordinates and transients [determines] ecosystem properties such as productivity, carbon sequestration, water relations, nutrient cycling and storage, litter quality, and resistance and resilience to perturbations."

Using the mass ratio hypothesis, autotrophic organisms can be considered the most pivotal in determining the function of the ecosystem (Grime 1998). The mass ratio hypothesis also does not infer the dominant individuals in the ecosystem are the only important ones. Ecosystem function is still determined to a lesser degree by the subordinates and the transient individuals. Transient individuals are possible future dominants. With high diversity of transients, ecosystem function will remain resilient. In the event of major disturbance or a severe decrease in the populations of current dominant species, transient species represent a possible replacement dominant species. Grime uses the example of prairie left unmanaged and undisturbed for a long period of time. This prairie will be subjected to woody encroachment, given the correct climatic requirement and the presence of transient woody saplings, and will eventually become a forest. In this scenario, the woody species would be the transients which assume dominance in the event of disturbance (change in disturbance regime). Grime hypothesizes the current decline in ecosystem function across the planet is in response to a loss of diversity in the transient populations occurring within modern ecosystems. This loss of diversity is caused by ecosystem isolation and fragmentation. Transients occur from seed banks in the soil and seed rain from the surrounding landscape. In a landscape which has been isolated, fragmentated, or poorly restored from a destroyed state (restored prairie which was previously farmed), there are little to no transients from the soil seed bank or surrounding landscapes. This loss of transient diversity means in the event of a large disturbance, no other possible dominants are available on the site to maintain ecosystem function in the absence of the current dominant. Therefore, to maintain resilience in the function of an ecosystem, diversity of autotrophic dominance is required to mitigate the effects of disturbance. To do this, a diversity of each dominance level (dominant, subordinate, and transient) must be maintained through proper management and inclusion of species diversity in the landscape seed bank.

Invasion of Introduced Cool Season Grasses

Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermus)* are introduced cool season grass problematic to the NGP (Grant et al. 2004, DeKeyser et al. 2013, 2015, Toledo et al. 2014). Toledo et al. explains the extent of Kentucky bluegrass and its effects on native systems in the NGP. They explain that Kentucky bluegrass is a major threat to species diversity, and it is competitive enough to outcompete the dominant species in an ecosystem. When Kentucky bluegrass invades an undermanaged system, it outcompetes many of the native species and decreases diversity of native grasses and forbs while also decreasing the overall soil vegetative cover of a landscape. The native prairie has evolved into a self-regulating system in reference to soil nutrient cycling, meaning that the species present are competitive because they are able to tolerate low levels of certain nutrients such as nitrogen. Kentucky bluegrass alters this natural control of nutrients in system it dominates by changing the natural carbon:nitrogen ratio. Native organic matter has a high carbon:nitrogen ratio while Kentucky bluegrass has a low carbon:nitrogen ratio. Native species have evolved to be more competitive in a nitrogen depleted system while Kentucky bluegrass performs better in a nitrogen rich system. Kentucky bluegrass also alters the infiltration of water into the soil column (Taylor and Blake 1982, Toledo et al. 2014). This is done by deflecting rainfall from the soil surface and altering the soil structure below the root layer. Kentucky bluegrass forms a shallow root mat and a layer of duff (called thatch) on the soil surface that repels precipitation when dry. A study by Taylor and Blake (1984) found that this combination of duff and dense root mass can cause significantly reduced infiltration (compared to no thatch) for 5 to 10 minutes. Toledo et al. (2014) continues to describe how the shallow root layer produced by Kentucky bluegrass causes the soil to lose its structure below the root mat decreasing water penetration. They state that more research is needed to determine if Kentucky bluegrass has a negative or positive effect on soil erosion.

Native prairie in the NGP is naturally resistant to short droughts lasting less than four years (Evans et al. 2011). Because of the effects on the infiltration of Kentucky bluegrass, less water is held in the soil in a system dominated by Kentucky bluegrass. With less water in the soil, droughts will have a more pronounced effect. Also, Kentucky bluegrass is less drought tolerant than native species, so a system dominated by Kentucky bluegrass is less drought tolerant than a native one (Toledo et al. 2014). Kentucky bluegrass will go dormant during hot and dry months that occur in the summer on the NGP, leading to decreased production. If drought persists, the dominant species of Kentucky bluegrass will not be able to survive and will leave the system with little or no production and susceptible to soil erosion. In a climate with frequent long-term droughts like the NGP (Evans et al. 2011), an ecosystem dominated by Kentucky Bluegrass cannot be considered resilient. Therefore, for the prairies in the NGP to be resilient to droughts the extent of drought intolerant invaders, such as Kentucky bluegrass, must be limited, and a highly diverse mix of drought tolerant native species must be maintained (Craine et al. 2013).

Previous Prairie Reconstruction

The Conservation Reserve Program (CRP) was created to protect erodible lands from intensive agriculture (Dunn et al. 1993). Its original purpose was to give farmers incentives to place these erodible lands into perennial vegetative cover to prevent soil erosion, but it has been found to have many other benefits. Dunn et al. state CRP reduces sediment in water ways, reduces nonpoint-source agricultural runoff, improves water quality and creates wildlife habitat, all of which increases the sustainability of agriculture, the most common land use in the NGP. While there are benefits to CRP, it also has its disadvantages. The seed mixes used to create CRP are characteristically low in diversity (Biondini 2007). In low diversity reconstructions similar to those created through CRP, rates of invasion and failure are higher (Norland et al. 2015). Increasing the diversity in the propagules introduced to a reconstruction may be critical to creating a stable system (Nemec et al. 2013). Reconstructions with higher diversity in seed, at least 9 different species, were found to have more stability in yearly variation of above ground biomass (Biondini 2007). By creating a diverse community, it is possible to create a community resistant to disturbance and invasion (Hooper et al. 2005). With a higher diversity in species present, more resources are utilized in the community, preventing excess resources from being available for any invading species. This diversity also allows for resilience to disturbance such as drought or fire. With a wide array of species present, it is more likely one species will be able to resist the disturbance well enough to prosper in the wake of the disturbance.

Benefits of Reconstructions to Wildlife

The role of pollinators as an ecosystem function is essential for modern crop management practices (Wratten et al. 2012). In order to create more efficient crop systems, maintenance of patches of biodiverse pollinator habitat is necessary to maintain a diversity of pollinators which will increase crop yield. Wratten et al. describe the secondary benefits of creating habitat for pollinators, and why doing so is important. They state creating habitat for pollinators can increase other wildlife populations, increase populations of organisms which prey on crop pests, protect soil and water quality, and enhance rural aesthetics. They state while some species of pollinators can benefit from mass bloom events, which occur in some monoculture crop systems, the benefits from these events are short term and do not benefit all pollinators. They stress the importance to providing diverse habitat and food for the pollinators on a season long basis; the pollinators can only benefit agricultural crops if they are able to survive on a year-round basis. Wratten et al. state most pollinator habitat occurs in buffer strips, hedgerows or tree rows, cover crops, and restoring prairie in close proximity to agricultural crop systems.

Thomas et al. (2001) studied the effects of habitat quality and patch isolation on pollinator population dynamics. They define their patches as any grassland greater than 500 m^2 in area containing larval food, the proper soils, and the proper vegetative composition. Their patches were separated by 30 to 100 meters of non-habitat depending on the species. They found habitat quality is a factor carrying more weight than patch size or isolation. Many land managers focus too much on creating patches and increasing size and lose sight of the quality of the patch, which can be the most pivotal factor of these. The vegetative composition of the patches is important in the management of certain species and maintaining productivity (Grant et al. 2004, Ratajczak et al. 2012). Grant et al. (2004) describe the effects of prairie habitat degraded by the encroachment of woody plant species. The location of their study site is in the area around J. Clark Salyer National Wildlife Refuge (North Dakota, United States) situated in one of the largest patches of remaining mixed grass prairie. Their study describes how several species of grassland birds react to this habitat degradation. They found presence of 11 out of 15 species decrease as woody cover increases, and grasslands became unusable for 9 out of 15 species studied when woody cover reaches 25%. They conclude many grassland bird species are particularly sensitive to woody encroachment and experience a quick decline in occurrence in the 5-20% range. They suggest land managers take note of this and focus on reduction of woody encroachment in conservation areas designed to increase bird populations.

It is also important to manage the connectivity of habitat patches to allow for the travel of individuals between populations to prevent spatial isolation (Herkert et al. 2003, Aguilar et al. 2006, Saura and Pascual-Hortal 2007, Saura et al. 2014). Changing land use is making it more difficult for species to move to different habitat patches in the event their current patch becomes unhospitable for their existence. A landscape mosaic of habitat patches can act as a series of “stepping-stones” for species to move between larger habitat patches (Saura et al. 2014). Saura et al. explain how these stepping-stones are critical for long-term dispersal of populations and genomes rather than short-term dispersal, that is, these stepping-stones allow for species to expand ranges and transmit genetic diversity similarly to the way it happened before extensive land use changes and fragmentation to the landscape. Because of the slow nature of this expansion, the stepping-stones must be of sufficient size and quality to support long-term populations. Smaller, lower quality patches can be detrimental to expansion of species because it takes away migration opportunity from better patches which could support a long-term population.

An increase in the number of habitat patches on the landscape can be achieved through the CRP (Dunn et al. 1993). CRP also causes an increase of bird species present in the prairie (Johnson 2000). Johnson states major declines in grassland habitat stemming from agricultural land conversion has caused bird populations to decrease. He also notes decreases in bird populations are due to agricultural land being unsuitable for breeding of bird species. This land is unsuitable due to the frequent disturbance which happens here preventing nest success. An increase of CRP leads to an increase of habitat for native birds to utilize and an increase of native bird diversity. The benefit of creating diversity is an increase in resiliency in the landscape (Duffy 2009).

With strategic planning for reconstructions, it is possible to increase the resilience and stability of the project, while maximizing the overall benefit. For a reconstruction to be successful, proper management and accurate records must be kept (Sutherland et al. 2004, Brudvig 2011, Norland et al. 2015). Every step along the way can have effects on the outcome of the reconstruction from the pre-seeding management to the seed mix, to the seeding method to the frequency of management after seeding (Hartnett et al. 1996, McLachlan and Knispel 2005, Anderson 2006, Rowe 2010, Bahm et al. 2011, Kirmer et al. 2012, Nemec et al. 2013, Norland et al. 2015). With the proper combination of frequency and intensity of management practices it is possible to increase the possibility of a successful reconstruction. These successful reconstructions will have benefits to the human environment and the fauna endemic to the NGP (Dunn et al. 1993, Johnson 2000, Thomas et al. 2001, Grant et al. 2004, Duffy 2009, Wratten et al. 2012, Saura et al. 2014).

CHAPTER 2: A RETROSPECTIVE OF HIGH DIVERSITY RECONSTRUCTIONS IN EASTERN NORTH DAKOTA AND EASTERN SOUTH DAKOTA

Introduction

Prairies in the NGP have been drastically reduced by conversion and invasion by introduced species (Samson et al. 2004, Toledo et al. 2014, DeKeyser et al. 2015). In order to conserve the flora and fauna of the NGP it is essential to restore and reconstruct degraded systems (Samson and Knopf 1994, Samson et al. 2004). In the process of repairing these damaged systems, it is essential to maintain the natural resilience to disturbance which characterizes these systems. The reconstruction of a degraded system is complex and time consuming (Norland et al. 2015). Due diligence should be taken in preparation of site and seed mixes to increase the likelihood of producing a resilient system. Accurate records should be kept of methods and results of each reconstruction so as to inform future practices and increase the efficiency of reconstructions (Sutherland et al. 2004). An increase of reconstruction projects collecting accurate data to be used for future analysis is critical to finding effective management tools for encouraging the desired vegetative composition of the site. Many factors may have a significant effect on seeding but may seem too insignificant to record (Dickens and Suding 2013). Research is needed to determine which factors are significant to the success of a reconstruction. Dickens and Suding state managers and researchers need to work together in order to determine the factors influencing the vegetative composition of the reconstruction.

Invasion of cool season grasses is a pervasive management concern across the NGP (DeKeyser et al. 2013, 2015, Toledo et al. 2014). Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) invade native prairie and create a self-perpetuating environment favorable for the expansion of these introduced plants but not native species (Bosy and Reader

1995, Toledo et al. 2014). These species respond poorly to disturbance, increasing under a disturbance-free regime (DeKeyser et al. 2013). With proper management, it is possible to remove the competitive advantage of these introduced cool-season grasses and decrease their prevalence in native systems. Management to control Kentucky bluegrass and smooth brome begins as early as the seeding of a reconstruction (Norland et al. 2015). Using the broadcast seeding method and a high diversity of seed can help reduce the prevalence of introduced species in the mature reconstruction. Use of fire and grazing in the years following seeding reduce the competitive ability of these introduced species while increase the competitiveness of native species adapted to this disturbance regime (Bahm et al. 2011, DeKeyser et al. 2013).

In order to create more successful reconstructions, we must look to the reconstructions we have completed in years past (Brudvig 2011). This study is retrospective, that is a look into practices performed, rather than using scientific method to design and execute an experiment. This study is an expansion to the study presented by Norland et al. (2015). Norland et al. determined using a high diversity of seed (>15 species of grasses, forbs, and small shrubs) in the reconstruction creates about an 80% chance of the site being dominated by native species and resisting invasion from introduced species. In hopes to expand on what causes the 20% of failures in this statistic, we conducted our study. This study investigated the vegetative outcome of numerous high diversity reconstructions performed by the United States Fish and Wildlife Service (USFWS) in an attempt to draw conclusions as to what management factors affected the outcomes of these reconstructions. Data collected by managers at the time of the seeding and after was used to capture the some of the management factors with major impacts both favorable and unfavorable. Factors were: 1) historic use of the site, 2) last vegetative cover of the site before reconstruction, 3) any special treatments applied to the sites by managers before seeding,

4) method of spreading propagules, 5) grazing treatments applied 6) prescribed burning treatment, 7) herbicide treatments, and 8) composition of the seed mix applied to the site. Goals of this study were to: 1) analyze the vegetative responses of the aforementioned management practices on reconstructions; 2) expand on missing knowledge in reconstruction practices; and 3) shed light on deficiencies in knowledge surrounding the management and creation of reconstructions in the NGP. In conducting this study, we expected to find large amounts of variation. We expect this study to provide more questions than answers, helping to guide future research.

Methods

Site Selection

A total of 78 sites were selected from a pool of 90 sites to be sampled between the summers of 2018 and 2019. Sites were USFWS managed lands and were selected using the following criteria: 1) Sites must have been seeded with a seed mix of 15 or more species including forbs, 2) sites must be at least five years post seeding by 2019, 3) sites must be a minimum of 4 hectares in size, and 4) current state of sites must be ignored as to prevent bias in the data. Sites were located throughout the East half of both North Dakota and South Dakota (United States) (Table A.2). The sites all occurred within the Northern and Northwestern Glaciated Plains regions (Bryce et al. 1998). Selected sites were divided into blocks depending on size. Sites from 4 to 20 hectares were allocated at least two blocks, while larger sites or sites with more variation in plant communities being allocated extra blocks. Surveys in each block consisted of three frames 2 m^2 in size approximately 7 m apart from each other in a triangular fashion. Frames were sampled for absolute canopy cover by vegetative species. Absolute cover was used as the sample variable to capture a more precise description of the vegetative composition throughout all canopy layers. One observer was used throughout the entirety of sampling to maintain consistency of coverage estimates, limiting multi-observer sample error. Location of sample points were selected by walking to the approximate center of each block and then going approximately 15 m in a random direction. During sampling the first two blocks, attention was payed to any species present but not captured in the frames. These species were recorded as "trace" and were given a cover of 0.01%. If after two blocks the surveyors determined an accurate sample of the community composition was not captured or there is a change is density and composition of the community elsewhere in the reconstruction, more sample sites were added to capture this change. Larger sites also triggered more blocks for due diligence. Blocks were selected in flat or slightly rolling uplands. Moist lowlands and dry hill tops were avoided to maintain consistency.

Analysis

For analysis, cover was averaged by species across all frames and blocks for each reconstruction site. A Nonmetric Multi-dimensional Scaling (NMS) ordination was performed using PC-ORD version 7 (MjM Software Design, Gleneden Beach, OR) to determine site plant community dissimilarity and structure in the dataset (Peck 2010). To find patterns in the data, we used the Sorenson (Bray-Curtis) distance measure and performed 500 iterations in PC-ORD to reduce from six axes to three. Model selection and the number of dimensions (axes) was based on: 1) a significant Monte Carlo test ($p \leq 0.05$), 2) stress <25, 3) instability < 0.0001, and 4) selection was halted when the next axis did not reduce stress by at least five. Pearson's Correlation Coefficients (*r*-values) were used to correlate species to the axes from the ordination. Any r-value ≥ 0.3 or ≤ -0.3 were considered significant for interpretation. Vegetative groups were created using species life history information (native or introduced, annual or perennial, forb or grass) and used to determine differences in vegetative composition compared to the ordination graph.

Sites were grouped into different management factors, these being: 1) USFWS administrative district, 2) historical use of the site, 3) last crop on the site the season previous to seeding, 4) unique pre-seeding preparations, 5) year of seeding, 6) method of seeding, 7) occurrence of grazing, 8) occurrence of burning, 9) occurrence of haying, 10) occurrence of spraying, and the 11) percentage of the portion of the seed mix composed of forbs (Table 2.1). A Permutation Multivariate Analysis of Variance (PERMANOVA) was performed on the canopy cover data for each site to determine significant ($P \leq 0.05$) difference between the various management grouping factors based on Sorenson (Bray-Curtis) distance measure as implemented in PRIMER-e™ (Quest Research Limited) (For more information on this method refer to Anderson et al. 2008). Paired comparisons from the PERMANOVA analysis did not adjust the *P*-value for multiple comparisons as suggest by Anderson et al. (2008). PERMANOVA analysis can determine if the groups were different by their centroid and can include differences due to spread of the data. Thus, significance can be due to difference and examining the graphical representations is necessary to determine how groups are different.

Table 2.1. List of factors and definitions. All sites were given a category for each factor.

Factor	Category	Occurrences	Description
Historic Use	Tame Grass	12	Sites not being used for row crop 3+ years prior to reconstruction. Generally CRP or degraded prairie.
	Row Crop	45	Sites being tilled and seeded every year for agricultural gain 3+ years prior to reconstruction.
	Unknown	17	Sites with unknown land use history
Last Crop	Grain	6	Last crop before reconstruction was a grain crop such as wheat
	Soybeans	21	Last crop before reconstruction was soybeans
	Mix	1	Last crop before reconstruction was a mix of multiple types of row crop
	Fallow	10	No crop was seeded the year before reconstruction. Land was left idle
	Unknown	36	Last crop was unknown.
Special Treatments	Fall till	8	Site was tilled after removal of the crop in the fall. This was done to allow freezing temperatures to kill regrowth of any volunteer species in the fall
	Glyphosate	11	Glyphosate was applied before seeding to kill all vegetative growth
	Broadleaf Herbicide	3	A broadleaf herbicide was applied before seeding to limit growth of introduced weeds
	Fallow	5	Land was left fallow for the year before seeding.
	Glyphosate/Burn	3	Vegetative cover present the year before seeding was sprayed with glyphosate then burned.
	Glyphosate after Seeding	1	A treatment of glyphosate was applied after seeding, but before emergence of seeded species.
	Unknown	43	No special treatments were listed. It is possible treatments were applied but not recorded
Seed Date	2000	1	Site was seeded between January and December of 2000
	2001	3	Site was seeded between January and December of 2001
	2005	1	Site was seeded between January and December of 2005
	2006	1	Site was seeded between January and December of 2006
	2007	1	Site was seeded between January and December of 2007
	2008	5	Site was seeded between January and December of 2008
	2009	4	Site was seeded between January and December of 2009
	2010	7	Site was seeded between January and December of 2010
	2011	11	Site was seeded between January and December of 2011
	2012	17	Site was seeded between January and December of 2012
	2013	10	Site was seeded between January and December of 2013
	2014	4	Site was seeded between January and December of 2014
	2015	7	Site was seeded between January and December of 2015
	Unknown	2	The Seed Date of the Site was not recorded
Seeding Method	Broadcast	16	Site was seeded using a broadcast seeding method
	Drill	33	Site was seeded using a drill
	Drill/Broadcast	11	Site was seeded using a broadcast seeding method and drill method. Generally sites had grass species drilled and forb species broadcasted
	Snow Seed	9	Site was broadcast seeded during the early spring or late winter onto snowpack
	Unknown	5	Seeding method was not recorded
Grazing	2011	1	Site was grazed in 2011
	2013	3	Site was grazed in 2013
	2015	1	Site was grazed in 2015
	2016	2	Site was grazed in 2016
	Multiple	11	Site was grazed multiple years
	Unknown	56	Site has no record of grazing history, but also was not known site was not grazed
Burning	Once	30	Site had a prescribed burn once since seeding
	Multiple	11	Site had prescribed burn more than once during seeding
	Unknown	33	Site had no recorded prescribed burns, but also no record stating no prescribed burns had happened

Table 2.1. List of factors and definitions (continued). All sites were given a category for each factor.

Factor	Category	Occurrences	Description
Spraying	Broadcast	1	Entire site was sprayed with herbicide after seeding for control of weeds
	Spot	9	Spots of the site were sprayed with an herbicide after seeding for weed control
	Unknown	64	No record was kept of spraying history, but also was not known if spraying had not occurred
Haying	Treated	12	Site was hayed after seeding
	Unknown	62	No record of haying was found, but also no record of not haying found.
District	Arrowood	1	Site was managed by the Arrowwood USFWS district office.
	Audubon	2	Site was managed by the Audubon USFWS district office.
	Devils Lake	11	Site was managed by the Devils Lake USFWS district office
	Kulm	2	Site was managed by the Kulm USFWS district office
	Long Lake	9	Site was managed by the Long Lake USFWS district office
	Madison	15	Site was managed by the Madison USFWS district office
	Sand Lake	24	Site was managed by the Sand Lake USFWS district office
	Tewaukon	10	Site was managed by the Tewaukon USFWS district office

Grouping factors were selected by using all available management data. Management histories provided by managers depended on if the manager determined information was pertinent enough to be recorded. Due to managers having numerous reconstructions they are managing; data collection was inconsistent. Each grouping variable had some sites without management data for the grouping. Where managers were uncertain of management, we were forced to classify sites as unknown so as to avoid miscategorizing the data.

Results

Analysis shows a large degree of variation in the data set. 74 sites were sampled with a total of 138 different species (Table A.1). Eleven different factors were analyzed with 10 that were found to be significant and interpretable of the variation in the data (Table 2.2). The NMS using Sorensen Bray-Curtis dissimilarity produced a 3-dimensional solution with a final stress of 16.1. The relationship between the different dimensions combined explained 76.4% of the variation, with even distribution between the three dimensions (Table 2.3). Because axis 3 had few vegetative groups and species that were at the level for interpretation, graphical representation of axis 3 was not shown (Table 2.4). Axis 3 appeared to be tied to a latitudinal gradient and was not useful in interpreting the different management factors beyond what is shown for axis 1 and 2.

Table 2.2. Results from the PERMANOVA analysis of the 11 management factors and the vegetative data. Degrees of Freedom (Df), sums of squares (SS), means of squares (MS), and pseudo F and *p*-value are listed.

Factor	Df	SS	MS	Pseudo F	P-value
District	7	45696.00	6528.00	3.35	0.001
Historic Use	2	14107.00	7053.60	3.13	0.001
Last Crop	3	18083.00	6027.60	2.70	0.002
Special Prep	6	22378.00	3729.70	1.65	0.002
Seed Date	13	55593.00	4276.40	2.16	0.001
Seeding Method	4	19301.00	4825.30	2.17	0.001
Grazing	5	17944.00	3588.90	1.56	0.002
Prescribed Burning	2	10998.00	5499.00	2.39	0.001
Spraying	2	7277.80	3638.90	1.55	0.023
Haying	1	3338.90	3338.90	1.41	0.166
Seed Mixes	3	15443.00	5147.50	2.29	0.001
Residual	70	1.57E+05	2245.2	-	-
Total	73	1.73E+05	-	-	-

Table 2.3. Coefficients of determination for the correlations between ordinations distances (axis scores) and distances in the original n-dimensional space.

Axis	Incremental	Cumulative
1	0.272	0.272
2	0.267	0.539
3	0.226	0.764

Table 2.4. Species correlations to the three axis scores. Vegetative factors for each species are listed. Only species with $r \geq 0.3$ and $r \leq -0.3$ are displayed.

Scientific Name	Native or Introduced	Annual or Perennial	Growth Form	Axis 1	Axis 2	Axis 3
Achillea millefolium	Native	Perennial	Forb	-0.406	0.085	0.164
Andropogon gerardi	Native	Perennial	Graminoid	0.203	-0.742	0.327
Bouteloua curtipendula	Native	Perennial	Graminoid	-0.478	-0.130	-0.533
Bouteloua gracilis	Native	Perennial	Graminoid	-0.114	-0.030	-0.426
Cirsium arvense	Introduced	Perennial	Forb	-0.065	0.429	0.387
Dalea candida	Native	Perennial	Forb	0.010	-0.254	-0.311
Elymus canadensis	Native	Perennial	Graminoid	-0.619	0.048	-0.018
Elymus trachycaulus	Native	Perennial	Graminoid	-0.556	0.149	-0.020
helianthus maximiliani	Native	Perennial	Forb	-0.257	0.467	0.224
Heliopsis helianthoides	Native	Perennial	Forb	-0.440	0.113	0.461
Lactuca tatarica	Native	Perennial	Forb	0.319	-0.040	-0.062
Monarda fistulosa	Native	Perennial	Forb	-0.251	0.107	0.371
Nassella viridula	Native	Perennial	Graminoid	-0.493	0.286	-0.211
Panicum virgatum	Native	Perennial	Graminoid	-0.376	-0.280	0.076
Pascopyrum smithii	Native	Perennial	Graminoid	-0.609	0.230	0.172
Poa pratensis	Introduced	Perennial	Graminoid	0.762	0.426	-0.026
Rudbeckia hirta	Native	Perennial	Forb	-0.431	-0.063	0.015
Schizachyrium scoparium	Native	Perennial	Graminoid	-0.063	-0.298	-0.520
Solidago canadensis	Native	Perennial	Forb	0.526	0.003	-0.044
Sonchus arvensis	Introduced	Perennial	Forb	0.083	0.440	0.388
Sorghastrum nutans	Native	Perennial	Graminoid	0.089	-0.117	-0.330
Symphyotrichum ericoides	Native	Perennial	Forb	0.440	0.041	-0.125
Taraxacum officinale	Introduced	Annual	Forb	0.320	0.146	0.257
Verbena stricta	Native	Perennial	Forb	-0.367	0.005	-0.100
Zizia aurea	Native	Perennial	Forb	0.025	-0.123	-0.339

Vegetative Groups

Using factors derived from the life history traits of the species present in the communities, we created vegetative groups to determine trends in the data. We use the phrase "introduced cover" as a descriptor for species not native to the NGP as stated by the United States Department of Agriculture (USDA) Plant Database (USDA 2019). Species coded as introduced are not necessarily invasive, so much as non-native. In the same way, species coded as native can also be invasive in their growth form, but native to the region. We found high levels of Native Cover (NC) to be negatively correlated with axis 1 and 2 while high Introduced Cover (IC) to be positively correlated with axis 1 and 2 (figure 2.1). We found total richness to have a low r-value (*r* = 0.146) signifying low correlation to the ordination axes, while native perennials (*r* = -0.687), native grasses (*r* = -0.632), and introduced perennials (*r* = 0.447) to have higher *r*-values signifying higher correlation to ordination axes (Table 2.5). These groups follow the trends of NC and IC. C_3 and C_4 graminoids were very strongly correlated to the second axis.

Table 2.5. *R*-values for vegetative groupings to ordination axes. *r*-values >0.3 and <-.03 were considered significant for analysis.

Group	Axis 1 *r*-value	Axis 2 *r*-value	Axis 3 *r*-value
Introduced Annual	-0.023	0.375	-0.149
Introduced Perennial	0.447	0.620	0.088
Native Annual	-0.158	0.105	-0.168
Native Perennial	-0.687	-0.289	0.121
Introduced Forb	-0.163	0.630	0.034
Introduced Grass	0.806	0.355	-0.023
Native Forb	-0.273	0.020	0.212
Native Grass	-0.632	-0.382	-0.044
Introduced Cover	0.374	0.696	0.011
Native Cover	-0.690	-0.286	0.115
Total Richness	0.146	0.132	-0.057
Native Richness	-0.014	0.064	-0.092
Introduced Richness	0.473	0.238	0.059
C_3 Graminoid	-0.265	0.507	0.067
C_4 Graminoid	-0.034	-0.799	-0.008

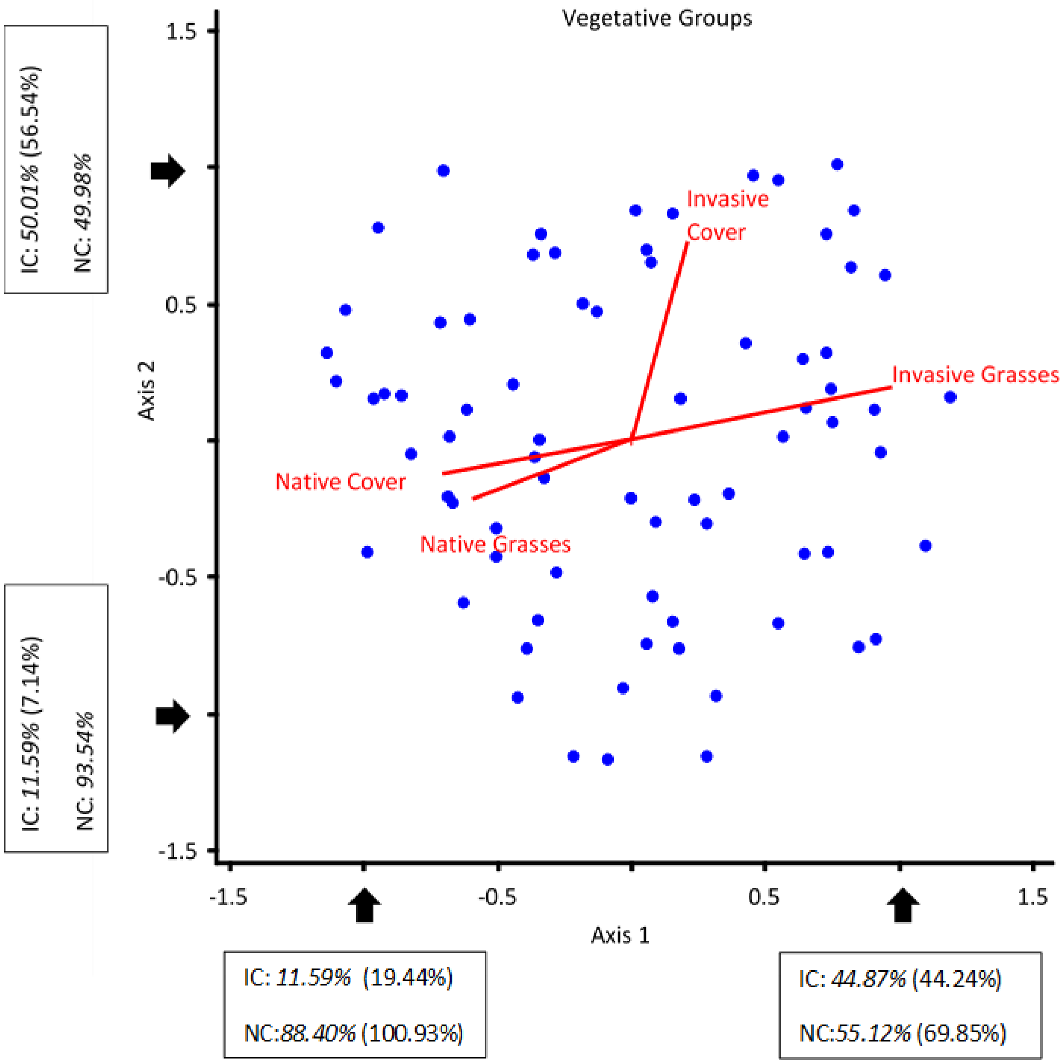

Figure 2.1. Ordination NMS graph of all the sample sites depicting how vegetative groupings relate to the axes. Lines indicate the directional strength of the groupings. Relative cover values (in italics) and absolute cover values (in parentheses) are listed on the axis for interpretation for the two vegetative group categories. Absolute cover for native species on axis 2 is not displayed because the *r*-value < 0.3 and was not interpretable (Table 2.5). A strong correlation between C_3 and C_4 graminoids to axis 2 shows a strong association with native warm season grasses and axes 2.

District

PERMANOVA analysis of district was shown to have a significant effect on the vegetative composition of the restoration (p = .001) (Figure 2.2). Pair-wise comparisons show sites in the Arrowwood district were not significantly different ($p \geq .05$) from sites in all other districts most likely due to small sample size in Arrowwood (n=1) (Table 2.6).

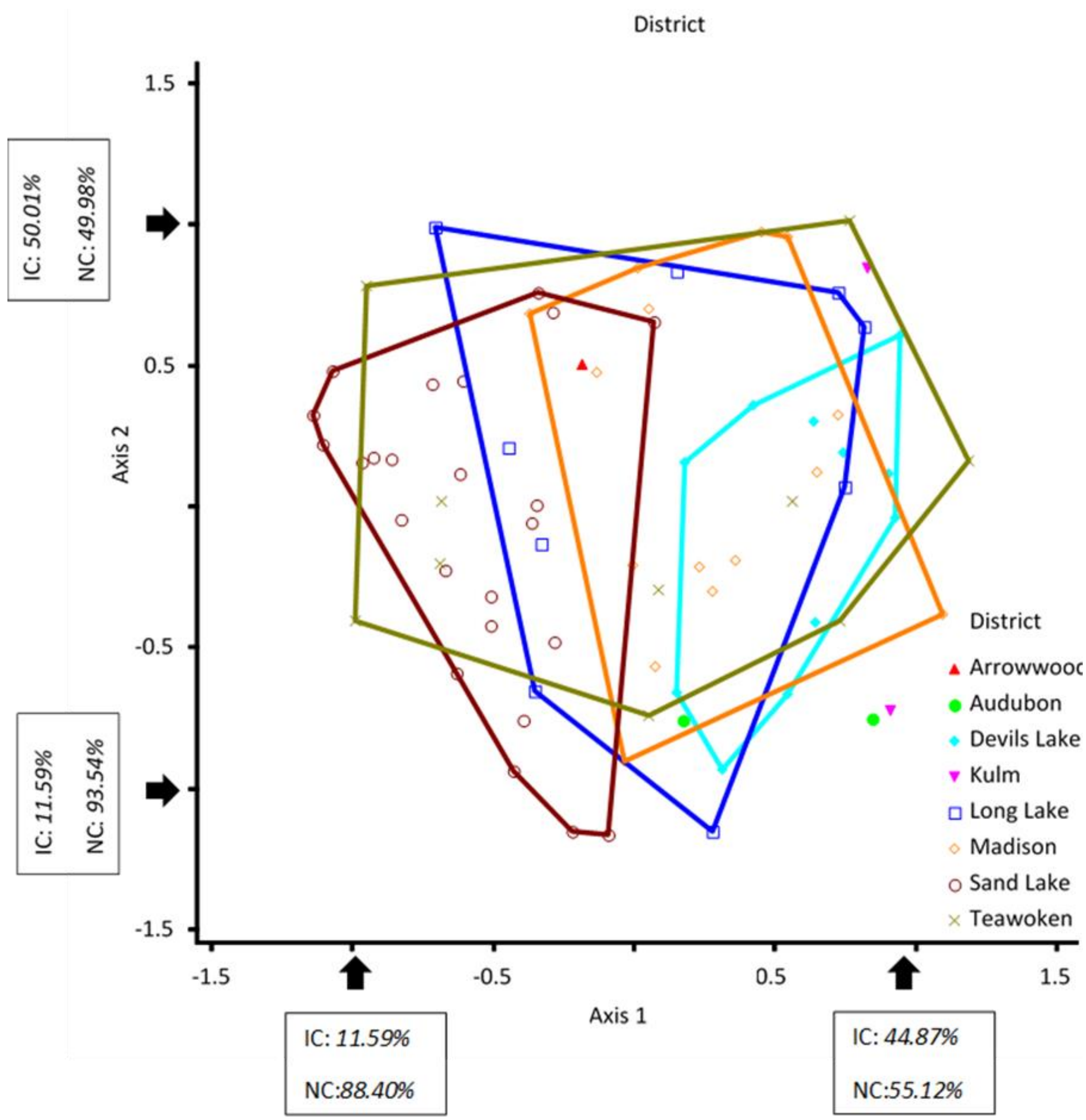

Figure 2.2. Ordination NMS graph depicting sites grouped by district. Pair-wise comparisons in Table 2.6 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.6. Pair-wise comparisons from the PERMANOVA analysis for district groupings.

Grouping	*t*	*p*-value
Arrowwood x Audubon	1.238	0.333
Arrowwood x Devils Lake	1.192	0.165
Arrowwood x Kulm	0.812	1.000
Arrowwood x Long Lake	0.982	0.584
Arrowwood x Madison	1.055	0.395
Arrowwood x Sand Lake	1.022	0.360
Arrowwood x Tewaukon	1.021	0.452
Audubon x Devils Lake	1.272	0.118
Audubon x Kulm	1.163	0.303
Audubon x Long Lake	1.475	0.015
Audubon x Madison	1.374	0.034
Audubon x Sand Lake	1.680	0.005
Audubon x Tewaukon	1.206	0.181
Devil Lake x Kulm	0.871	0.695
Devils Lake x Long Lake	2.024	0.001
Devils Lake x Madison	1.542	0.005
Devils Lake x Sand Lake	2.930	0.001
Devils Lake x Tewaukon	1.688	0.006
Kulm x Long Lake	1.189	0.152
Kulm x Madison	1.074	0.335
Kulm x Sand Lake	1.723	0.009
Kulm x Tewaukon	1.274	0.094
Long Lake x Madison	2.185	0.001
Long Lake x Sand Lake	2.422	0.001
Long Lake x Tewaukon	1.846	0.002
Madison x Sand Lake	2.526	0.001
Madison x Tewaukon	1.569	0.008
Sand Lake x Tewaukon	2.287	0.001

Historic Use

The PERMANOVA analysis showed historic use to be a significant factor (p=0.001) in explanation of the variation in the data set (Figure 2.3). All paired comparisons were significant, but it appears the spread of the data was why the pairs were different showing that variability among sites is high (Table 2.7).

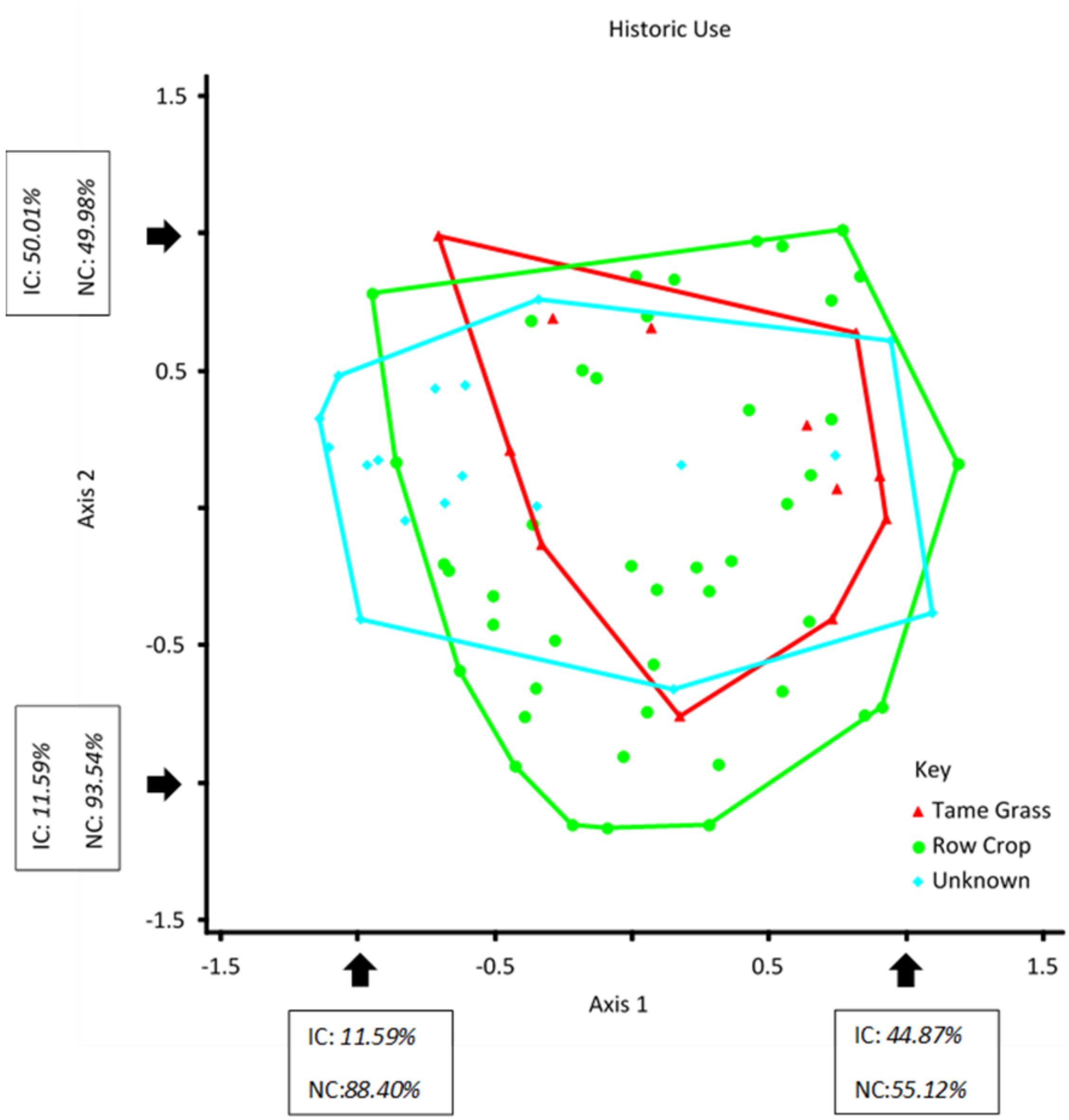

Figure 2.3. Ordination NMS graph depicting sites grouped by historic use. Pair-wise comparisons in Table 2.7 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.7. Pair-wise comparisons from the PERMANOVA analysis for historic use groupings.

Grouping	*t*	*p*-value
Tame grass x Row crop	1.461	0.019
Tame grass x Unknown	1.883	0.002
Row crop x Unknown	1.964	0.001

Last Crop Before Seeding

The PERMANOVA analysis showed this factor to be significant (p = .002) in the vegetative composition of the site with all factors being significantly different from each other except soybeans and unknown (p = .163) (Table 2.8). Grain had the least spread and was associated with higher levels of IC (Figure 2.4).

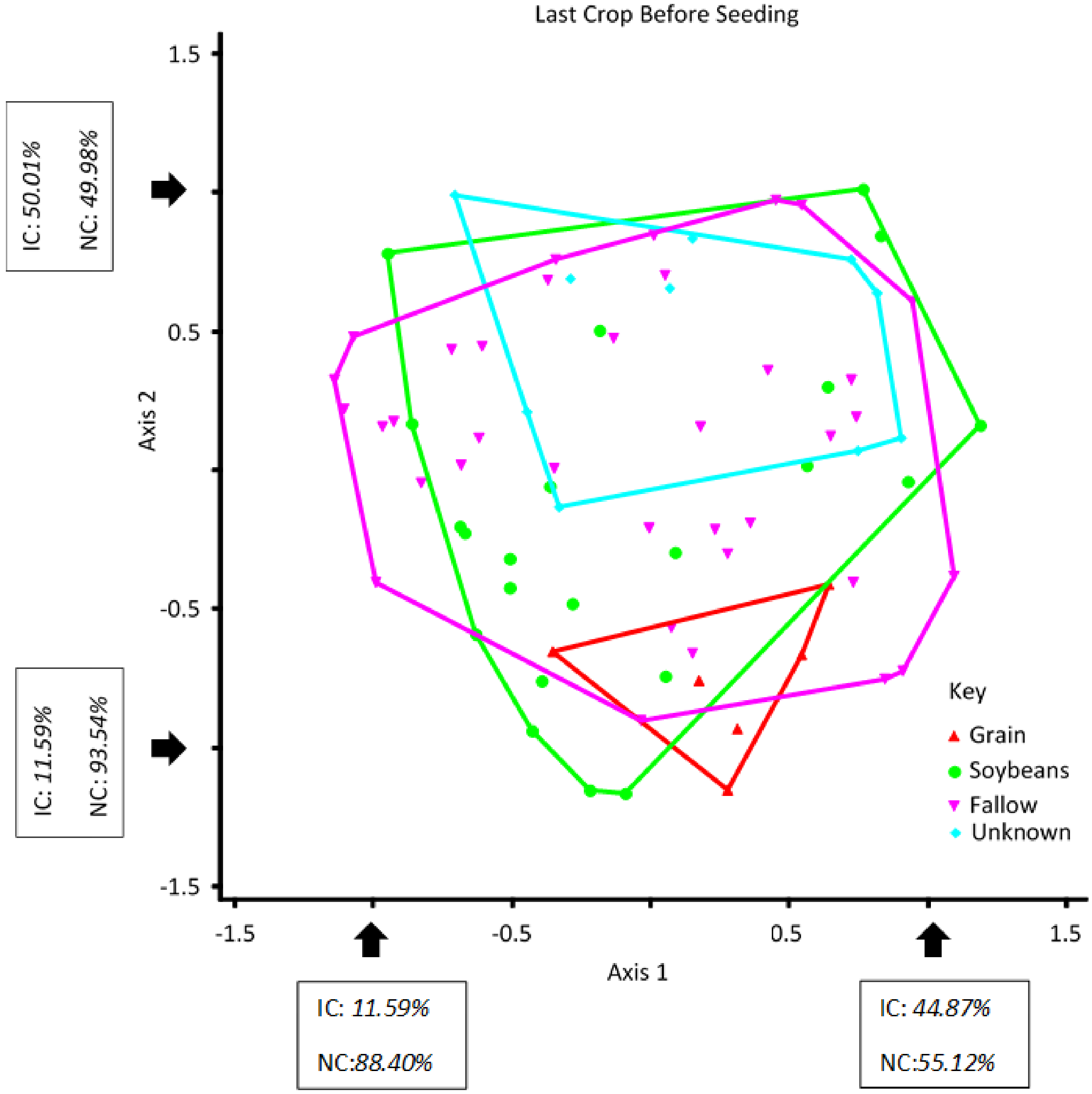

Figure 2.4. Ordination NMS graph depicting sites grouped by last crop before seeding. Pair-wise comparisons in Table 2.8 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.8. Pair-wise comparisons from the PERMANOVA analysis for grouping by last crop before seeding.

Grouping	*t*	*p*-value
Grain x Soybeans	1.481	0.021
Grain x Fallow	2.027	0.001
Grain x Unknown	1.742	0.002
Soybeans x Fallow	1.839	0.002
Soybeans x Unknown	1.186	0.163
Fallow x Unknown	1.866	0.001

Special Site Treatments

Some sites had extra treatments prior to seeding in hopes to improve the outcome of the restoration. These factors were found to have a significant effect (p =0 .002) on the vegetative composition of the restoration (Figure 2.5). Pair-wise comparisons show significant difference ($p < 0.05$) between unknown and all categories except glyphosate after seeding. Application of a broadleaf herbicide was different from fallow ($p = 0.045$) and fall tillage ($p = 0.039$). Of the special treatments fallow tends to be associated with higher IC (Table 2.9).

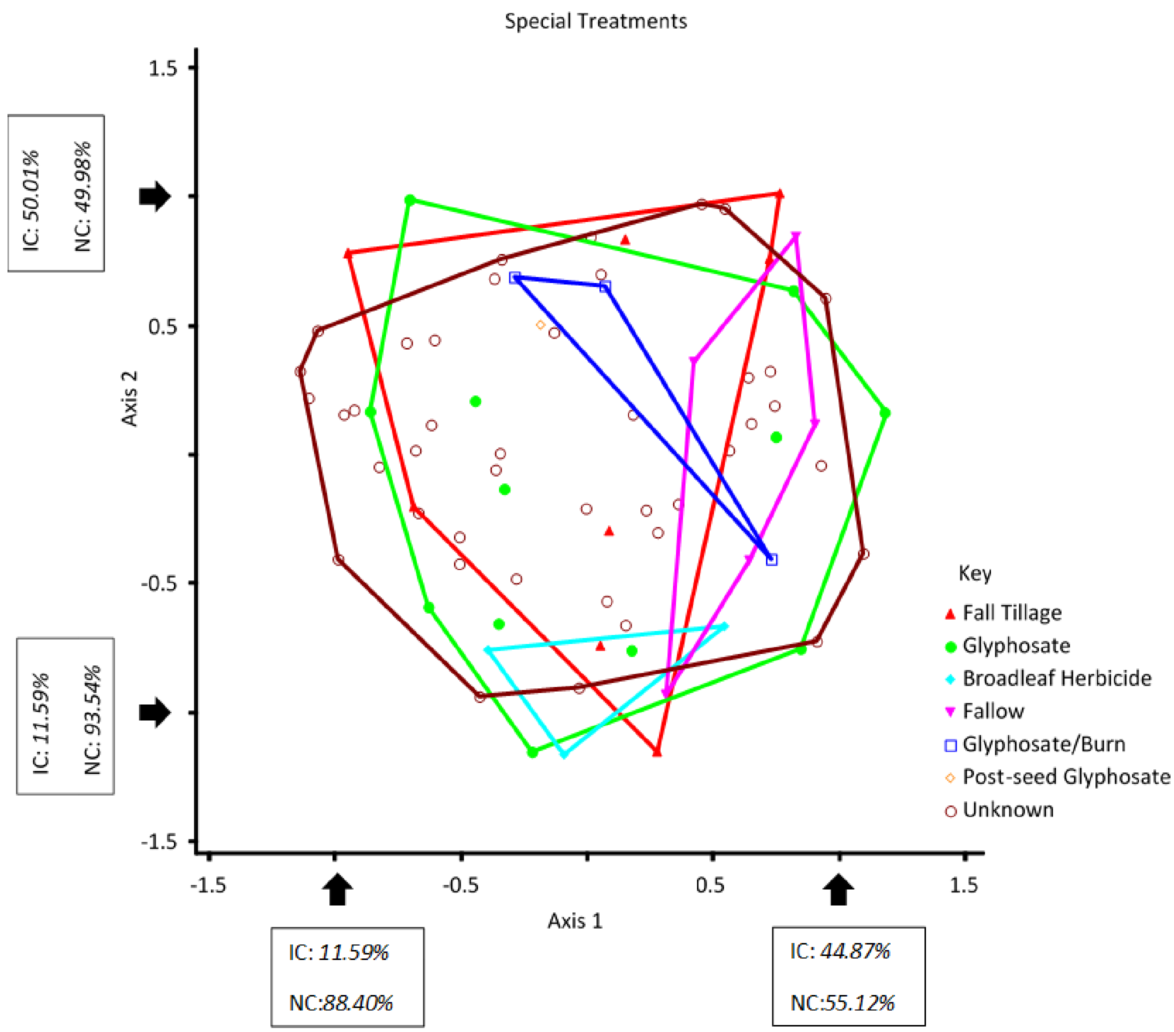

Figure 2.5. Ordination NMS graph depicting sites grouped by special treatments applied to the site. Pair-wise comparisons in Table 2.9 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.9. Pair-wise comparisons from the PERMANOVA analysis for grouping by special treatments to the site.

Grouping	*t*	*p*-value
Fall till x Glyphosate	1.043	0.363
Fall till x Broadleaf herbicide	1.369	0.039
Fall till x fallow	1.134	0.246
Fall till x Glyphosate/Burn	1.123	0.252
Fall till x Post seeding Glyphosate	0.857	0.891
Fall till x Unknown	1.354	0.042
Glyphosate x Broadleaf herbicide	1.174	0.174
Glyphosate x Fallow	1.299	0.082
Glyphosate x Glyphosate/Burn	1.199	0.140
Glyphosate x Post seeding glyphosate	0.865	0.850
Glyphosate x Unknown	1.476	0.021
Broadleaf herbicide x Fallow	1.576	0.045
Broadleaf herbicide x Glyphosate/Burn	1.678	0.091
Broadleaf herbicide x post seeding Glyphosate	1.473	0.259
Broadleaf herbicide x Unknown	1.421	0.026
Fallow x Glyphosate/Burn	1.502	0.088
Fallow x Post seeding Glyphosate	1.098	0.338
Fallow x unknown	1.447	0.035
Glyphosate/burn x Post seeding glyphosate	1.150	0.482
Glyphosate/Burn x Unknown	1.337	0.044
Post seeding glyphosate x Unknown	0.859	0.840

Seeding Method

Drill/broadcast seeding was found to be significantly ($p < 0.05$) different from broadcast seeding, drill seeding, and snow seeding (Figure 2.6). Broadcast seeding and drill seeding were also found to be significantly different ($p = 0.002$) (Table 2.10). All seeding methods had a large spread except for unknown but that method was not different from the others.

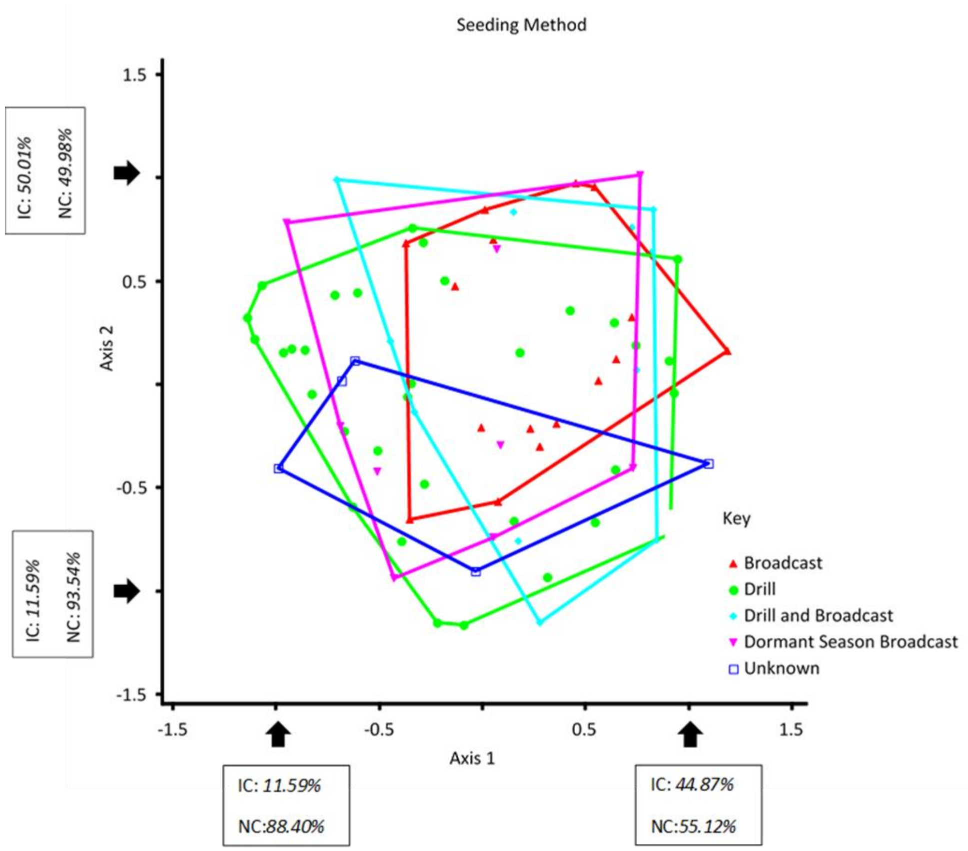

Figure 2.6. Ordination NMS graph depicting sites grouped by seeding method used. Pair-wise comparisons in Table 2.10 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.10. Pair-wise comparisons from the PERMANOVA analysis for grouping by seeding method.

Grouping	*t*	*p*-value
Broadcast x Drill	1.853	0.002
Broadcast x Drill/Broadcast	1.845	0.001
broadcast x Dormant Season Broadcasting	1.276	0.068
Broadcast x Unknown	1.262	0.086
Drill x Drill/Broadcast	1.795	0.001
Drill x Dormant Season Broadcasting	1.268	0.098
Drill x Unknown	0.952	0.496
Drill/Broadcast x Dormant Season Broadcasting	1.494	0.019
Drill/Broadcast x Unknown	1.190	0.157
Dormant Season Broadcasting x Unknown	0.653	0.943

Grazing

Grazing history was recorded on a yearly basis and coded by year, multiple years, and unknown (Figure 2.7). Pair wise comparison showed grazing did make a significant difference in sites not grazed, and sites grazed in the year 2013, 2015, and 2016. Some years had only one instance of grazing and so comparison with those with many sites might be misleading (Table 2.11). Grazed sites are associated with higher levels of IC.

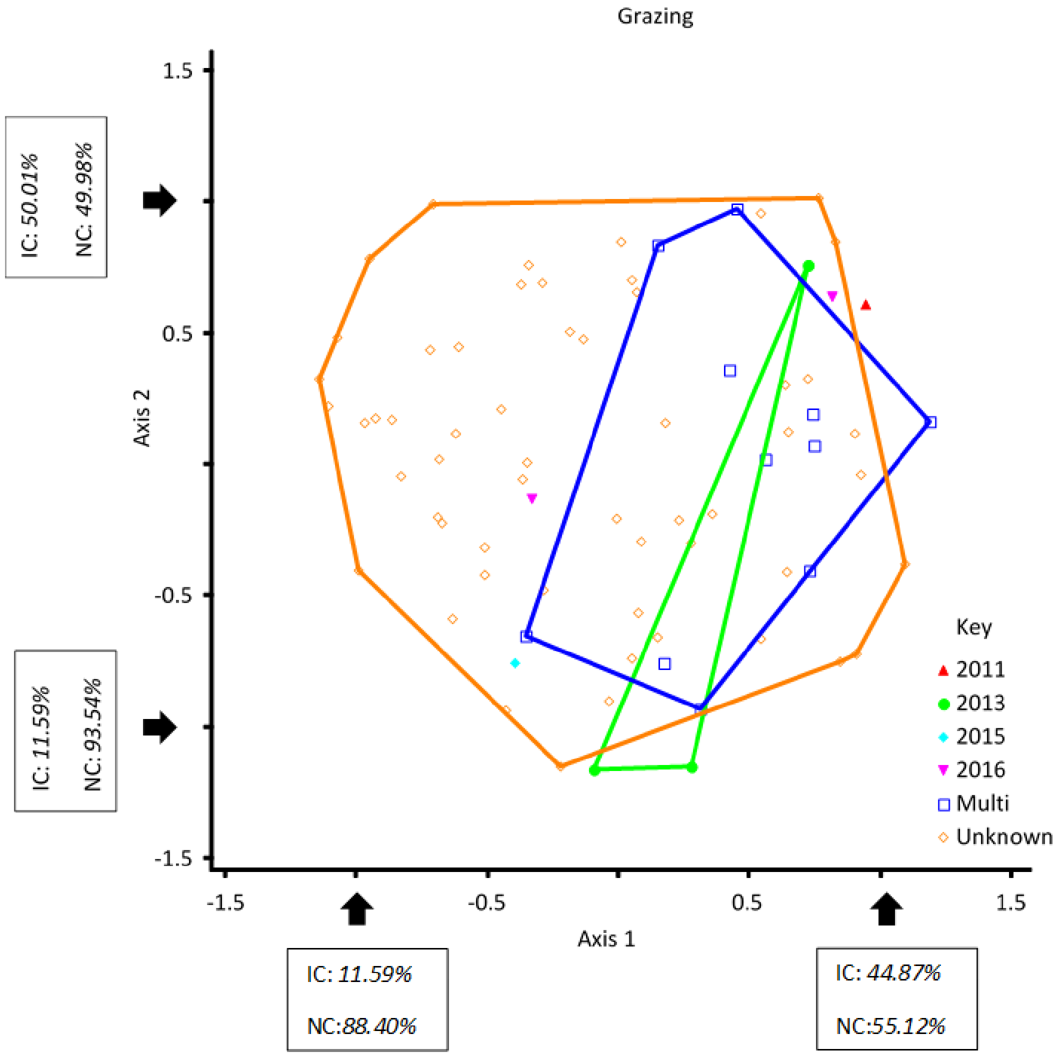

Figure 2.7. Ordination NMS graph depicting grouping by grazing history of the site. Pair-wise comparisons in Table 2.11 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.11. Pair-wise comparisons from the PERMANOVA analysis for grouping by grazing history.

Grouping	*t*	*p*-value
2011 x 2013	1.088	0.515
2011 x 2016	1.277	0.327
2011 x Multiple	0.939	0.670
2011 x Unknown	1.096	0.249
2013 x 2015	0.812	0.524
2013 x 2016	1.232	0.311
2013 x Multiple	1.089	0.277
2013 x Unknown	1.304	0.045
2015 x 2016	1.184	0.330
2015 x Multiple	1.105	0.333
2015 x Unknown	0.912	0.723
2016 x Multiple	0.988	0.440
2016 x Unknown	1.406	0.012
Multiple x Unknown	1.576	0.003

Prescribed Burning

Burning once was significantly different from burning multiple times but was not significantly different from unknown (Figure 2.8). Burning multiple times was significantly different from unknown and was associated with higher IC (Table 2.12).

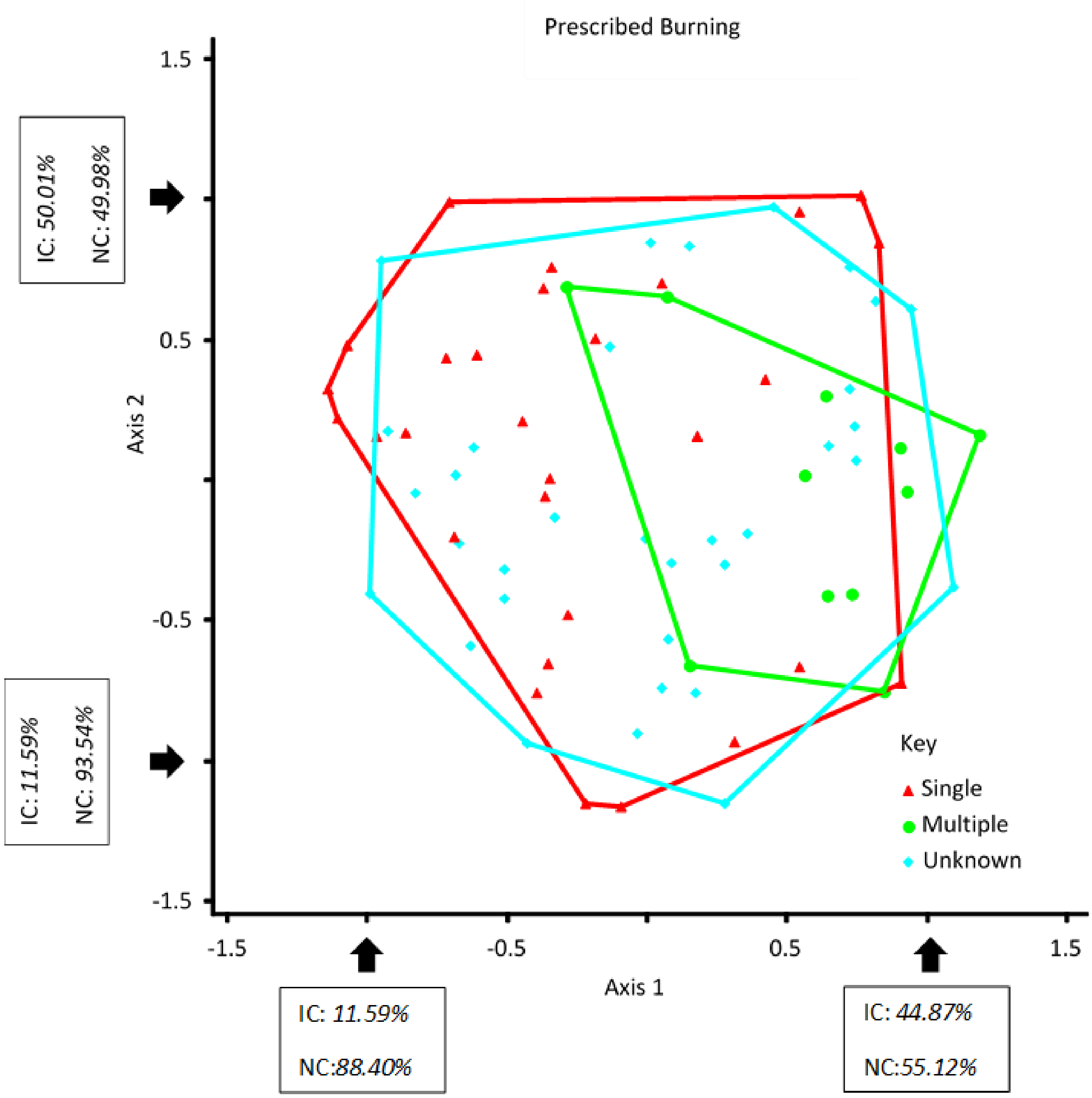

Figure 2.8. Ordination NMS graph depicting sites grouped by prescribed burning history. Pair-wise comparisons in Table 2.12 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.12. Pair-wise comparisons from the PERMANOVA analysis for grouping by prescribed burning history.

Grouping	*t*	*p*-value
Single x Multiple	1.883	0.001
Single x Unknown	1.247	0.103
Multiple x Unknown	1.626	0.002

Spraying

Some sites were sprayed with herbicide for weed control in the years following seeding. We categorized these sites as: spot sprayed, broadcast sprayed, or not sprayed (Figure 2.9). This factor was found to have a significant effect, but the only significant pairing was between spot spraying and unknown which is mostly made up of not sprayed (p=0.008) (Table 2.13). Spot spraying had a less of a spread than unknown and was associated with higher levels of IC. To have spot spraying associated with higher IC cover is not surprising since spot spraying would be done in reconstructions with high levels of IC.

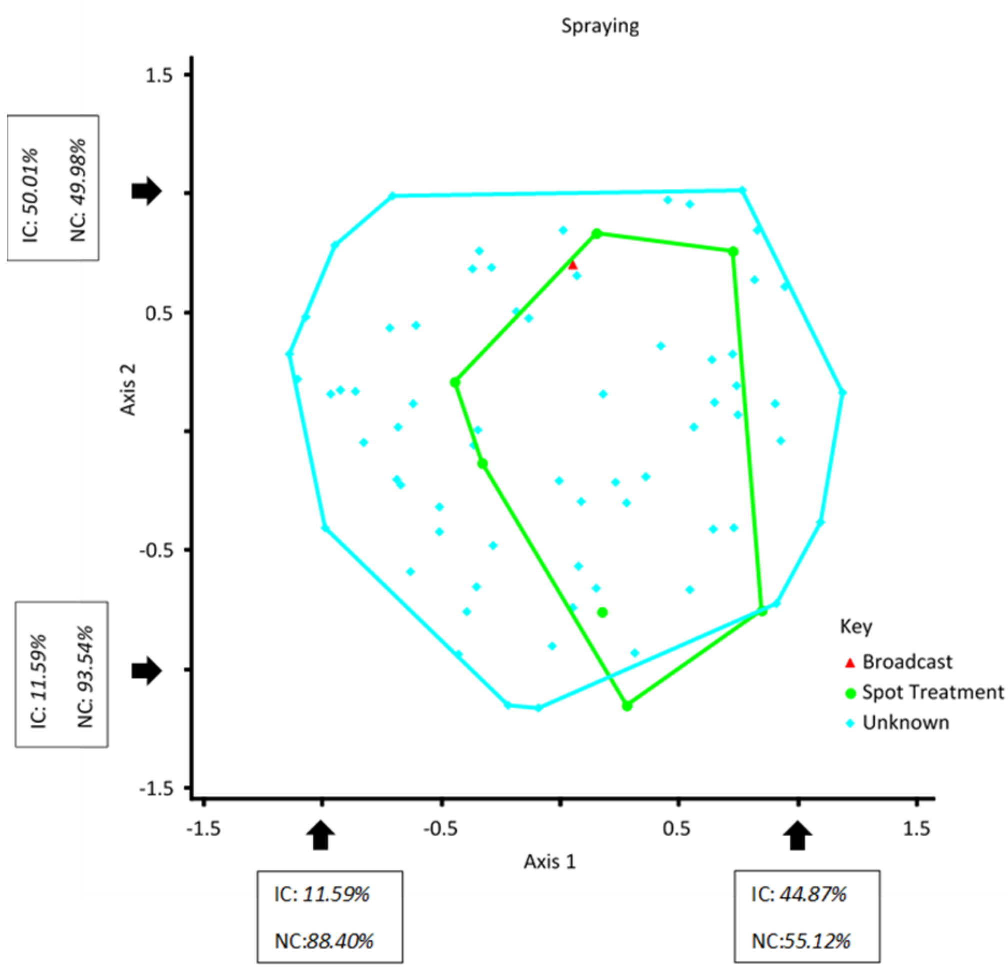

Figure 2.9. Ordination NMS graph depicting site grouped by herbicide application history. Pair-wise comparisons in Table 2.13 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.13. Pair-wise comparisons from the PERMANOVA analysis for grouping by spraying history of the sites.

Grouping	*t*	*p*-value
Broadcast x Spot treatment	1.122	0.237
Broadcast x Unknown	0.921	0.709
Spot treatment x Unknown	1.492	0.008

Seed Mix Composition

There was no significant difference between the known mixes, but there was a significant difference between the unknown category and all the known categories (Figure 2.10, Table 2.14). This may be attributed to low sample size (*n*=15) and almost all unknown samples were located closely together in the same district.

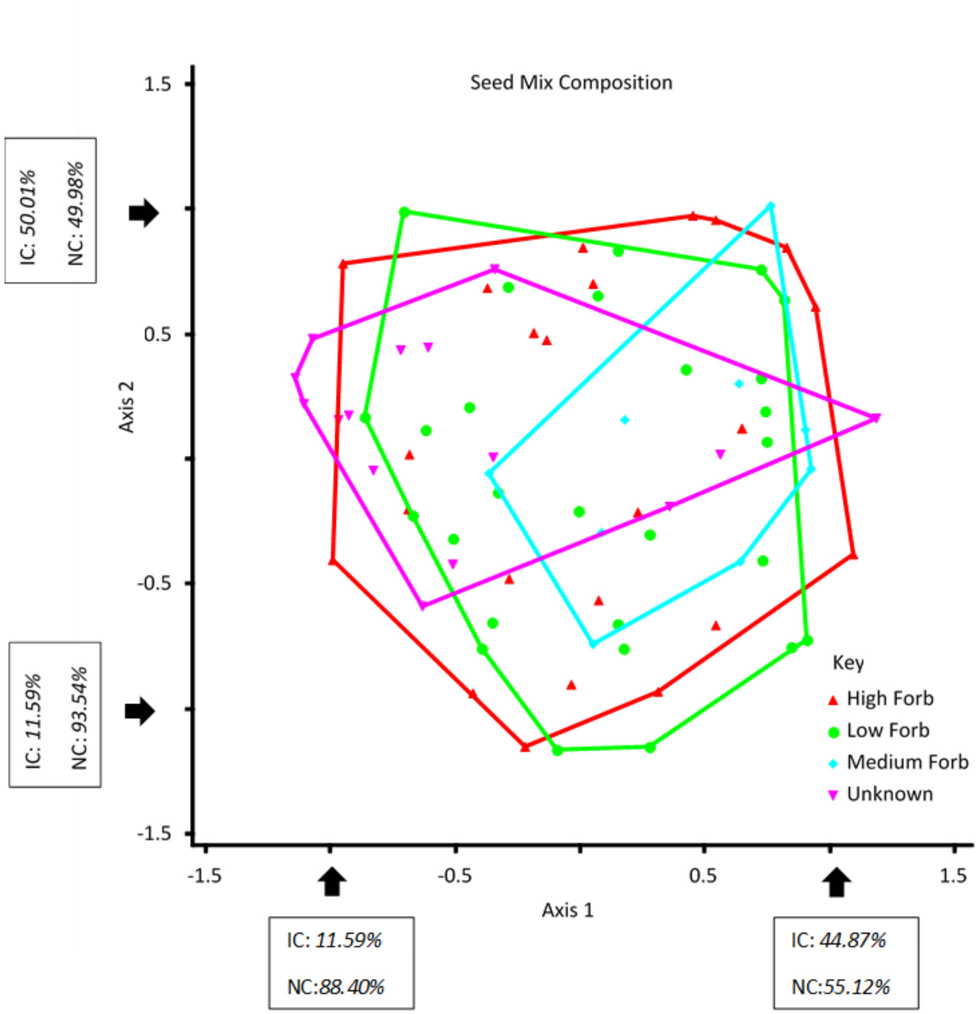

Figure 2.10. Ordination NMS graph depicting sites grouped by the composition of the seed mix applied to the site. Seed mixes were coded by the percentage of seed in the mix which was forb seed. These codes were grouped as: Low (0%-15%) forb, Medium (15%-30%) forb, and High (30%+) forb as well as an unknown. Pair-wise comparisons in Table 2.14 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.14. Pair-wise comparisons from the PERMANOVA analysis for grouping by seed mix composition.

Grouping	*t*	*p*-value
High Forb x Low Forb	1.184	0.130
High Forb x Medium Forb	1.018	0.382
High Forb x Unknown	1.801	0.003
Low Forb x Medium Forb	1.218	0.121
Low Forb x Unknown	1.874	0.001
Medium Forb x Unknown	2.047	0.007

Haying

Haying groups were not significantly different, and so pair-wise comparisons are not necessary (Figure 2.11).

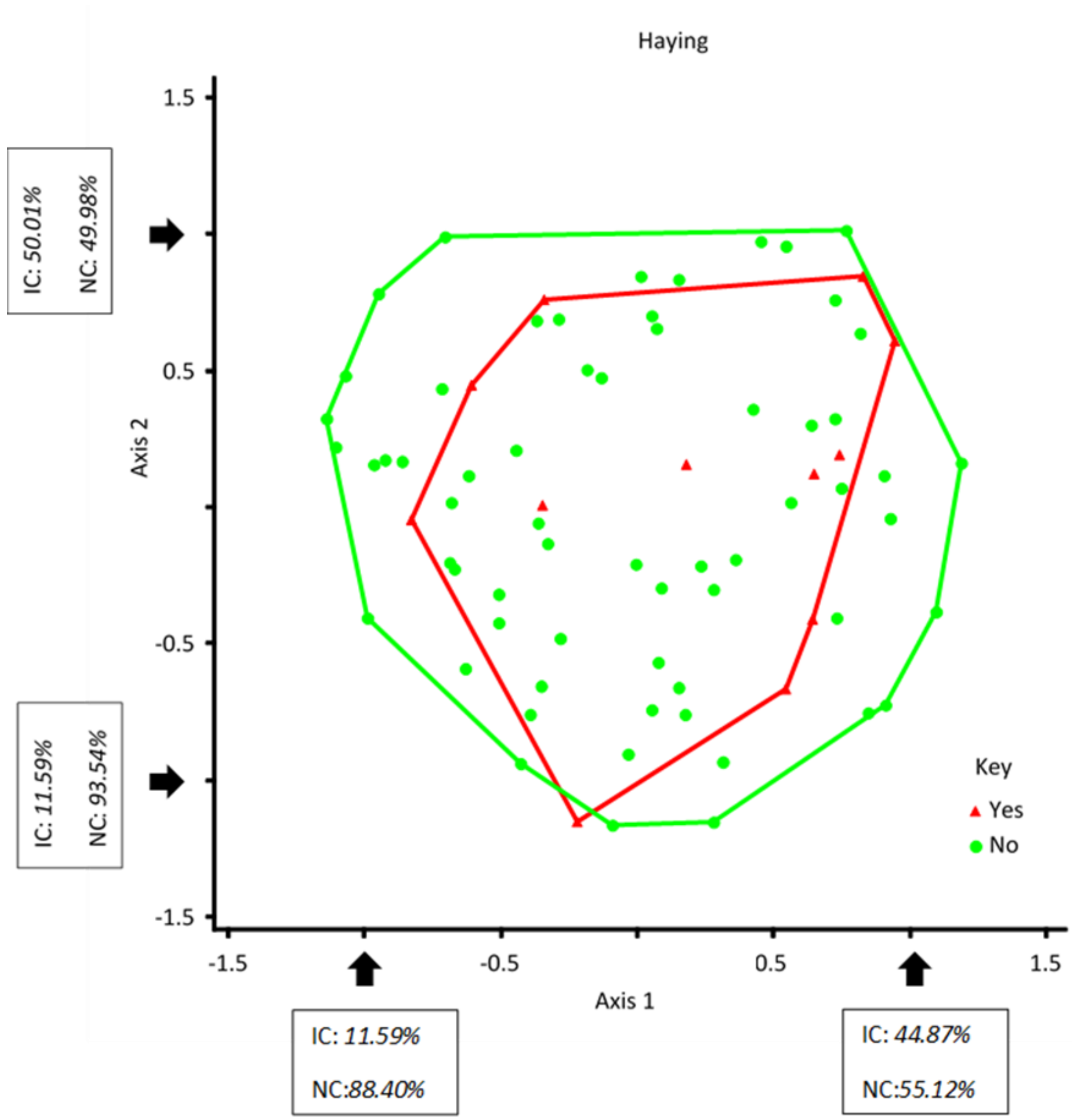

Figure 2.11. Ordination NMS graph depicting sites grouped by the haying history. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Seeding Year

Seeding year was used as proxy for yearly variation such as weather (Figure 2.15). Years were significantly different with some years associated with high level of NC while others with high levels of IC. This analysis shows a high amount of viability with some years with large spreads (Table 2.15).

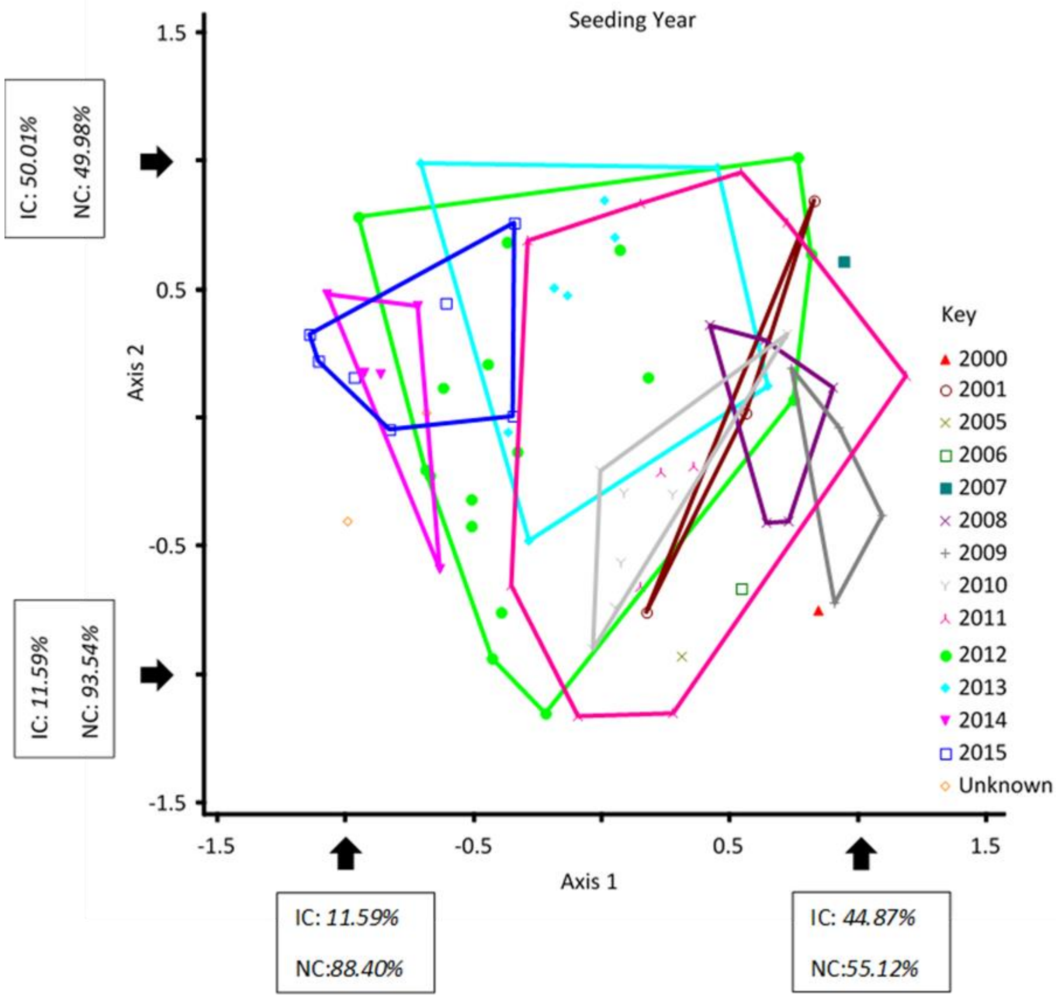

Figure 2.12. Ordination NMS graph depicting sites grouped by the seeding year. Pair-wise comparisons in Table 2.15 show statistical difference between groupings. See figure 2.1 for what IC and NC values mean. Groups with more than three sites are enclosed in a convex hull.

Table 2.15. Pair-wise comparisons from the PERMANOVA analysis for grouping by seeding year. Because of the low number of sites seeded in certain years paired comparisons were not always possible. Some comparisons were not able to test because not enough samples were present to allow for adequate permutation.

Groups	*t*	*p*-value
2000, 2001	1.054	0.490
2000, 2005	No test	-
2000, 2006	No test	-
2000, 2007	No test	-
2000, 2008	1.344	0.152
2000, 2009	1.265	0.195
2000, 2010	1.197	0.133
2000, 2011	1.066	0.491
2000, 2012	1.219	0.184
2000, 2013	1.244	0.177
2000, 2014	1.606	0.157
2000, 2015	2.200	0.129
2000, Unknown	1.309	0.334
2001, 2005	1.152	0.484
2001, 2006	0.844	0.739
2001, 2007	0.934	0.481
2001, 2008	0.788	0.739
2001, 2009	0.968	0.525
2001, 2010	1.151	0.227
2001, 2011	0.880	0.627
2001, 2012	1.219	0.123
2001, 2013	1.198	0.106
2001, 2014	1.776	0.027
2001, 2015	2.221	0.007
2001, Unknown	1.342	0.214
2005, 2006	No test	-
2005, 2007	No test	-
2005, 2008	1.433	0.169
2005, 2009	1.271	0.192
2005, 2010	1.072	0.240
2005, 2011	1.084	0.508
2005, 2012	1.141	0.277
2005, 2013	1.212	0.197
2005, 2014	1.465	0.166
2005, 2015	2.260	0.126
2005, Unknown	1.310	0.346
2006, 2007	No test	-
2006, 2008	1.060	0.346
2006, 2009	1.044	0.396
2006, 2010	0.912	0.857
2006, 2011	0.865	0.734
2006, 2012	1.061	0.401
2006, 2013	1.146	0.203
2006, 2014	1.531	0.172
2006, 2015	2.183	0.121
2006, Unknown	1.164	0.352
2007, 2008	1.018	0.507
2007, 2009	0.899	0.788
2007, 2010	1.291	0.130

Table 2.15. Pair-wise comparisons from the PERMANOVA analysis for grouping by seeding year (continued). Because of the low number of sites seeded in certain years paired comparisons were not always possible. Some comparisons were not able to test because not enough samples were present to allow for adequate permutation.

Groups	*t*	*p*-value
2007, 2011	1.044	0.479
2007, 2012	1.159	0.217
2007, 2013	1.032	0.404
2007, 2014	1.600	0.181
2007, 2015	2.351	0.130
2007, Unknown	1.511	0.327
2008, 2009	1.017	0.425
2008, 2010	1.621	0.010
2008, 2011	1.056	0.329
2008, 2012	1.586	0.011
2008, 2013	1.571	0.003
2008, 2014	2.470	0.006
2008, 2015	3.134	0.002
2008, Unknown	1.966	0.038
2009, 2010	1.663	0.016
2009, 2011	1.095	0.279
2009, 2012	1.627	0.005
2009, 2013	1.765	0.001
2009, 2014	2.339	0.008
2009, 2015	3.057	0.003
2009, Unknown	1.890	0.070
2010, 2011	1.497	0.024
2010, 2012	1.597	0.008
2010, 2013	1.545	0.004
2010, 2014	2.009	0.004
2010, 2015	2.679	0.002
2010, Unknown	1.445	0.055
2011, 2012	1.234	0.119
2011, 2013	1.497	0.010
2011, 2014	1.850	0.001
2011, 2015	2.332	0.001
2011, Unknown	1.385	0.021
2012, 2013	1.323	0.064
2012, 2014	1.411	0.033
2012, 2015	1.849	0.001
2012, Unknown	1.166	0.149
2013, 2014	1.394	0.023
2013, 2015	1.949	0.001
2013, Unknown	1.389	0.030
2014, 2015	1.082	0.287
2014, Unknown	1.381	0.050
2015, Unknown	1.872	0.030

Discussion

The dataset collected by this study creates a picture of the high variability exhibited in reconstructions. Once visually displayed through the ordination, we see the sites are generally unique, being relatively evenly distributed throughout the graph. Most of the sites were dominated by native species (relative cover of native species >50%). Looking at the data compared to the lower diversity sites found in the study by Norland et al. (2015), we still have a lower rate of sites dominated by introduced species.

The study performed by Norland et al. (2015) determined sites similar to those sampled in this study should create a high rate of success (81% of sites with >50% relative cover of native species) compared to those with less diversity in the seed mix. A majority of the sites we sampled had high levels of NC, in fact we found a similar 81% (61/74 sites) of sites being dominated by native species (>50% relative cover). As observed by grouping the sites by proportion of the seed mix composed of forb seed, we suggest 15 species per mix may reach a point of diminishing return as to the success of the seeding. While high diversity should still be used when seeding sites, our data suggests using extremely high proportions (>15 species) of forbs may not actually be associated with an increase likelihood of NC but may be associated with an increase in levels of forb richness and diversity. While Norland et al. suggest success is NC >50%, the USFWS has a more optimistic goal in mind. USFWS would label success as 30% or less of the site being IC (personal communication with Cami Dixon, Dakota Zone Biologist USFWS). Using this level, 56% of sites inventoried would be considered successful (42/74 sites). In order to reach this goal, more management must be performed to lower relative IC.

Selective bias in management might play into the results found from this study. Managers use multiple factors in deciding which management treatments to implement. Treatment decisions for burning, grazing, haying, mowing, or herbicide application are commonly based on factors such as the following: age of the seeding, treatment history, best professional judgement, litter thickness, or vegetative composition (personal communication with Cami Dixon, USFWS). In the example of burning, we see an increase of burning frequency seems to push sites towards higher IC. We suggest this may be due to managers pushing management on sites which may not be performing as well as other sites. If a site is progressing well with low density of introduced species or weeds, managers are less likely to perform management. If a site is becoming overtaken by introduced species managers may be more likely to perform treatments on the site such as burning or grazing. We postulate this effect may be occurring throughout other treatment variables as well, driving confounding results. For example, it appears from our data that fire is associated with an increase in IC, although it has been linked to increasing NC (Brudvig 2011)

It would seem uncontrollable factors are driving the composition of some of these sites. Sites do not group well to any one factor and for most graphs do not separate from one another clearly. We expect factors such as quality of seed purchased, ecotype of the seed commercially available, weather, and logistical issues may be some of the factors driving variation (Brudvig et al. 2017). For example, we cannot say with certainty the viability of the seed used for these reconstructions. Without a scientific-based seed test by the mangers, it is possible seed may have less viability given the various sources of seed used. Seed sources range from seed that comes from reputable sellers to seed collected opportunistically by managers. This can cause unevenness in the sites and reduce establishment. Logistically, sites may have complications due to the low staffing rate of large USFWS districts or distance from district headquarters possibly forcing management on days with less than favorable climatic conditions. Seeding of sites may be performed in windy conditions for example. This may cause uneven distribution of seed or even blowing seed off-site. It may not be possible to postpone management for more favorable conditions due to workload. This may cause a decrease in the effectiveness of management and variation in the results of management factors. It would seem chance factors has influence on the effectiveness of management. No manager can tell the future and predict climatic conditions of the days, weeks, and months after performing a management technique. It is possible for detrimental factors like drought can drive the failure of the reconstructions, as likely as favorable climatic conditions create a perfect environment for the success of a reconstruction (Bakker et al. 2003). This issue may be exacerbated by climate change (Perkins et al. 2019). This combined with a change landscape, it becomes essential for managers to act proactively, attempting to create resilient systems through adaptive management and new management techniques. Without being able to predict these uncontrollable factors, it is impossible to guarantee the success (or failure) of management.

Individual sites have subtle differences which make them unique (Brudvig et al. 2007, Bakker et al. 2003). While management tactics may be executed differently, they are still the same tactic. It can also be argued management tactics are similar enough to not make a difference, that individual site characteristics are more of a driving force to the outcome of the site. In order to compensate for the individual nuances of individual sites an individual management plan may be required. For more success in reconstruction, it may be necessary for innovative management plans to be tried in an adaptive management process.

Grouping by year presented some interesting results. It appears as sites become older, they seem to have an increase of IC (Allison 2002). This creates the question: Are we getting better at reconstructing prairies, or do sites tend to become invaded overtime even with management? If reconstructions tend to become invaded overtime even when using high diversity seedings and good practice, how can this be prevented? This retrospective study creates more questions than it answers. The questions in this study should be used as directions to foster future research. Can the variation in this study be controlled by a designed experiment? Or do we accept that variation is inherent in these complex systems and adjust our management to accommodate this reality (Brudvig et al. 2007, Norland et al. 2018). Do we use the correct management tools to limit the invasion of introduced species? Can we use innovative new management techniques to guide reconstructions toward a more stable state? Are there larger landscape scale factors we need to account for in the management of these sites?

Conclusion

Restorations are complex systems with an extensive spread of factors which synergistically affect the vegetative composition of the restoration (Norland et al. 2018). Sample data was limited by a number of unforeseen circumstances. We started with 90 sites provided by the USFWS. Our sample pool was limited to 78 sites after filtering by the criteria for the study. For analysis, we were only able to use 74 sites due to insufficient site history data and inconsistencies on some sites. This means 18% of the sites provided were seeded with the proper seed mix. Furthermore, for each factor we sampled, a portion of the sites had to be categorized as "unknown" due to lack of records. So, when a system has a large set of factors, each significant to the vegetative composition of the system and many of the factors are not recorded, it becomes difficult, if not impossible, to determine good management practices. The data we provide urges caution when attempting to determine "one size fits all" management techniques and promotes field studies of reconstruction. Lab studies limit variation such as landscape influences on the site and uncontrollable climatic conditions. Caution should be used by land managers and restorationist when attempting to find a formula to a perfect restoration (Norland et al. 2018, Perkins et al. 2019). Because seemingly small factors such as what crop was seeded on the site the year prior to the seeding can influence a reconstruction, it becomes difficult to present a management method which provides consistent results. We stress proper record keeping and a variety of management techniques is necessary to manage multiple reconstructions. Because not every reconstruction is the same, it is important to remember managing every reconstruction should not be the same either (Brudvig et al. 2007, Perkins et al. 2019).

Management Implications

Due to the lack of information on some sites, it becomes difficult to say definitively if certain management techniques consistently effect reconstructions. Also, exact parameters of the management technique are not completely recorded (example: climate during and severity of prescribed burn). Better records should be kept by managers to help with future retrospective studies. In order to limit uncertainty, it is paramount for accurate and detailed records to be kept tracking management, climate, and changes in reconstructions. We suggest diversity in management. It is difficult to have a uniform management plan in complex ecological systems. Such broad categories in this study failed to display more subtle trends in data. More precise management data may have led to greater separation of groupings leading to better recommendations for future reconstructions. In the process of reconstruction, it is essential that land managers collect detailed data, and adapt to site and landscape conditions to increase the effectiveness of management as well as the health of reconstructions.

CHAPTER 3: ESTABLISHMENT OF SPECIALIZED SEED MIXES USING PRECISION PRAIRIE RECONSTRUCTION

Introduction

Restoration of native systems in the NGP is essential to maintain ecosystem services and wildlife populations in the region (Samson and Knopf 1994, Samson et al. 2004). The species endemic to the NGP are resistant to the disturbances which characterize the region (Evans et al. 2011). Disturbances such as fire and drought frequent the region creating an environment with species adapted to thrive under frequent disturbance. With the expansion of European settlement has come the expansion of introduced species from Eurasia (DeKeyser et al. 2015). Kentucky bluegrass (*Poa pratensis*) is a problematic species which invades native systems reducing the dominance of hardy native species. Kentucky bluegrass thrives in undermanaged systems where native species lose their competitive edge without having to resist disturbance (Toledo et al. 2014). It creates a self-perpetuating system which modifies soil chemistry and reduces vegetative soil cover. It also reduces infiltration of water into the soil decreasing the usability of precipitation (Taylor and Blake 1982). Kentucky bluegrass also reduces soil stability due to its shallow rooting structure (Toledo et al. 2014). This creates a system favorable to soil erosion and degradation.

The ecosystem services a prairie provides are dependent on the quality of the patch of grassland (Thomas et al. 2001, Grant et al. 2004). With low quality patches, ecosystem services are diminished and overall benefit of the patch are mitigated (Hooper et al. 2005). Many patches created in the NGP were created through the CRP (Dunn et al. 1993, Biondini 2007). These patches have been critical for the survival of numerous native species by increasing the amount of prairie in the NGP (Johnson 2000). Pollinators can also have some benefit from increasing the number of habitat patches on the landscape (Thomas et al. 2001) which can have benefits to agricultural systems in the NGP (Wratten et al. 2012). CRP has some benefits to native wildlife and soil health (Dunn et al. 1993) but the systems created by CRP are low quality and quickly invaded due to lack of management and low diversity in reconstruction (Biondini 2007).

Kentucky bluegrass creates an environment which favors the dominance of Kentucky bluegrass (Toledo et al. 2014). Native systems in the NGP have high rates of diversity, increasing their resilience (Barker and Whitman 1988). Systems invaded with Kentucky bluegrass tend to have less diversity, being dominated by Kentucky bluegrass. Being Kentucky bluegrass is susceptible to disturbance, it is possible to decrease its dominance with proper management (DeKeyser et al. 2013). In this aspect, some invaded systems are able to recover from the invasion by management alone (Smith 1981). This process of restoration uses management to return a system to a less invaded state. It is hypothesized for restoration to be successful, 20% of the vegetative matrix must be composed of native species (Willson and Stubbendieck 2000). If the density of native species is not enough, management alone will not be enough to restore the system; propagules must be added to the system to recover the dominance forfeited by Kentucky bluegrass. A process called Precision Prairie Reconstruction (PPR) can be used to increase diversity in an invaded system without reconstructing the entire system (Grygiel et al. 2009). PPR was developed after Grygiel et al. observed small disturbances caused by burrowing mammals. These small disturbances can act as settlements for new species to establish populations. Disturbed soil can make an excellent seed bed for native species such as *Penstemon grandifloras* (Davis et al. 1995) This process uses small scale disturbances to increase the diversity of the system by creating miniature reconstructions spatially throughout the system. Using this method, less area needs to be reconstructed allowing for use of more expensive high-quality seed mixes for the same cost as total site reconstruction, creating the possibility of a higher quality reconstruction.

In this study, we test the PPR method using specialized seed mixes which would be economically infeasible to use to reconstruct the entirety of a large system. Our goal is by expanding our knowledge of the establishment rates of these species, we can create more diverse systems for lesser cost. The target group of this study are forbs which create spring floral resources for pollinators. These floral resources are frequently missing from larger reconstructions, creating a lack of resources for spring pollinators (Cami Dixon, personnel communication). It is our goal that we can establish species in these PPR plots which are difficult and costly to acquire large amounts of seed for. We expect in the future this practice can be used to establish rare flora species and increase proclivity of species important for the survival of endangered pollinators and wildlife.

Methods

Site Description

Our study site was a 0.5 hectare plot in the Albert Ekre Grassland Preserve, Kindred, ND (46°32'20.65" N 97°08'21.03" W). The site was a sub irrigated loamy fine sand in the Garborg series. The site had been previously farmed until being reclaimed as prairie 20+ years prior to this study. Although previously reconstructed, the site was heavily invaded by introduced grasses. The study site was fenced using an electric fence to prevent grazing by cattle in the surrounding pasture.

Experiment Design

The study site was partitioned off into 30 7m by 7m plots with 3m between each plot. Plots were disturbed using a disk harrow taking multiple passes in each direction to ensure proper disturbance of any rhizome activity. Disking was performed in the fall to allow frost to limit regrowth of any vegetative cover present before the study (Sheley et al. 2005, Smith 2006). Sites were organized using a randomized block design with 5 repetitions of 6 treatments. Repetitions were aligned in the same direction to limit effects from a topographical gradient across the site. Seed mixes were selected giving preference to species frequently missed in reconstructions and forbs which flower in the spring (figure 3.1). Due to limited availability of some species, we were not able to seed all the species planned. Five of the 6 seed mixes were "spiked" as described by Norland et al. (2013). Amount of seed per species was equal, where all non-spike species were seeded at the same rate, and spike species were seeded at a rate 3 times greater than the target species. An aggressive spike was used on 2 mixes, a less aggressive spike was used on 2 mixes, a combined spike was used on one, and no spike was used on the one treatment mix. Species in the aggressive mix are species that establish more quickly and spread more readily. Sites were hand seeded in March on recent snowfall. Samples were taken in August of 2018 and 2019. Vegetative cover was estimated in 4 - ¼ m^2 frames in each plot.

	Achillea millefolium**	Antennaria neglecta	Dalea purpurea*	Dodecatheon meadia	Echinacea angustifolia	Fragaria virginiana	Oxytropis lambertii	Pedicularis canadensis	Penstemon grandiflorus	Ratibida columnifera*	Rudbeckia hirta**	Senecio plattensis*	Zizia aptera
Treatment 1	X	X				X					X		
Treatment 2	X	X			X						X		X
Treatment 3			X	X			X		X	X		X	
Treatment 4		X	X		X					X			X
Treatment 5	X		X			X				X	X	X	
Treatment 6		X				X							

** Aggressive Spike * Non aggressive spike

Figure 3.1. List of species included in each treatment.

Analysis

The four frames of data were averaged by species for each site. Data for sample years 2018 and 2019 were analyzed seperately. All species observed were coded as “Target”, “Spike”, or “Volunteer”. A chi-square test was used to assess if spike species interfered with establishment of target species.

Results and Discussion

Of the 30 sites seeded, only four did not exhibit any seeded species (Table 3.2). Twenty four sites contained spike seeded species, and 12 contained target species. The chi-square test showed spiked plots had a higher rate of target species than non-spike plots, (X^2 (1, N=30) =17.328, p<.001) showing the spike mix did not interfere with the establishment of target species. Six target species and four spike species were found across all treatments.

Table 3.1. Absolute cover of species sampled in 2019. Cover values may exceed 100% due to capture of different layers of canopy.

Site	Spike Species	Target Species	Volunteer Species
R1T1	7.50	0.00	60.50
R1T2	8.25	0.00	44.25
R1T3	4.75	4.50	37.75
R1T4	8.75	0.50	48.25
R1T5	9.50	0.00	58.75
R1T6	0.00	0.00	68.25
R2T1	15.25	1.25	37.00
R2T2	13.00	0.00	51.25
R2T3	8.00	2.50	45.00
R2T4	2.50	0.25	61.75
R2T5	11.25	0.00	51.25
R2T6	0.00	0.00	62.00
R3T3	2.50	0.00	61.00
R4T1	25.50	0.25	61.25
R4T2	26.75	3.75	47.50
R4T3	7.75	0.00	54.50
R4T4	4.75	0.00	60.75

Table 3.1. Absolute cover of species sampled in 2019. Cover values may exceed 100% due to capture of different layers of canopy (Continued).

Site	Spike Species	Target Species	Volunteer Species
R4T5	17.25	3.75	58.00
R4T6	0.00	0.00	75.25
R5T1	27.25	0.75	115.25
R5T2	22.75	0.75	119.25
R5T3	7.75	0.00	61.75
R5T4	6.75	0.00	63.50
R5T5	29.25	0.00	48.75
R5T6	0.00	0.75	151.75

The results of this study seem to support the findings of Grygiel et al. (2009) that diversity can be increased using this method. Although early in the lifespan of the reconstruction, 1.5 years after seeding, some target species are occurring within the treatment sites. The basic goal of this study, establish some seeded species, seems to be achieved. *Penstemon grandiflorus, Zizia aptera*, *Antennaria neglecta*, *Fragaria virginiana*, and *Viola pedatifida* were all found in sites seeded with those species.

Viola pedatifida was a species which inspired this study due to its ecological importance to the regal fritillary (*Speyeria idalia*) (Kopper et al. 2000). It was our hope to establish this species and encourage the long-term expansion of the population. While it only occurred on one seeded site, we still consider this a success. Given the small quantity of seed we were able to purchase, the occurrence in one treatment is encouraging. We believe if more seed were available, we might have been able to establish a larger population.

Fragaria virginiana was a species with ample availability from our supplier, but at high cost ($1,030.20 seed needed to seed all plots). We were able to observe seeded growth of this species in one plot. Seeding this species across the site would have been financially impractical. Using this method, we were able to establish a start to a population with lower cost. The other species we established were not as uncommon as these two. These species can be found in large-scale reconstructions and are commercially available. It is our hope these species will expand from the seeded locations in the years following this study and increase the diversity of the site.

The spike mix species established well, with all spike treatments exhibiting strong establishment of the spike species. This was to be expected and agrees with the data presented by Norland et al. (2013). Long-term effects of spike species will need to be analyzed in future studies. We found certain species perform better as candidates for a spike. We planted *Sencio plantensis* as a spike in two treatment and did not observe any in the sites. Some spike species occurred in sites not seeded with that species. For example, *Achillia millefolium* occurred in four sites not seeded with this species, suggesting seed existing in the seed bank before treatment. Site history may be important to determine the success of this method, similar to other reconstruction methods (Brudvig 2011).

Future study of these treatments will be necessary to determine long-term effectiveness of this form of reconstruction. Reconstructions typically take several years to reach maturity and our reconstruction was only 1.5 years old at time of sample. We suggest future studies continue to evaluate the establishment of seeded species within the boundaries of the treatments as well as the expansion into the prairie matrix surrounding the treatments. We also suggest more studies mirroring this with different mixes of specialized species as well at different sites to learn more about how site characteristics influence the success of this method.

Conclusion

It is possible to use PPR with specialized seed to introduce diversity into a degraded system. By using PPR, one can use seed only available in limited quantities or at a high cost. The total cost of this project was $2,749.11 to seed a total of 840m^2. If we were to seed a site in hopes to achieve the same increase of diversity, we would have had to seed 3,360m^2. Assuming the cost per m^2 was the same, this would have cost $10,996.44 (if seed was even available in this quantity). This method allows land managers with limited fiscal freedom to introduce higher quality seed mixes to degraded restorations. This method creates source populations for target species missing in the site. Currently, it is too early to determine if long-term establishment is realistic and if expansion of target species from sites occurs. Future sampling of the study site will be necessary to determine if this will have long-term effectiveness. To increase the effectiveness of this method, seed must be available for rare species, which are frequently not harvested by commercial seed dealers. In our study, many of the species we had hoped to seed were unavailable for purchase. As most remaining tallgrass prairie is reconstructed, it is becoming more important to increase diversity to prevent species from going extinct.

This method should be used by land managers as an alternative to total site reconstruction. In degraded sites using this method will allow for using higher quality seed for similar Using proactive management to limit the dominance of the species in the surrounding system may allow for faster expansion of target species. More research is needed as to methods to increase the rate of expansion from PPR sites as well as other studies to test the viability of this method in other environments, with other target species, and at a larger scale.

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APPENDIX

Table A.1. List of species encountered across all USFWS managed lands.

Scientific Name	Native or Introduced	Annual or Perennial	Growth Form
Acer negundo	Native	Perennial	Forb
Achillea millefolium	Native	Perennial	Forb
Agastache foeniculum	Native	Perennial	Forb
Agropyron cristatum	Introduced	Perennial	Forb
Agrostis gigantea	Introduced	Perennial	Graminoid
Agrostis hyemalis	Native	Perennial	Graminoid
Allium cernuum	Native	Perennial	Forb
Amaranthus retroflexus	Introduced	Annual	Forb
Ambrosia artemisiifolia	Native	Annual	Forb
Ambrosia psilostachya	Native	Perennial	Forb
Amorpha canescens	Native	Perennial	Forb
Andropogon gerardii	Native	Perennial	Graminoid
Anemone canadensis	Native	Perennial	Forb
Anemone cylindrica	Native	Perennial	Forb
Apocynum cannabinum	Native	Perennial	Forb
Argentina anserina	Native	Perennial	Forb
Artemisia absinthium	Introduced	Perennial	Forb
Artemisia biennis	Introduced	Annual	Forb
Artemisia frigida	Native	Perennial	Forb
Artemisia ludoviciana	Native	Perennial	Forb
Asclepias syriaca	Native	Perennial	Forb
Asclepias tuberosa	Native	Perennial	Forb
Asclepias verticillata	Native	Perennial	Forb
Astragalus canadensis	Native	Perennial	Forb
Bassia scoparia	Introduced	Annual	Forb
Bouteloua curtipendula	Native	Perennial	Graminoid
Bouteloua dactyloides	Native	Perennial	Graminoid
Bouteloua gracilis	Native	Perennial	Graminoid
Bromus arvensis	Introduced	Annual	Graminoid
Bromus inermis	Introduced	Perennial	Graminoid
Bromus kalmii	Native	Perennial	Graminoid
Calamovifa longifolia	Native	Perennial	Graminoid
Camelina microcarpa	Introduced	Annual	Forb
Carduus acanthoides	Introduced	Annual	Forb
Carex brevior	Native	Perennial	Graminoid
Carex Spp	Native	Perennial	Graminoid
Carduus nutans	Introduced	Annual	Forb
Chenopodium album	Introduced	Annual	Forb
Cirsium arvense	Introduced	Perennial	Forb
Cirsium flodmanii	Native	Perennial	Forb
Cirsium undulatum	Native	Perennial	Forb
Cirsium vulgare	Native	Annual	Forb
Convolvulus arvensis	Introduced	Perennial	Forb
Conyza canadensis	Native	Annual	Forb
Coreopsis palmata	Native	Perennial	Forb
Dalea candida	Native	Perennial	Forb
Dalea purpurea	Native	Perennial	Forb
Desmodium canadense	Native	Perennial	Forb
Desmanthus illinoensis	Native	Perennial	Forb
Descurainia sophia	Introduced	Annual	Forb

Table A.1. List of species encountered across all USFWS sites (continued).

Scientific Name	Native or Introduced	Annual or Perennial	Growth Form
Echinacea angustifolia	Native	Perennial	Forb
Echinacea purpurea	Native	Perennial	Forb
Elymus canadensis	Native	Perennial	Graminoid
Elymus repens	Introduced	Perennial	Graminoid
Elymus trachycaulus	Native	Perennial	Graminoid
Erigonum annuum	Native	Annual	Forb
Euphorbia esula	Introduced	Perennial	Forb
Euphorbia glyptosperma	Native	Annual	Forb
Euthamia graminifolia	Native	Perennial	Forb
Galardia aristida	Native	Perennial	Forb
Galium boreale	Native	Perennial	Forb
Geum aleppicum	Native	Perennial	Forb
Grindelia squarrosa	Native	Perennial	Forb
Hedeoma hispida	Native	Annual	Forb
Helianthus annuus	Native	Annual	Forb
Heliopsis helianthoides	Native	Perennial	Forb
Helianthus maximiliani	Native	Perennial	Forb
Helianthus pauciflorus	Native	Perennial	Forb
Hesperostipa comata	Native	Perennial	Graminoid
Hordeum jubatum	Native	Perennial	Graminoid
Iva annua	Native	Annual	Forb
Koeleria macrantha	Native	Perennial	Graminoid
Lactuca tatarica	Native	Perennial	Forb
Lepidium Spp.	Introduced	Annual	Forb
Liatris pycnostachya	Native	Perennial	Forb
Linum lewisii	Native	Perennial	Forb
Lotus corniculatus	Introduced	Perennial	Forb
Lotus parviflorus	Native	Annual	Forb
Lycopus asper	Native	Perennial	Forb
Medicago lupulina	Introduced	Annual	Forb
Medicago sativa	Introduced	Perennial	Forb
Melilotus officinalis	Introduced	Annual	Forb
Monarda fistulosa	Native	Perennial	Forb
Nassella viridula	Native	Perennial	Graminoid
Oligoneuron rigidum	Native	Perennial	Forb
Panicum capillare	Native	Annual	Graminoid
Panicum virgatum	Native	Perennial	Graminoid
Pascopyrum smithii	Native	Perennial	Graminoid
Pediomelum argophyllum	Native	Perennial	Forb
Penstemon grandiflorus	Native	Perennial	Forb
Phalaris arundinacea	Native	Perennial	Graminoid
Phleum pratense	Introduced	Perennial	Graminoid
Poa palustris	Native	Perennial	Graminoid
Poa pratensis	Introduced	Perennial	Graminoid
Polygonum convolvulus	Introduced	Annual	Forb
Populus deltoides	Native	Perennial	Forb
Potentilla arguta	Native	Perennial	Forb
Pycnanthemum virginianum	Native	Perennial	Forb
Ratibida columnifera	Native	Perennial	Forb
Ratibida pinnata	Native	Perennial	Forb
Rosa woodsii	Native	Perennial	Forb
Rudbeckia hirta	Native	Perennial	Forb

Table A.1. List of species encountered across all USFWS sites (continued).

Scientific Name	Native or Introduced	Annual or Perennial	Growth Form
Rumex crispus	Introduced	Perennial	Forb
Schizachyrium scoparium	Native	Perennial	Graminoid
Securigera varia	Introduced	Perennial	Forb
Setaria species	Introduced	Perennial	Graminoid
Silphium laciniatum	Native	Perennial	Forb
Silene latifolia	Introduced	Annual	Forb
Silphium perfoliatum	Native	Perennial	Forb
Sisymbrium altissimum	Introduced	Perennial	Forb
Solidago canadensis	Native	Perennial	Forb
Solidago gigantea	Native	Perennial	Forb
Solidago missouriensis	Native	Perennial	Forb
Solidago nemoralis	Native	Perennial	Forb
Solanum rostratum	Native	Annual	Forb
Sonchus arvensis	Introduced	Perennial	Forb
Sonchus oleraceus	Introduced	Annual	Forb
Sorghastrum nutans	Native	Perennial	Graminoid
Sporobolus cryptandrus	Native	Perennial	Graminoid
Sporobolus heterolepis	Native	Perennial	Graminoid
Symphyotrichum ericoides	Native	Perennial	Forb
Symphyotrichum falcatum	Native	Perennial	Forb
Symphyotrichum laeve	Native	Perennial	Forb
Symphyotrichum lanceolatum	Native	Perennial	Forb
Symphyotrichum novae-angliae	Native	Perennial	Forb
Symphoricarpos occidentalis	Native	Perennial	Forb
Tanacetum vulgare	Introduced	Perennial	Forb
Taraxacum officinale	Introduced	Annual	Forb
Thalictrum dasycarpum	Native	Perennial	Forb
Tragopogon dubius	Introduced	Annual	Forb
Trifolium repens	Introduced	Perennial	Forb
Ulmus parvifolia	Introduced	Perennial	Forb
Verbena stricta	Native	Perennial	Forb
Veronicastrum virginicum	Native	Perennial	Forb
Vicia americana	Native	Perennial	Forb
Violet species	Native	Perennial	Forb
Zizia aptera	Native	Perennial	Forb
Zizia aurea	Native	Perennial	Forb

Table A.2. List of USFWS sites sampled.

District Office	Unit Name	Coordinates
Arrowwood NWR	D10	47°09'47.34" N 98°46'43.42" W
Audubon NWR	Danielson WPA	47°53'36.81" N 101°25'02.10" W
Audubon NWR	Blomeke WPA South Unit	47°47'19.93" N 100°41'15.65" W
Devils Lake WMD	Register WPA East	48°35'34.50" N 99°14'30.27" W
Devils Lake WMD	Register WPA West	48°35'22.14" N 99°16'08.49" W
Devils Lake WMD	Vollrath WPA	48°49'35.62" N 99°13'06.83" W
Devils Lake WMD	Hofstrand WPA South	48°12'35.69" N 99°27'26.83" W
Devils Lake WMD	Martinson WPA West	48°28'15.94" N 98°37'04.05" W
Devils Lake WMD	Martinson WPA Middle	48°28'15.94" N 98°37'04.05" W
Devils Lake WMD	Lake Alice NWR - Pintail Prairie	48°22'12.48" N 99°04'39.95" W
Devils Lake WMD	Hofstrand North	48°13'25.38" N 99°26'18.07" W
Devils Lake WMD	Kneeling Moose	48°28'17.64" N 98°46'45.24" W
Devils Lake WMD	Twin Lakes	48°14'23.54" N 99°37'54.01" W
Devils Lake WMD	Neer	47°53'25.19" N 99°20'00.84" W
Kulm WMD	Allison WPA	46°34'55.64" N 98°51'02.19" W
Kulm WMD	Linnard WPA	46°33'29.06" N 98°03'16.59" W
Long Lake NWR	A-12-2011	46°42'39.75" N 100°06'53.42" W
Long Lake NWR	A-13-2011 Northeast	46°43'19.35" N 100°00'24.76" W
Long Lake NWR	A-13-2011 Middle	46°43'10.16" N 100°00'42.61" W
Long Lake NWR	A-13-2011 Southwest	46°42'54.95" N 100°00'55.77" W
Long Lake NWR	FMU 9 - 2012	46°50'07.54" N 99°44'34.56" W
Long Lake NWR	FMU 12 - 2012 North	46°50'16.29" N 99°42'06.12" W
Long Lake NWR	FMU 1 - 2012	46°50'48.43" N 99°43'32.60" W
Long Lake NWR	FMU 6 - 2012	46°50'53.69" N 99°42'52.94" W
Long Lake NWR	A-2 - 2013	46°45'38.76" N 100°00'20.86" W
Madison WMD	Pearson WPA	43°52'44.08" N 97°18'41.91" W
Madison WMD	Nelson WPA	44°54'31.69" N 96°37'40.43" W
Madison WMD	Island Lake WPA	43°48'05.51" N 97°07'24.19" W
Madison WMD	Dry Lake WPA North	44°21'26.82" N 97°02'43.31" W
Madison WMD	Rottum WPA	44°32'09.72" N 96°32'38.34" W
Madison WMD	Regan WPA	44°08'59.72" N 97°03'46.95" W
Madison WMD	Lake Henry WPA North	43°55'19.89" N 97°19'36.40" W
Madison WMD	Ramsey WPA	44°11'21.52" N 96°58'03.16" W
Madison WMD	Lake Henry WPA South	43°55'19.89" N 97°19'36.40" W
Madison WMD	Madison WPA	43°58'06.67" N 97°05'17.68" W
Madison WMD	Wolf WPA	43°58'01.35" N 97°05'19.35" W
Madison WMD	Clear Lake WPA	43°46'05.53" N 97°00'06.78" W
Madison WMD	Thornber WPA	44°02'08.74" N 96°50'10.33" W
Madison WMD	Dry Lake WPA South	44°20'40.06" N 97°02'56.07" W
Madison WMD	Hartle WPA	43°36'13.40" N 97°05'53.41" W
Long Lake NWR	Southeast Corner of Refuge - West	45°39'59.79" N 98°17'24.11" W
Long Lake NWR	Field #4 Hanson Point - Site 11	45°42'56.33" N 98°16'30.42" W
Long Lake NWR	Hanson Point - Site 14	45°42'56.33" N 98°16'30.42" W
Long Lake NWR	15 Acre HQ Research Seeding	45°43'24.69" N 98°18'11.77" W
Long Lake NWR	21 acre HQ Research Seeding	45°43'24.69" N 98°18'11.77" W
Long Lake NWR	21 acre HQ Research Seeding	45°43'24.69" N 98°18'11.77" W
Long Lake NWR	31 Acre Spurr Field	45°46'38.78" N 98°15'50.26" W
Long Lake NWR	South of 4-Mile Grade West	45°49'15.08" N 98°14'55.12" W
Long Lake NWR	South of 4-Mile Grade East	45°49'15.08" N 98°14'55.12" W
Long Lake NWR	Dinger Oat Seeding	45°51'34.56" N 98°11'24.01" W
Long Lake NWR	Southeast Corner of Refuge - East	45°39'59.79" N 98°17'24.11" W
Long Lake NWR	Field #5 Hanson Point - Site 63	45°42'56.33" N 98°16'30.42" W

Table A.2. List of USFWS sites sampled (continued).

District Office	Unit Name	Coordinates
Long Lake NWR	16 Acre HQ Research Seeding	45°43'24.69" N 98°18'11.77" W
Long Lake NWR	17 Acre HQ Research Seeding	45°43'24.69" N 98°18'11.77" W
Sand Lake NWR	Helfenstein South	45°49'40.81" N 99°23'25.76" W
Sand Lake NWR	Helfenstein East/West	45°49'40.81" N 99°23'25.76" W
Sand Lake NWR	Helfenstein Middle	45°49'40.81" N 99°23'25.76" W
Sand Lake NWR	Helm	45°38'44.01" N 99°48'57.55" W
Sand Lake NWR	Miller	45°19'02.09" N 99°33'35.78" W
Sand Lake NWR	Scatterwood North	45°12'47.24" N 98°44'25.46" W
Sand Lake NWR	Scatterwood South	45°12'47.24" N 98°44'25.46" W
Sand Lake NWR	Pfaff	45°18'12.88" N 99°03'37.92" W
Sand Lake NWR	Ryam Middle	45°18'01.80" N 99°27'25.43" W
Sand Lake NWR	Ryam West	45°18'01.80" N 99°27'25.43" W
Tewaukon NWR	Gaukler - Spike	46°00'27.41" N 97°21'06.61" W
Tewaukon NWR	Gaukler - NonSpike	46°00'17.70" N 97°21'02.30" W
Tewaukon NWR	Pool 4	46°00'36.68" N 97°25'20.76" W
Tewaukon NWR	Pool 2	46°00'33.59" N 97°22'43.91" W
Tewaukon NWR	Horseshoe Slough Field D12	46°02'47.45" N 97°31'53.07" W
Tewaukon NWR	Mann Lake D7	46°01'38.94" N 97°32'08.73" W
Tewaukon NWR	Smith/Tanner WPA	46°21'25.82" N 97°59'54.65" W
Tewaukon NWR	Wollitz WPA	45°58'28.88" N 97°11'22.26" W
Tewaukon NWR	Horseshoe Slough Field 13	46°02'36.68" N 97°32'41.47" W
Tewaukon NWR	Mann Lake D8	46°01'23.54" N 97°32'06.52" W