Development of a Rapid Monitoring Approach to Inform Management Decisions on a Large Tallgrass Prairie Undergoing Restoration

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Dedication

This thesis is dedicated to Lila and Elvis, for their unconditional love regardless of many days away in the field.

Abstract

Prairie restoration is currently unpredictable, with many sites resulting in low diversity grasslands that do not fulfill expectations. As both government agencies and nongovernmental organizations look to utilize this practice on conservation and working lands (i.e. pastures and biofuels), there is an urgent need to pause and evaluate restoration outcomes. The site specific outcomes of ecological management ubiquitous in the restoration literature and the many interacting factors common to ecological problems emphasize the need for an increase in and improvement of vegetation monitoring to assess progress and predict outcomes in the long term. In 2008, in collaboration with faculty at the University of Minnesota, I developed a rapid monitoring approach for Glacial Ridge National Wildlife Refuge, a large grassland in northwest Minnesota undergoing restoration. My goals were to reliably capture vegetation information, link outcomes to site history and utilize results to inform land manager decision-making. The rapid approach performed well in comparison with the previous effort on site. Through analysis of monitoring data, I identified several correlations among vegetation and site history parameters that were supported by the restoration literature. Restoration and reserve management professionals responded favorably to the approach in a focus group and offered suggestions for further development. With limited adjustment and testing, the rapid approach can provide goal-oriented information to land managers that will improve the effectiveness and efficiency of reserve management.

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Chapter 1

The purpose of this thesis is to address the information needs of land managers at Glacial Ridge National Wildlife Refuge (GR) through the development of a rapid vegetation monitoring approach. GR is the largest tallgrass prairie restoration in North America; as such, it presents many difficult monitoring and management challenges. In this chapter I will discuss some of the factors that contribute to vegetation development on a prairie restoration, the challenges that are important to consider regarding vegetation monitoring and the evaluation of monitoring data to inform management. In the second chapter I will delve into the specific challenges faced at GR and how they were, or were not, addressed by the monitoring approach developed.

North American tallgrass prairies are among the most threatened ecosystems in the world, suffering a loss of as much as 99.9% since European settlement (Samson & Knopf 1994), and are one of the most targeted ecosystems of ecological restoration. Pioneering naturalist Aldo Leopold began what is considered the first prairie restoration in the 1930s (Meine 1988) and the science and practice have developed considerably in nearly a century. Restoration is now relied upon heavily to reverse the effects of human activities. This reversal is a process, by which restoration practitioners assist the transition of vegetation to a more natural, self-sustaining state through reinstatement of natural disturbance regimes, addition of native propagules and removal of nonnative species (SER 2004).

It is hypothesized at the outset that a diverse native assemblage can be established and a suitable disturbance regime introduced, creating a system in a more sustainable state, at which point management intensity can be reduced. However, this strategy often falls short of expectations, partially because data indicating the effectiveness of various restoration practices on long-term ecosystem viability is not gathered or reported (Hobbs & Norton, 1996; Holl et al., 2003; Sluis 2002). Restoration is an ongoing process that requires ongoing monitoring and reporting to guide management actions; however, attempts to improve restoration practice and inform management are often limited by a lack of useful data and/or inadequate use of available data.

Without monitoring to guide actions, many prairie restorations result in low-diversity, C_4 grass-dominated landscapes. The following is a discussion of some of the issues facing vegetation management on a restoration, the most commonly used tools, and the science and reasoning that support - or refute - their use. This discussion will be followed by a summary of some of the challenges faced when developing a vegetation monitoring approach. Finally I will discuss how vegetation monitoring can be used as a guide to improve the effectiveness and efficiency of management actions.

Historical drivers of plant community development in the tallgrass prairie ecosystem include, soil, climate, propagule availability, disturbance, and competition. Ideally restoration activities would manage for and reintroduce these elements in a way that approximates their natural occurrence in a balancing act of disturbance and dispersal events, maximizing diversity across the landscape. Unfortunately, if there is a formula that lends itself to optimal arrangements of plant communities and species, only the variables are known. As a result of insufficient and irregular vegetation monitoring, many restoration practices are propagated as effective with little knowledge of their limitations. A given practice can be considered effective, in terms of vegetation, if it aids prairie restoration in one of two categories: 1) management/eradication of invasive species and/or 2) establishment of native species.

According to recent surveys, land managers spend a median of 50% of their time on invasive species control (Rowe, 2010). The methods called on to reduce the presence of problem species are prescribed burning, chemical treatment and mowing. Numerous studies have examined the effectiveness of these methods on grassland restorations, but discrepancy abounds and may be attributable to site history and environment. Fire is often prescribed to reduce the presence of non-native cool season grasses, however this effect may only be significant in dry years, as an additional stress to non-adapted taxa (Hansen & Wilson, 2006; Bakker et al., 2003). In many systems herbicide treatment has provided only limited control, not eradication and degree of success has been attributable to precipitation and site-specific factors, including soils, hydrology and the targeted species (MacDonald et al., 2007). Mowing is the major alternative method to chemical treatment utilized by restoration practitioners in an attempt to reduce seed production of nonnative biennials and increase light reaching establishing native species. Hansen & Wilson (2006) found that clipping reduced seed production of the nonnative grass *A. cristatum*, which, when coupled with increased light for native species, may be enough to shift the system to a more diverse community. Many restoration practitioners point to the increased success of native seedlings on mowed sites and recommend regular mowing for several years, depending on the vigor of native plant growth.

In addition to management, invasive presence is likely affected by soil characteristics and position on the landscape. Larson et al. (2001) reported that mesic communities had higher frequencies and numbers of invasive species than drier types on a large grassland in North Dakota. If land managers knew this to be the case in their system, control measures could be focused on areas the least likely to recover without assistance. Expanding this line of thinking, it is likely that treatment effects are also dependent on community type; for example, if chemical treatment is more successful in dry years, it may also be most effective on dry sites.

Another strategy, establishment of natives quickly after a disturbance, may be sufficient to limit invasion, if the natives are of the same guild as the problem species (Fargione et al. 2003; Bakker & Wilson 2004). This idea is supported by the fact that the majority of tallgrass prairie invaders are cool season (C_3) species, whereas the dominant native species are warm season (C_4) grasses. Although the work of Cully et al (2003) draws attention to the site and taxa specificity of diversity as an exclusion factor, introduction of cool season natives may function as an invasive management tool in some situations.

Many prairie restorations that successfully manage nonnative species, still fail to increase diversity because they result in C_4 grass-dominated landscapes, with little or no native forb establishment (Baer et al. 2002). If the native seed bank is depleted, seed addition is necessary to promote diversity at historical levels (Kindscher & Tieszen 1998; Martin & Wilsey 2006). There are two means of seed dispersal on large restoration projects, drilling and broadcast. Drilling was favored by many practitioners in the recent past, but research suggests that it tends to favor native grasses over forbs and planting rows may persist long after restoration has begun. Broadcasting is believed to promote the establishment of native forbs and can greatly increase the survivorship of native grasses compared with drilling (Bakker et al. 2003). However, seed drills are still the tool of choice for many restorationists because of perceived efficiency and ease of use.

Post-seeding management actions undertaken to promote native species establishment overlap with those utilized for weed control, and include prescribed burns and mowing. Many land managers prescribe annual burns for the first 2-3 years of a site undergoing restoration to control invasive species and it is accepted that fire promotes native seedling establishment and plant vigor through the promotion of nutrient cycling and suppression of woody vegetation (Bowles et al., 2003; Anderson, 1990); however there is no consensus on the influence of the frequency and timing of prescribed burns. While some practitioners recommend yearly burns (see Schramm, 1992), some studies suggest that variation in timing and frequency promotes greater species diversity. Dalgleish and Hartnett (2009) reported that yearly burning greatly decreases the bud bank of forbs, 125%, in comparison with burning every 4^{th} year and as a result, annual burns may result in increased invasion due to greater resource availability when forbs are lacking. The timing of burns is also an important factor; MacDonald et al. (2007) reported that spring burns decreased cover of *C. maculosa*, but also increased C_4 cover on an experiment in dry, degraded soils typical of lands in need of restoration; increased C_4 cover could further complicate native forb establishment via competition.

The range of results reported in studies examining prescribed burning of grasslands suggests careful consideration of current conditions is necessary to ensure restoration actions don’t lead to decreased diversity. The challenge for managers is to recognize the degree to which site-specificity influences success of various actions on their working restorations, often without the benefit of controlled experiments. Currently, the two challenges faced by managers on a restoration, decrease of invasive cover and increase of native cover, are addressed very similarly across temperate North America, with limited knowledge of how local factors may influence results.

Another challenge faced by land managers is the limited scale at which management can take place; many of the processes that influence vegetation patterns, from seed dispersal to disturbance are affected by landscape-scale activities. Research supports that disturbance - including farms, urban areas and trails - facilitates the distribution of invasive propagules to nearby natural areas (Larson et al., 2001; Tyser & Worley, 1992). This information can be taken into account when planning management actions, but land managers have little influence over land-use patterns at this scale. Within the area to be restored, land use history is also an important influence on vegetation development, one that we are only beginning to understand (Vila & Ibanez, 2011; VonHolle & Motzkin, 2007).

The consensus among land managers who participated in recent surveys is that restoration is highly effective, but all techniques need improvement (Rowe, 2010). Land managers have limited time to back up management actions with scientific literature, so their opinion of many methods will be based solely on personal experience and the expertise of other managers (Pullin, et al., 2004). This information void could be filled by a targeted, efficient monitoring approach. A monitoring approach that provides managers with vegetation data that is tied to management actions and environmental conditions through a spatial component can reduce some of the uncertainty about restoration actions. A Successful monitoring effort should address what information is necessary to assess progress toward goals and provide an evaluation plan to inform future actions. Two major challenges are associated with the development of a vegetation monitoring approach for a site that is both spatially challenging and dependent on ongoing management: 1) developing a methodology that is both informative and repeatable and 2) incorporating data into end products that inform management decisions.

A monitoring approach that is both efficient and effective on a large site will require a compromise between comprehensive assessment and rapid data collection. This compromise will necessarily lead to a unique methodology tailored to the site, one that includes parameters selected not only for their usefulness, but also their ease of use. Parameters must be repeatable and reliable, which means the likelihood of observer error must be minimized. Observer error in vegetation monitoring is commonly the result of misidentification of taxa and over/underestimation of cover. Correct identification of taxa is a factor that is limited by experience of the observers; this condition can be improved by a training period prior to data collection or, as suggested by Kercher et al. (2003), an initial survey with crew members to identify difficult taxa and agree on what level of identification is appropriate for each, i.e. genus or species. Others recommend that multiple observers work together on each survey and discuss all problems encountered (Klimes et al., 2001).

From the limited number of quality control studies in the literature, it can be concluded that cover estimates are the greatest source of variation in data sets from multiple observers (Carlsson et al., 2005; Guo & Rundel, 1997; Kercher et al., 2003; Oredsson, 2000; Scott & Hallam, 2002; Smith, 1944). If cover classes are necessary to effectively evaluate a study site, frequent visual recalibration and selection of fewer cover classes that are relevant to site goals may improve reliability (Kercher et al., 2003). How these issues are handled in development will determine the reliability of monitoring data as a tool for informed decision-making.

In addition to site goals, the landscape should dictate the selection of survey units in order to capture the heterogeneity on site. In most plans, ecosystem monitoring relies on sampling of patches as surrogates for the entire site, or canvassing of the entire site (Spellerberg, 2005); the former is not realistic on a large tract of land and the latter is not feasible on a regular basis. When the former is chosen, plot-level assessments are relied upon to estimate species richness and cover of the area to be monitored. Plots are commonly selected randomly or with stratified random approaches that divide the landscape into units based on known differences, then sampling is done within those units. This works well when the landscape is well-understood and the number of units is manageable. Problems arise when there is a great deal of heterogeneity over a large landscape, creating a large number of units about which managers need timely information to make decisions. The solution is to decrease the amount of detail gathered at each collection point, allowing for an increase in the number of sites sampled, while retaining the quality of information.

Heterogeneity and size do pose a monitoring challenge, but the variety of site conditions and management actions found on these landscapes also presents an opportunity to improve the effectiveness and efficiency of land management. It is often recommended that monitoring data be evaluated in such a way as to suggest relationships between actions and outcomes, leading to further testing of hypotheses through scientific experiments (Bisbal, 2001; Spellerberg, 2005); examples that document this process and its results can be found in the adaptive management literature (Aldridge et al., 2004; McLain & Lee, 1996). It is also important to recognize that factors beyond management actions, including land use history, position on the landscape, and climatic variation, all contribute to vegetation development on a site and should be considered in monitoring and evaluation (Kettle et al., 2000). Through collaboration with stakeholders, including non-profit organizations, government agencies, landowners and researchers, a monitoring approach can provide the information necessary to guide management and research over the long term by incorporating site goals and characteristics.

The second chapter of this thesis documents the effort to develop, test and evaluate a rapid monitoring approach with the above challenges in mind. It is the result of collaboration with The Nature Conservancy, the United States Fish and Wildlife Service, advisors and committee members at the University of Minnesota. This thesis is a product of the input I received during this process; however I take full responsibility for the final direction of the work and any errors or omissions within.

Chapter 2

Ecological restoration as a management tool represents an assumption that the actions taken will lead to a desired outcome; although crucial, monitoring is often overlooked as a test of these assumptions (Peterson, 1993). There is a need for an increase in and improvement of vegetation monitoring to assess progress and predict the outcomes of ecological management in the long term. Experimental data can help to assess the effectiveness of land management tools, but vegetation monitoring may also provide useful data. There is a paucity of published work pertaining to the use of monitoring data to guide management; most references are to the design of monitoring approaches or statements about the need for increased, long-term efforts.

The notable exception is adaptive management; adaptive management is an approach designed to utuilize adaptive learning to guide management decisions. Guidance is provided through a process that includes modeling the system to be managed, goal-setting, evaluation of management outcomes via monitoring, communication among stakeholders and the redesign of management approaches based on results (Walters, 1986). Adaptive management represents the best use of monitoring data because it ensures that information about the current health of the system is not only collected, but utilized in a way that can ensure future ecosystem health. This sort of use may seem like an obvious part of the management process, but the work done by Pullin et al. (2004) suggested that inaccessibility and disinterest prevent the incorporation of data-backed evidence into management plans. Adaptive management can address the inaccessibility facet of this roadblock by providing a solid framework that promotes the ongoing collection and utilization of monitoring data (Haney & Power, 1996; Grant et al., 2009).

In turn, the design of vegetation monitoring approaches will determine the potential usefulness of data to inform management. Ideally information about outcomes will be linked to what management has implemented on the landscape, their actions. A small number of studies have utilized monitoring data to gain an understanding of vegetation development in relation to management and landscape in riparian ecosystems in the southwestern U.S. and grasslands and scrublands in Spain (see Bay & Sher, 2008; Chust et al., 2006), but there does not seem to be a comparable study of the tallgrass prairie in relation to restoration actions. One notable study was conducted by Grant et al. (2009) that used the results of monitoring to outline an adaptive management approach suitable for North American grasslands. Such studies are needed to improve our understanding of vegetation dynamics in prairie ecosystems because prairie restoration is currently unpredictable, with many sites resulting in low diversity grasslands that do not fulfill expectations.

Monitoring is a vital part of the restoration process that can contribute to improvements in practice and planning, yet assessment and reporting of vegetation outcomes is rarely undertaken. Land managers are often forced to make decisions with limited knowledge of the site-specific factors that may influence a given project. Considering the relatively small amount of resources allocated to monitoring and analysis, the process must provide goal-oriented information if it is to become a significant part of decision-making. Monitoring can, and should, be tailored to a specific site. For example, large, heterogeneous expanses relying on data from small plots or a limited number of transects can result in under and over-sampling of some communities and under-representation of rare species. These conditions render any assumptions made by scaling-up observations from small plots to whole landscapes unreliable.

Glacial Ridge National Wildlife Refuge (GR) is one of the largest tallgrass prairie restoration projects in North America, 8500ha, and an excellent model system to evaluate restoration and management outcomes through monitoring. In 2008, with the guidance of Dr. Susan Galatowitsch at the University of Minnesota, I developed a spatially explicit, rapid monitoring approach for use on this large, heterogeneous landscape undergoing restoration. This approach was focused on community and species richness, sacrificing more detailed plot-level information in order to cover more area. However, because simply providing a snapshot of the vegetation is not enough to facilitate long-term planning, I included a spatial component that aimed to link vegetation outcomes to management and site history. My goal was to assess the effects of management actions in relation to site objectives on a working landscape, one that has not been set up with experimental units in mind.

GR represents such a working landscape; it has been undergoing restoration since 2001and variation in both natural and management factors can provide information about the effectiveness of restoration actions across a spectrum of conditions. Understanding the interaction of these factors is vital to maximizing the efficiency with which limited resources are utilized to develop diverse native systems. The spatially explicit monitoring approach utilized in this study was developed to take into account landscape heterogeneity and site history with the intent to inform The Nature Conservancy (TNC) and partners (hereafter referred to as stakeholders) about progress so far, and assist managers in their planning for future management.

This research had three objectives:

1. Develop a monitoring approach to obtain information about the condition of plant communities at GR in relation to site objectives. The objectives set forth by stakeholders included: increases in species and community diversity, decreases in invasive species cover and conservation of rare species. In the site master plan (Brown et al., 2005), species diversity specified both a richness and cover component. Community diversity included 1) the type of plant communities found on the landscape, the arrangement of which are expected to follow patterns of soils and hydrology, and 2) the number of 'essential species', native species that are expected to be found in a given community. The community objective is necessary because, for restoration to be successful at GR, the actions taken should bring about the type of landscape heterogeneity historical to the area, instead of a large expanse of indistinguishable grassland, which would decrease overall diversity from historic and expected levels. Invasive species cover stands in direct opposition to native species cover and diversity, so its decrease was also a priority. Additionally, it is important that in the process of

restoring diversity, rare species populations are not damaged; GR is home to one endangered species of orchid, *Platanthera praeclara*, and many more taxa of conservation interest both in the local area and tallgrass region.

2. Evaluate the reliability of monitoring data to provide insights into the associations between site history and plant community development. My goal was to identify correlations that could inform management decisions without the need for experimental units that may interfere with ongoing management actions. I selected statistical tests that allowed me to analyze data in a way that incorporated restoration activities and site variation. I then evaluated these analyses in the context of the restoration literature; a successful monitoring effort will yield results that are backed by the experimental evidence reported in other studies. I expected to find positive relationships among native plant diversity indicators and broadcast seeding (as opposed to seed drilling) (Bakker et al., 2003), attempts to restore disturbance regimes with fire and mowing (Collins, 1987; Wilsons & Partel, 2003) and age of the site as a result of ongoing management. I expected to find negative relationships among native plant diversity indicators and herbicide application. I also expected that these relationships would be affected by other variables, including hydrology, soils, previous land use and season of seeding, but the relationships were not generally agreed upon in the literature and may be highly site-dependent.

3. Evaluate the overall success of the monitoring development effort. I considered several different, but complementary approaches, settling on two that captured the objectives in the most direct fashion. First, considering stakeholders goals to develop a more informative yet still rapid approach, I compared the monitoring data to a previous assessment effort at GR in terms of site objectives addressed. The previously used approach was developed by TNC and undertaken in 2007 by two contracted botanists, Beth Nixon and Melissa Arikian, from Emmons & Olivier, a private natural resources company. The 2007 effort resulted in surveys of a 1,165 ha portion of the GR restoration. As a second method of evaluation, I presented findings to restoration

professionals and land managers in a focus group, eliciting their response about the utility of the approach. The two evaluation methods selected, comparison of results and professional feedback, will inform me about the utility of the information gathered, which is a significant step toward understanding this new rapid approach.

Study Location

GR is located in Northwest Minnesota 8 miles east of Crookston, within the boundaries of the prairie pothole region of North America (Figure 1). The historic landscape was a mosaic of prairies and wetlands within the beach ridges formed by Glacial Lake Agassiz. Since the 1980s cultivation, gravel mining and wetland drainage have degraded native plant communities (Brown et al., 2005). TNC, the US Fish and Wildlife Service (USFWS) and the Natural Resources Conservation Service (NRCS) have partnered in the planning and restoration of the prairies and wetlands on this 8,500ha tract of land. As of 2008, approximately 2,800 ha of upland prairie had received site preparation, seeding and ongoing management.

Restoration of GR over consecutive years provided a chronosequence of restorations spanning a variety of environmental and management parameters. I utilized space-for-time substitution (Pickett, 1989) via the sampled chronosequence to gain insight into how vegetation may be changing over time on this large landscape. In this method, age is utilized as a surrogate for the passage of time at a single site; older sites are assumed to approximate the vegetation development that will take place over time on younger sites. Space-for-time substitution is not necessarily reliable at predicting vegetation dynamics (Johnson & Miyanishi, 2008), in fact temporal change is influenced by many factors that vary spatially, making no two surveyed units equal to repeated samples; however it can reliably predict general patterns of vegetation change over time (Foster & Tilman, 2000).

The goals established at the outset of restoration projects commonly address native plant diversity, and invasive species presence; at GR community diversity was also identified as an important goal because landscape heterogeneity is an integral piece of this site's ecological significance. Vegetation monitoring is used to gather information on community diversity, however, the type and frequency of monitoring will be limited by budget shortages as oversight of GR is transferred from TNC to the USFWS. Without improvements in the way data are collected and utilized, it will be difficult for land managers to make the decisions that best direct the restoration effort at GR.

Methods

Objective 1: Develop a monitoring approach to obtain information about the condition of plant communities at GR in relation to site objectives. Several development considerations were addressed in this process.

- There is a tradeoff between detail of information and time spent per unit inherent in the development of a rapid approach. Detailed species cover information collected in plots increases the amount of time spent per unit or decreases the area that could be covered in an allotted time. Less detailed information requires a sacrifice in quality. Due to the heterogeneity of this site, it was important to cover more area, so I chose vegetation parameters that could provide useful information without the level of detail traditionally gathered in plots. The selected paramters incorporate fewer categories of relative cover and utilize group cover (native, weed) instead of species cover.

- Because community diversity was one of the desired metrics of the stakeholders it was important to determine how plant communities could be defined in the field to facilitate rapid yet consistent classification. Plant communities can be distinguishable units on well-developed native landscapes; however there will be uncertainty in identification on developing restorations; young restorations are often dominated by generalist taxa and the assignment of community type is partially dependent on species composition. This uncertainty can result in highly variable classifications among surveyors, so guidelines were developed to improve reliability by including not only species information, but also various structural components of each community, including graminoid type (grass, sedge), vegetation height, and percent bare ground.

- Environmental and management factors varied across the GR site, but some did not vary enough to allow for any detectable difference in vegetation development. For example, because the majority of the restoration was under the direction of one restorationist, I did not find variation in the make-up of seed lots, beyond tailoring to specific communities, because experimentation was not the goal. Therefore, I selected site factors for which information was available and variation was apparent; this limited my analysis to some extent but it is to be expected on the type of working landscapes for which this approach was developed.

Site Selection. Fourteen 64.75 hectare plots (1/4 sections) were selected for floristic surveys in 2008 (Figure 2). These sites were chosen to provide a diverse array of soil type, land-use history, year of first seeding, seed lot, seeding method, and restoration management actions. Four components of vegetation that directly address site objectives were targeted: species diversity, community diversity, invasive cover and presence of rare species.

Species diversity. Each site was surveyed for eight hours along ten equally spaced 402.3m transects, and all species in view were recorded. Plot-level cover for each species was sacrificed to decrease time invested at each unit; the end result is a species list for each surveyed unit.

Community diversity. In addition to presence/absence data, community type and essential species richness were recorded within the eight hour time frame. This information was collected at ten equally spaced points along each of the ten transects, for a total of 100 entries into a GIS database. Community information was entered on a PDA in the field utilizing GIS technology (ArcPad, ESRI). At each data point, species composition and total vegetative cover were assessed within an approximately 3x3m area. A community type was selected from those listed in Appendix A. The community classifications span a range of development from entirely native assemblages to monotypic invasive stands (Appendix A) and were determined based on Minnesota Department of Natural Resources (MNDNR) relevé data (2005).

If the community was a native or mixed type (>20% native cover), indicators of graminoid and forb richness (essential species richness) were assigned at the point. Indicators were developed based on preliminary information gathered at a benchmark site. The benchmark site, Pembina Trail, is remnant grassland adjacent to GR. An essential species richness designation of low indicates low quality in relation to Pembina (0-2 graminoid species present; 0-5 forbs), medium indicates moderate quality in relation to Pembina (3-4 graminoids; 6-10 forbs) and high indicates high quality in relation to Pembina (5+ graminoids; 11+ forbs). I developed a unique list of essential species for each community type using Browne et al. (2005) and DNR (2005); these were the only species included in the count at each collection point (Appendix B). Nonnative and many generalist species were not counted when determining essential species richness within native community types because it was assumed that if there were many nonnative species present either richness would be lower because fewer of the essential native species would be present or the community would have been classified as a nonnative type due to high nonnative cover. While the assumption of a relationship between native cover and nonnative richness is not always valid, excluding a nonnative species count was one of the sacrifices made to ensure the rapidity of the approach. Likewise, essential species richness was not recorded in weed communities (those with 80% or greater relative cover of invasive species) because high native species richness was unlikely on a restoration with high invasive cover (personal observations); this was also one of the time-saving measures selected in the development of the rapid approach.

Points of interest were recorded during the survey when necessary. These points included washouts, invasive species, rare species, tire tracks, etc. This information addresses the invasive and rare species components of the site objectives and can lead to targeted management actions without increasing time spent monitoring the site.

Objective 2: Evaluate the reliability of monitoring data to provide insights into the associations between site history and plant community development.

Site History Database. A searchable site history database was compiled using ArcGIS (ESRI) with information from the Polk County Soil Survey, TNC records and interviews with the restorationist at GR. Interviews took place in June, August and October of 2008. Parameters elucidated during interviews include land use history (crop or pasture), season of seeding (spring, fall or winter), year of restoration (2001-2007), seed lot, method of seeding (drilled or broadcast), chemical application (type, extent and frequency), fire regime (season and frequency), and mechanical activity (tilling prior to seeding, mowing) (Table 2).

Linking outcomes to actions. My sampling locations in the 2008 surveys had diverse site histories including previous land use, years since restoration and seeding method. These locations were selected after examining GIS files showing management units across the landscape and interviewing the restorationist on site. Site history data were incorporated into the GIS database to look for associations between vegetation change and site history. I hypothesized that:

1) Native communities will increase in abundance and essential species richness will increase over time with ongoing management. These were stated goals of the GR restoration and improvements that can be expected based on results from other studies that examined the type of management ongoing at GR (Bowles et al., 2003; Wilson & Partel, 2003; Bakker et al., 2003)

2) Vegetation parameters should be associated with disturbance (fire, mowing), restoration actions and time in ways that correspond to those found in the literature (Table 2), indicating that the rapid monitoring approach is a reliable method of assessment.

Data Organization. Each quarter section surveyed included multiple management polygons and each management polygon included multiple soil types. Of the 100 points at which community information was gathered along the transects for each unit, those within the same soil type within a management polygon were considered sites because of their similar history, close proximity and date of sampling. Only sites with a minimum of 10 data points were included in data analysis. The data set contained 31 sites after grouping of points based on management and soils. All desired community types were represented in the surveyed area. The vegetation data for each site were converted to proportions of these points or the average of the measurement for that site. For example, if essential species richness for a given site was reported as 0.25 Low, this means that 25% of the sample points within that site were assigned a community richness level of low.

Data Analysis. To identify correlations between matrices, Mantel tests were run with PC-ORD version 5 (McCune & Mefford, 1999) using vegetation information as the dependent variable and site history components as the predictor variables. The Mantel statistic was tested using randomization to assign significance (Legendre & Legendre, 1998). The Mantel test is a powerful statistical tool because it allows for consideration of multiple interacting factors simultaneously. Seabloom & Van der Valk (2003) utilized this test to identify patterns of development in prairie pothole wetlands that were dependent on site specific factors, such as elevation and wetland type. Chust et al. (2006) were able to separate out the influence of various environmental factors and habitat fragmentation on community composition while also considering geographic distance.

Four distance matrices were computed using Jaccard's coefficient. Jaccard's coefficient was chosen because it can handle multimodal data (see McCune & Grace, 2002) and does not count the lack of data in two units as similarities, for instance two units for which previous land use is unknown would not be counted as similar for that variable. Matrix 1 contained similarity in community classification among sample units; matrix 2 similarity in environmental factors; matrix 3 similarity in pre-seeding management actions and matrix 4 contained similarity in post-seeding management actions. The environment group (matrix 2) included six binary variables (1 indicating yes, 0 indicating no) and one quantitative variable. The binary variables were: parent material of the soil (beach deposits, glacial deposits or till), soil type (loam or sand) and previous land use (crop or pasture). The quantitative variable was age (number of growing seasons since seeding). The pre-seeding management group (matrix 3) included six binary variables and one quantitative variable. The binary variables were: season of seeding (spring, fall, winter), seeding method (broadcast or drill), mechanical preparation of the site ("yes" included cultivation, discing, harrowing, stubbling), and soil disturbance if mechanical preparation was done ("yes"included all but stubbling from the previous category). The quantitative variable was number of chemical applications. The post-seeding management group (matrix 4) included one binary variable and 2 quantitative variables. The binary variable was chemical application and the quantitative variables were: number of fires and mowing frequency (once or twice for the first two growing seasons).

For the second method of statistical analysis the four distance matrices were reduced to two, vegetation and site history (which includes all variables from environment, pre-seeding and post-seeding management) in order to include all variables in one test that could capture interaction between management and environmental factors in terms of vegetation change. These two distance matrices were subject to ordination using nonmetric multidimensional scaling (NMS) PC-ORD version 5. Ordination allowed us to visualize the distribution of sites in variable space and identify relationships among site history variables and vegetation development. Distance matrices were calculated using Sorensen (Bray-Curtis) distance measures. A random starting point was used and 50 runs were performed each with random and real data. Six dimensions were considered and the number was reduced through iteration to optimize the stress of the final configuration. A final stress <10 indicates little risk in making inferences, whereas interpretation of an ordination with a final stress >10 may be misleading (Clarke 1993). Kendall correlations with ordination axes were then calculated for each variable.

Objective 3: Evaluate the overall success of the monitoring development effort.

Comparison with 2007 monitoring approach. I summarized the information from both monitoring efforts to quantitatively compare the two approaches. Parameters examined included time spent per survey, area covered per survey, species recorded per hour and number of stakeholder objectives addressed

Focus Group. I conducted a two hour focus group in Crookston, MN to elicit the opinion of restoration and reserve management professionals on the utility and effectiveness of the rapid monitoring approach. Land managers and researchers working in the study area or ecoregion were selected for participation by the authors and recruited via email. All individuals who responded were included in the final group, which consisted of 9 participants from the USFWS, TNC, USGS and University of Minnesota, Crookston. Five of the participants were primarily involved with land management and four of the participants were primarily involved with research.

The session began with an introduction to the monitoring approach, followed by a group question-and-answer session led by the primary investigator and a co-author. Questions asked of the participants covered their opinions on three main aspects of the work: the utility of the approach as a tool to inform decision-making on nature reserves, the strengths and weaknesses of the approach and the feasibility of implementation.

Responses were recorded as hand-written notes by the primary investigator and an assistant. Notes were later used to divide responses into categories based on the subject matter and the conversations were summarized. These responses were used to measure the effectiveness of this new monitoring approach, what Vos et al. (2002) refer to as the "quality and utility of the information gathered".

RESULTS

Monitoring Outcomes

The first objective of or the rapid monitoring approach was to estimate vegetation development rapidly over a large, heterogeneous site undergoing restoration. Using the new rapid approach, in 2008, over fourteen days of surveying one botanist averaged 20 acres per hour to record 1,240 data points and 14 species lists across 14 survey units. Four of the 14 surveys were less than 90% complete due to the presence of wetlands which were not the focus of restoration, or, in one case, a near monoculture of impassable vegetation (*Melilotus* sp). Of the 2800ha of restored area, the 2008 surveyed area included approximately 803ha, 29% of the entire area. Of the ten surveys that were completed at 90% or greater, the average number of taxa recorded was 118 (range 95-134, Table 1).

Community diversity, also a stakeholder priority, was recorded across the surveyed area as community type and essential species richness at the 1,240 data points in 2008. All expected communities were recorded on the 14 units, with quality varying throughout. The most commonly recorded community types were mixed perennial/biennial weed upland and lowland (Table 3). The least commonly recorded community types were fens, mixed weed fens and dry prairies. The most commonly recorded native community was wet prairie. The highest native graminoid richness was found on wet prairies (56% of the points recorded as this community type were assigned high essential species richness) and mixed annual weed lowlands (43%). The lowest native graminoid richness (excluding weed communities, for which essential species richness was not recorded) was found on mixed perennial weed uplands (43%) and mixed perennial weed lowlands (40%). The highest native forb richness was found on wet prairies (7%) and mesic prairies (6%). The lowest native forb richness was found on dry prairies (100%) and wet meadows (88%). From these results it would appear that perennial weeds have the greatest effect on graminoid richness and that forb richness may be influenced by a factor related to community type.

Vegetation Development and the Influence of Site History

The second objective of the rapid monitoring was to link vegetation outcomes to activities taking place on this working landscape. I was able to identify correlation between vegetation and site history and to identify the relative importance of site history variables. I analyzed the correlations between the three vegetation parameters (community status, graminoid and forb richness) and three elements of site history (environment, pre-seeding management and post-seeding management) using Mantel tests. The vegetation matrix was significantly correlated with all three site history matrices. The strongest correlation was found between the vegetation and post-seeding management matrices (r=0.28, P =0.001); this correlation indicates that the measured vegetation outcomes are related to management actions that take place after native seeds are distributed. The correlation between vegetation and environment was nearly as strong (r = 0.27, P = 0.001). The weakest, but still statistically significant, correlation was found between vegetation and pre-seeding management (r = 0.10, P =0.042). To gain insight into which site history variables were strongly correlated with individual vegetation parameters, I performed ordinations.

I assessed the relative importance of the site history variables to vegetation outcomes in an ordination of vegetation and all site history variables. The 3 vegetation parameters explained 66% of the variance along axis 1 and 30% along axis 2 in an NMS of 31 sites (Figure 3). A positive correlation with any variable indicated a greater likelihood of higher vegetation values (greater richness, more native cover) with that variable. There was strong correlation between the three vegetation parameters and several site history variables (Table 4). Graminoid and forb species richness were strongly associated with loam soils, post-seeding mowing and fire along axis 1. These results indicate that greater richness was associated with loamy soils, the use of mowing as a management tool and burning. Community status and graminoid richness were associated with the number of growing seasons along axis 2, suggesting that native species cover and the number of graminoid species present increase over time post seeding. These results support my first hypothesis that native communities will increase in abundance and essential species richness will increase over time.

I was surprised at the predominance of weak correlations (r <0.5) revealed by the analysis (Table 4); this does not necessarily indicate that causal links among these variables were generally weak, which would be counter to the findings of previous experimental studies, but rather that the findings are the likely result of a combination of 2 factors; 1) the limited ability of the analysis method to reveal causal links with the given information, including monitoring and record-keeping and 2) the interaction of the selected variables with many more that were not considered in the analysis. As previously stated the level of detail of the monitoring data was limited to what could be collected rapidly; therefore the variables are somewhat generalized. Keeping this need for rapid data collection in mind, the approach could be improved by the inclusion of an additional cover category for the definition of community types. Analysis would also benefit from a larger data set from multiple years of monitoring. The influence of excluded variables on those measured can also be addresses over time; for example, precipitation in the year of seeding can be included as an environmental variable and will likely have a strong causal relationship with species richness because it influences seed germination. Another important variable that was excluded from this study is seed lot composition, which is a limiting factor in the development of species-rich communities that are spatially isolated from other seed sources.

Evaluation of the Rapid Monitoring Approach

Using the previous 2007 rapid approach, two botanists from Emmons and Olivier were contracted by TNC to perform vegetation monitoring utilizing the rapid approach developed by TNC. They completed 18 sampling units of 160 acres each (1/4 sections) in 6 hours on each unit; this effort amounted to approximately 26.6 acres per hour and yielded 18 species lists. Using the updated rapid monitoring approach developed for this study in 2008, one botanist completed 14 sampling units in 8 hours on each unit; this effort yielded 14 species lists and 1,240 community data points in 20 acres per hour. Species lists were compiled for each unit with both approaches, but there was not a direct overlap of units covered between years. The average number of species recorded per unit was 55 for the 2007 approach, compared with 118 with the 2008 approach; an increase of 53%.

The focus group discussion revealed clear distinction among the groups present (agency, non-profit and university) in their reactions to the monitoring approach; this separation may have stemmed from the background of the members representing each group, which include a spectrum of responsibilities spanning from predominantly research to mainly management activities. The USFWS managers, as a rule have a great deal of land to manage and a large number of stakeholders to answer to on a regular basis; this limits the time they can dedicate to conducting research or reading scientific papers (Pullin et al., 2004). Further along the spectrum, the university representatives are immersed in research, both for scientific and management purposes, but do not necessarily have the time commitment or financial constraints brought on by land management itself. The TNC representatives fall out along this spectrum, dependent on the nature of their employment. These distinctions were reflected in the reactions of participants to the methods of the monitoring approach: agency personnel were wary of the complexity and concerned about the level of detail of the information, TNC representatives were more open to the challenge of the approach itself and framed potential at the landscape scale, and researchers were intrigued by the potential of the information but also critical of aspects that were not included.

Two main information categories stemmed from the focus group conversation to evaluate the success of the 2008 rapid monitoring approach: utility of information and implementation potential.

A key tradeoff made when developing monitoring approaches occurs between the detail of information and the time invested in data collection. The group addressed the detail of information provided by the approach in terms of management decision-making. One of the TNC members began by stating that this approach was ideal for a large landscape, because the detail provided a snapshot of the vegetation across the landscape. A USFWS member of the focus group wondered if this type of snapshot could instead be obtained via remote sensing, but a TNC member pointed out the limited detail possible with remote sensing images and dependence upon season and availability. The researchers present stated that the approach would perform quite well as a way to identify areas in need of more detailed investigation. A TNC employee pointed out a level of information that could easily be changed to improve the results: the majority of data points collected were classified as “Mixed Weed” communities, this stems from the large range of cover values dedicated to this grouping (20-80%). If the mixed categories were instead divided into two categories, it would greatly improve the detail of information without sacrificing time or repeatability.

One of the most important, yet often overlooked steps to a complete monitoring approach is the transition from data to interpretation and ultimately decision-making. The information provided by this approach ultimately needs to facilitate the answering of day-to-day management questions, however a USFWS employee thought it may be more suitable as a status and trends revealer. They expressed uncertainty about whether the detail of information was enough to answer the types of questions that they were often called upon to answer because this approach was perhaps taking on too many goals at once. In contrast, TNC managers and researchers saw this as a protocol that can be used for many purposes.

Overall, participants in the focus group agreed that the approach was a useful tool that needed little change to fulfill many of the needs of land managers on lands undergoing restoration. The remaining piece of our conversation then was implementation. Could such an approach be adopted by an agency or non-profit and successfully, reliably fulfilled? To answer this I need to address funding and experience/repeatability. Funding and experienced help were the main concerns of the USFWS in undertaking this sort of approach.

Discussion

Monitoring Outcomes

The reason for developing this approach was to rapidly estimate vegetation outcomes of restoration in a way that addressed stakeholder objectives and informed management. The 2008 effort, using the new rapid approach, differed from the 2007 approach in both the quantity and quality of information collected, in a way that improves the utility of the data to management decision-making.

Although some of the increase in species recorded from 2007 to 2008 can likely be attributed to annual and spatial variation, a variety of sites were sampled in 2008, some of which were younger and less developed than those sampled in 2007, so I expect some offset of these effects. In addition to the apparent increase in species recorded per unit, the 2008 approach addressed stakeholder objectives of community richness, presence of essential species in communities and invasive species cover, whereas the 2007 approach only addressed species richness and did not include a spatial component.

The spatial component of the 2008 approach is vital to the utility of the data to land managers because it resulted in end products that can inform decision-making. End products that are unique to the 2008 approach include a searchable GIS database and statistical analysis of vegetation outcomes in relation to site history.   The GIS database allowed us to utilize the spatially explicit community data to create maps (Figure 4) that show status of units with simple queries that employees can perform even with limited GIS knowledge. The ease of use of this feature decreases the transition time from data to interpretation, thereby decreasing costs. Without the spatial component provided by this monitoring approach, managers are not able to utilize the results of monitoring to plan tasks, such as targeted treatment of invasive species infestations, without further surveys.

The analysis of vegetation data in relation to site history can potentially identify trends over time immediately using space for time substitution across the site, but also over the long term as sampling is repeated. It does not directly identify cause and effect relationships; however this could be addressed if units were set up as uncontrolled experiments. As it stands, I was able to identify some interesting relationships among vegetation parameters, environment and management.

Factors Influencing Vegetation Development

Managers rely heavily on accounts from other restorations/managers (Pullin et al.,2004), a reliance that emphasizes the need for quality monitoring to improve understanding of what is occurring on the landscape in both the long and short-term, and to what the results may be attributed. Land managers have a unique opportunity to stay on a site long term and gain a deeper understanding of the many factors contributing to perceived results; however they often have little time to keep up with scientific literature in a meaningful way. Thus, any improvements in the information they glean from other managers and their own monitoring are likely to have large impacts on how management activities affect the success of restorations.

From the monitoring performed in 2008, I was able to identify correlations that can point managers and restorationists in the direction of more effective actions at GR. For instance, native species cover, native graminoid richness and native forb richness were positively associated with burning and mowing. These results support the belief that post-seeding actions may be the most efficient and effective tools to manage diversity on this restoration. The idea that disturbance, such as fire and mowing, is an important driver of community development on prairies is supported by the literature (Bowles et al., 2003; Collins 1987), but effectiveness varies considerably as local conditions and additional management interact (Hansen & Wilson, 2006; Dalgleish & Hartnett, 2009). The complex relationship of disturbance factors and environmental variation across the landscape is reflected in the results of analysis of GR data; I did not reveal direct correlation of vegetation parameters with site history variables, nor was all of the variation explained by the study variables. However, the revealed trend, combined with knowledge from the literature, indicated that managers can benefit from focusing on these two tools when searching for ways to improve their results. For example, most of the burning on GR, and at restorations across temperate North America, takes place in the spring, when environmental conditions are most conducive to a safe, controlled burn. However, several studies point to varied fire frequency and timing as a tool to support species diversity (MacDonald et al., 2007;). As part of an adaptive management approach, managers can use the information gathered from monitoring results at GR, which indicated that fire is an important driver of native species richness, to include more variation in fire application, thereby gaining a better understanding of community and species response to fire regime.

There was also an association between both native cover and graminoid richness and site age; both parameters were positively correlated with the number of growing seasons. Realizing the limitations of the chronosequence approach, we cannot read too much into this result. Although it appears that essential species richness is increasing over time, many studies have found that species richness decreases over time on grassland restorations (Sluis, 2002; McLachlan & Knispel, 2005). As this monitoring approach is repeated over time at GR, actual temporal change can be compared with these early results to improve understanding. While the goal is to assist land managers in decision-making, no management approach should be abandoned because of the initial results of this monitoring approach; rather the answers found in the early years of monitoring will raise some interesting questions that warrant further investigation, both through experimental studies and the introduction of variation into management approaches.

I did not find an association between native forb richness and site age; this emphasizes the importance of other factors, management and environmental, in the establishment of native forbs (Williams et al., 2007). Native forb richness was associated with loam soils, indicating more success on mesic sites. This could be the result of several factors including, but not limited to, the need for seed lots tailored specifically to dry sites, the need for stratification of dry type seeds, or less success with the management techniques utilized for restoration on dry sites. All of the preceding explanations require further investigation by experimental studies, but insights can still be gained by focusing management actions on these alternate methods. I did not find enough variation in seed lot data to support analysis of the GR restored site, but Biondini (2007) found that composition of seed mixes affects richness.

The goal of this part of the project was to help managers identify links between restoration practice and vegetation community development on a large grassland undergoing restoration. While the analysis showed many relationships between vegetation and the factors examined in this study, these factors did not explain all of the variance in vegetation quality. Other factors that are likely to be important include season of burning, seed lot composition, and geographic distance from sources of invasive or native propagules. This analysis approach can also be expanded to monitor vegetation transitions in response to long-term changes in climate, soils, hydrology and/or disturbance regimes.

Response of Restoration and Reserve Management Professionals

The distinction between the groups in this case may have stemmed from the types of information with which they were familiar; detailed species cover data are more the norm for land managers, but may not be available on a large, heterogeneous site. The question that land managers and stakeholders would need to address is "do we need detailed, plot level information about species presence and cover"? I would argue that on large areas the answer is often no; the goals set forth for this project can be addressed with the data provided by the rapid approach. The type of plot-level information mentioned above seems more suited to smaller areas and experimental units, which could be incorporated into an adaptive management approach as needed. University representatives suggested that this approach could identify those areas in need of such detailed investigation.

The rapid approach, as with all effective monitoring approaches (Vos et al, 2000), would require dedicated funding not only for data collection, but also data analysis, management and dissemination. There is however, the potential for significant savings if an approach can facilitate more efficient management and monitoring strategies. For example, knowledge of both the invasive and native vegetation present on a site may lead to mechanical instead of chemical control, which can lead to less native species mortality from herbicides, healthier native populations and less invasion over time (Fargione et al., 2003). The frequency of the surveys can be modified over time in accordance with data needs and financial constraints. One of the USFWS employees stated that 2 weeks of surveying yearly would be a reasonable amount of time spent on monitoring. With the rapid approach, two weeks would allow for the completion of 10 units, roughly 1600 acres. The other concern of participants was repeatability; it is recommended that a permanent employee, one that could become familiar with the flora of the area, or a contract botanist, undertake the activities of the rapid monitoring approach.

Developing Rapid Monitoring Approaches

As with a well-designed scientific experiment, objectives must guide the development of a monitoring approach to ensure its utility to land managers. As an initial attempt, this approach performed admirably in terms of analysis and manager response, the chosen tests of its success, but there are still drawbacks and further development considerations to discuss. These include relevant scale, repeatability, uses and limitations,

Relevant scale is addressed through survey unit selection. I utilized the ¼ section as the survey unit in this approach; while this is convenient for design and implementation purposes, it has no ecological relevance. I recommend that the stakeholders at GR determine the scale at which they can tailor management actions, such as soil units or community types. It may at first appear that this would complicate monitoring efforts, but with limited effort employees can create polygons of any size and shape in advance that delineate management and monitoring boundaries, allowing the GPS and GIS to guide them. GIS can greatly contribute to the usefulness of monitoring data by creating easily accessed visual aids and allowing users to ask question and receive output with minimal GIS experience.

This rapid monitoring approach can be greatly improved by addressing repeatability and the development of community diversity indicators. Repeatability is vital to the utility of survey information and should be explicitly addressed. While there is a great deal of literature concerning the repeatability of various survey methods, it was not within the scope of this project to test the approach with various field crew members. I did discuss in detail the specifics of the approach with various project participants and land managers. Assigning community composition is likely to be the most subjective part of this monitoring approach, and this could easily be overcome by spending time in the field prior to the start of surveys to allow for calibration among crew members.

The other issue affecting repeatability is experience of the field crew; to ensure the most adequate and reliable data collection, a botanist should perform these surveys. However, given that many agencies do not retain botanists on their staff, a biologist or citizen scientist who is familiar with the area should suffice. More development to improve the accuracy of the community diversity indicators (categories representing the number of native graminoids and forbs in a given community) will also improve repeatability. For this project four 402.3m transects were surveyed at one remnant site to establish ranges of species richness; these ranges then guided the development of categories (high, medium, low) for the diversity indicators. In the future, diversity indicators should be developed for multiple community types using data from multiple remnant sites.

This rapid approach was designed for a large, heterogeneous landscape and, as designed, cannot incorporate detailed cover information. The quarter sections used for surveys do not match up directly with management polygons therefore species lists cannot be utilized in the analyses presented. The GR project is not designed as a research experiment, rather a working landscape that incorporates both physical and practical landscape issues, such as soil types and accessibility. This approach can function as part of an early-control monitoring program (as described by Vos et al, 2000), in which management actions represent uncontrolled experiments and the data collected can lead to direct action regarding management decisions. It improves upon the invasive-only monitoring that many land managers rely on to make decisions, because this function is incorporated into the collection of native species and community data. Invasive species surveys would still have a place on non-surveyed areas each year, but could be incorporated into other management activities or performed by a seasonal employee as they require much less botanical knowledge.

Managers seldom feel that monitoring results are sufficient to make decisions (Pullin et al, 2004). This study makes it clear that complex vegetation monitoring approaches can provide information that is relevant to management decisions in a timely manner, if implementation challenges can be overcome. These include economic constraints and expertise of employees. There is enough flexibility in this design that it could be adjusted to the level of expertise of the employee, however utilizing permanent, long-term individuals who are familiar with the restored area would limit the extent of adjustment required.

This approach is comparable to the less spatially-intensive approach utilized at GR in 2007 in terms of area covered per unit time. As an additional efficiency measure, monitoring can be focused on areas undergoing management operations when necessary. Information gathered through monitoring can be considered over the long term in tandem with interacting environmental variables, producing a rich data set over time with more diagnostic power. The immediate utility of the data, even after only one year of monitoring, is in identifying invasive species outbreaks, locations of rare species, rare communities and areas of high species richness that may become sources of seed for further restoration. With the current data, managers are able to assess progress towards objectives and report to stakeholders. In the unique situation at GR, an adaptive management scheme could tell us much about the success of management across many tallgrass prairie community types and situations.

This approach as designed is specific to the Glacial Ridge region, but with adaptations could be applicable to other large grassland restorations. Community classifications and essential species lists would need to be tailored to each site, with the aid of local botanists, groups like TNC and the MNDNR who were responsible for the publication of the resources utilized for development of this approach for GR.

Recommendations to Land Managers

The value of good record-keeping around pre and post-seeding management cannot be overestimated; even if the rapid approach as designed here is not utilized, the ability to link any form of monitoring data and management actions is a valuable tool when assessing the progress of a restoration. Additionally reserves would benefit from making GIS a standard part of documentation, data collection and organization because it provides easy access to records in the field and an excellent link to landscape.

I recommend that land managers pay attention to the natural variation across the landscape and attempt to incorporate it with management variation as part of an adaptive management plan. That is not to say that managers should necessarily expend time setting up experimental units, but instead take advantage of the potential inherent in the landscape to make small adjustments to management actions that may inform future replicated projects while still keeping progress toward site goals as the main objective.

If the budget is not conducive to the employment of a full-time or seasonal botanist, consider yearly contracts with botanists to monitor landscapes where vegetation development and conservation are goals. In all situations, managers should consider ways in which citizen science can contribute. It is also important to utilize the resources already available from other agencies and organizations, for example the Minnesota Department of Natural Resources Field Guide to Native Plant Communities (2005), to educate employees and volunteers.

Table 1. Species richness and percent completion of 2008 survey units.

Site (1/4 section)	% Complete	NativeSpecies (# Recorded)	Introduced Species (# Recorded)	Total Species (# Recorded)	Date Surveyed
Crossroads NW26	100	100	30	130	22nd July
Maple Lake SW10	100	93	24	117	23rd July
Dugdale NE34	100	102	25	127	24th July
Tilden C21	100	75	20	95	28th July
Pembina SW32	100	70	29	99	29th July
Crookston NW20	75	96	31	127	30th July
Gravel SE17	99	76	30	106	31st July
Moose WC24/23	30	66	21	87	1st Aug
Paintball SE35	100	103	31	134	4th Aug
Crookston NE19	65	92	24	116	5th Aug
Pembina SW29	100	83	26	109	6th Aug
Crossroads SC26/35	90	108	25	133	12th Aug
Dugdale SE34	79	100	26	126	13th Aug
Pembina SE31	93	98	27	125	14th Aug

Table 2. Site history variables examined at Glacial Ridge and their expected influence on restoration outcomes. Literature was identified through searches of the peer-reviewed literature and technical reports.

Site Variable	Categories	Influence on Restoration	Reference
Site Type	Dry, Mesic, Wet	More invasive spp. cover on mesic-wet sites.	Larson et al., 2001
Previous Land Use	Crop, Pasture	Higher diversity on crop lands.	Technical Reports
Year of Restoration	2001-2007	Unclear, seems to be dependent upon site history.	Sluis, 2002 McLachlan & Knispel, 2005
Season of Seeding	Spring, Fall, Winter	Greater establishment when seeded in dormant season.	Technical reports
Seed Lot	Lot name/number	Restoration leads to less invasive cover.	Bakker & Wilson, '04; Biondini, '07; Blumenthal et al., '05; Pywell et al., '02
Method of Seeding	Broadcast, Drill	Higher survivorship of natives when broadcast; More grass, invasive spp cover on drilled.	Bakker et al., 2003 Yurkonis et al., 2010
Chemical Application	Frequency, Timing	Decreased invasive cover; Greater effect in dry years, on dry sites.	Bakker et al., 2003; Hansen & Wilson, 2006; Wilson & Partel, 2003
Fire	Burned, Not Burned	Increase in native and decrease in invasive spp. cover. Decrease in native cover without other management. Diversity effects dependent upon frequency.	Bowles et al., 2003; Collins, 1987; Brudvig et al., 2007 Collins, 1987 Dalgleish & Hartnett, 2009
Mowing	1 year, 2 years, None	Decreases cover of invasive spp	Wilson & Partel, '03

Table 3. Frequency of community types as the total number of recorded points over all units.

Community Type	Number of Points
Dry Prairie	12
Mesic Prairie	32
Mixed Perennial Weed Upland	412
Mixed Annual Weed Upland	13
Wet Prairie	56
Wet Meadow	16
Mixed Perennial Weed Lowland	514
Mixed Annual Weed Lowland	23
Perennial Weed Upland	32
Perennial Weed Lowland	22

Table 4. Pearson and Kendall's rank correlations with the NMS ordination axes for vegetation parameters and site history variables. Pearson correlations greater than 0.5 are shown in bold and can be found along the ordination axes in Figure 3.

Axis		1			2	
	r	r^2	τ	r	r^2	τ
Community Status	0.446	0.199	0.222	**-0.749**	0.560	-0.613
Graminoid richness	**0.780**	0.608	0.552	**-0.919**	0.844	-0.751
Forb richness	**0.910**	0.828	0.777	-0.202	0.041	-0.122
Beach deposits	-0.195	0.038	-0.154	-0.229	0.053	0.166
Glacial deposits	0.375	0.140	0.319	-0.070	0.005	-0.081
Till	-0.188	0.035	-0.173	-0.157	0.025	-0.083
Loam	**0.561**	0.315	0.479	-0.316	0.100	-0.243
Crop	0.323	0.104	0.229	-0.477	0.227	-0.372
Pasture	-0.151	0.023	-0.071	0.320	0.102	0.250
Spring	-0.037	0.001	0.018	-0.199	0.040	-0.188
Fall	-0.232	0.054	-0.232	0.154	0.024	0.185
Winter	0.326	0.106	0.252	0.085	0.007	0.033
Broadcast	0.076	0.006	0.066	0.059	0.003	-0.018
Mechanical site preparation	-0.295	0.087	-0.249	-0.110	0.012	-0.127
Soil disturbance	-0.360	0.130	-0.303	0.258	0.067	0.182
Chemical app. (pre-seeding)	-0.215	0.046	-0.170	0.419	0.175	0.362
Mow frequency	**0.666**	0.443	0.513	-0.327	0.107	-0.227
Fire number	**0.581**	0.337	0.458	-0.489	0.239	-0.413
Chemical app. (post-seeding)	-0.360	0.130	-0.303	0.258	0.067	0.182
Age	0.132	0.017	0.063	**-0.629**	0.396	-0.436

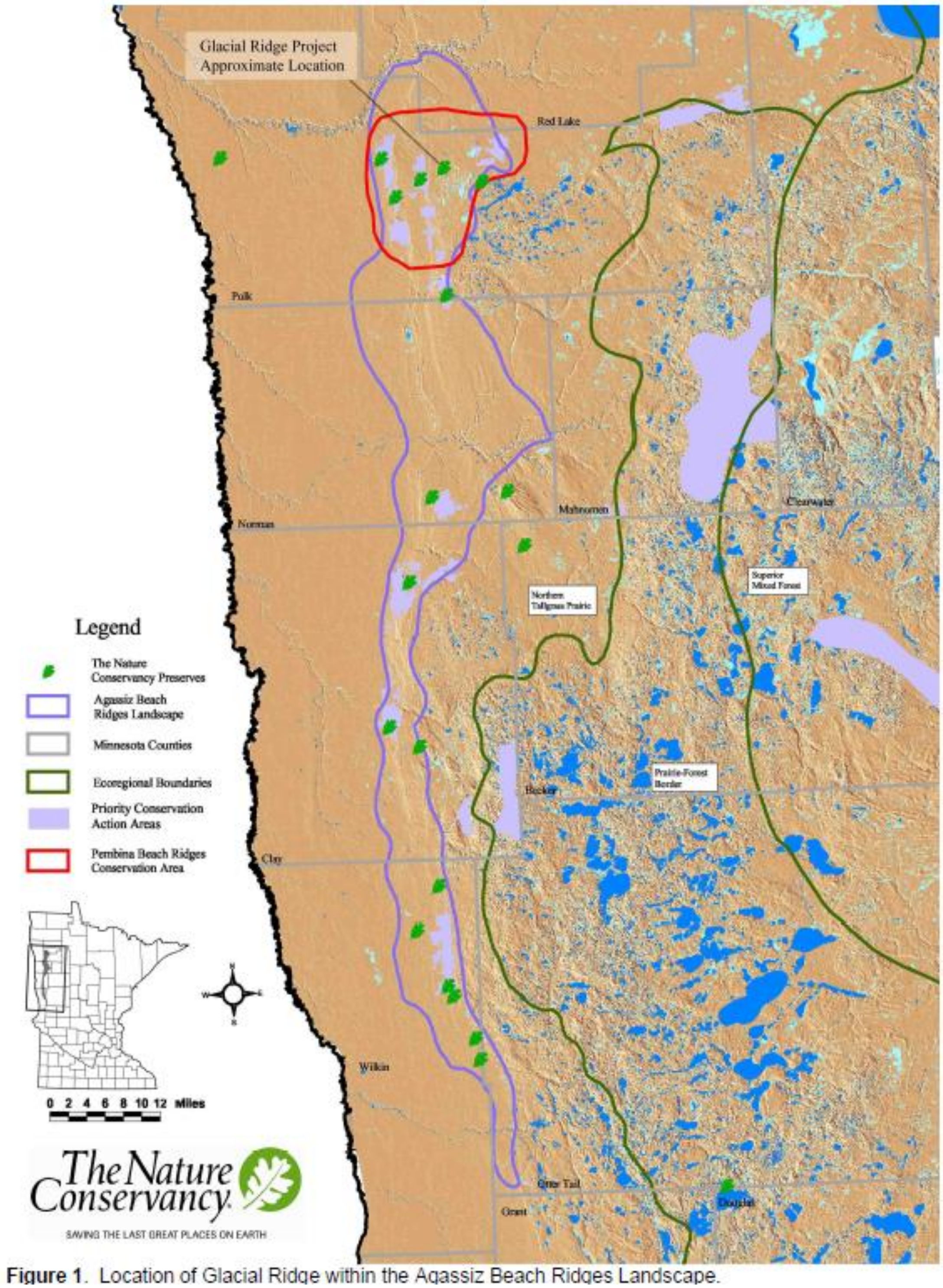

Figure 1. Location of Glacial Ridge within the Agassiz Beach Ridges Landscape.

Taken from Brown et al., 2005

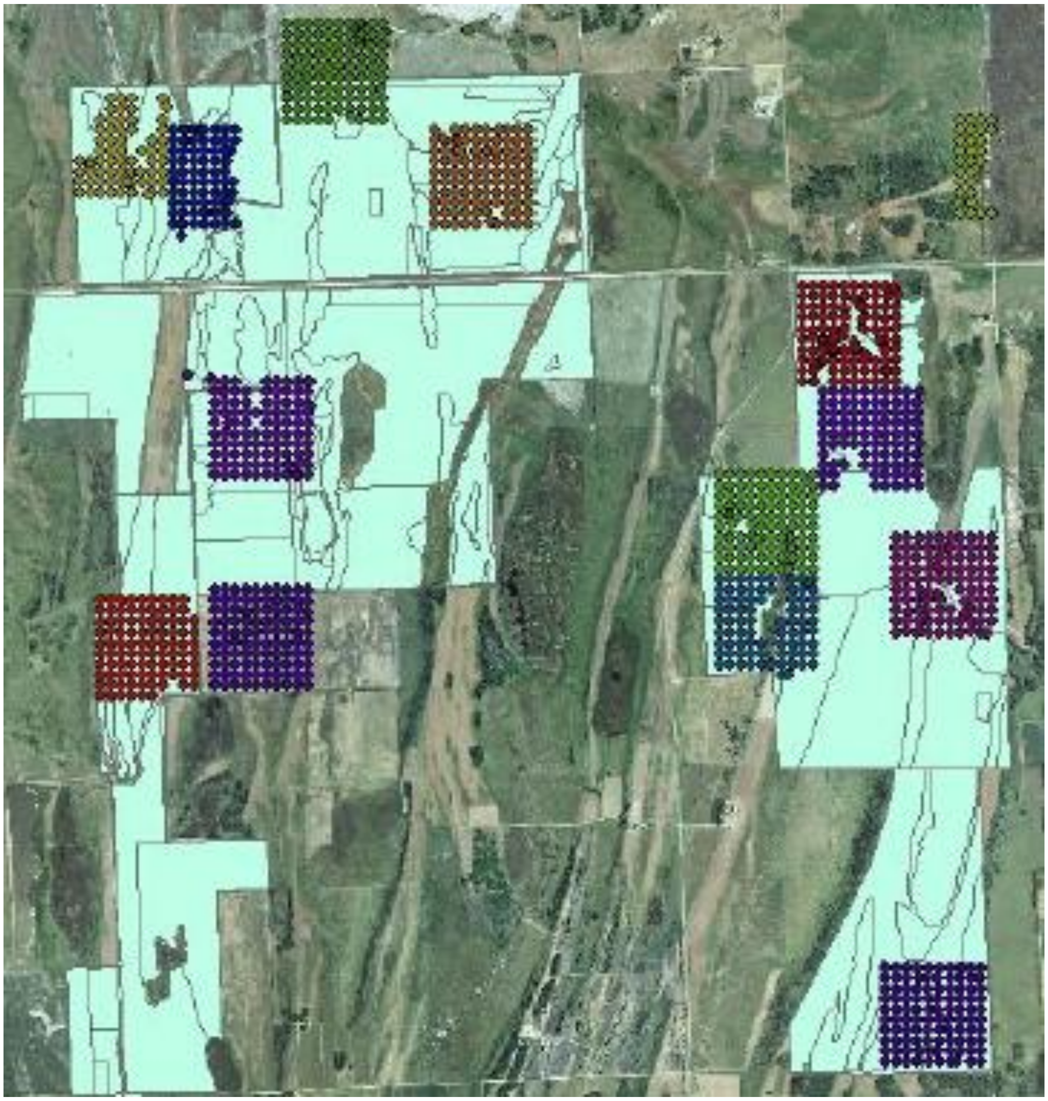

Figure 2. Glacial Ridge area showing 2008 survey units, shown as collections of points forming ¼ section squares. Management polygons can be seen within the colored GR area, outlined in grey.

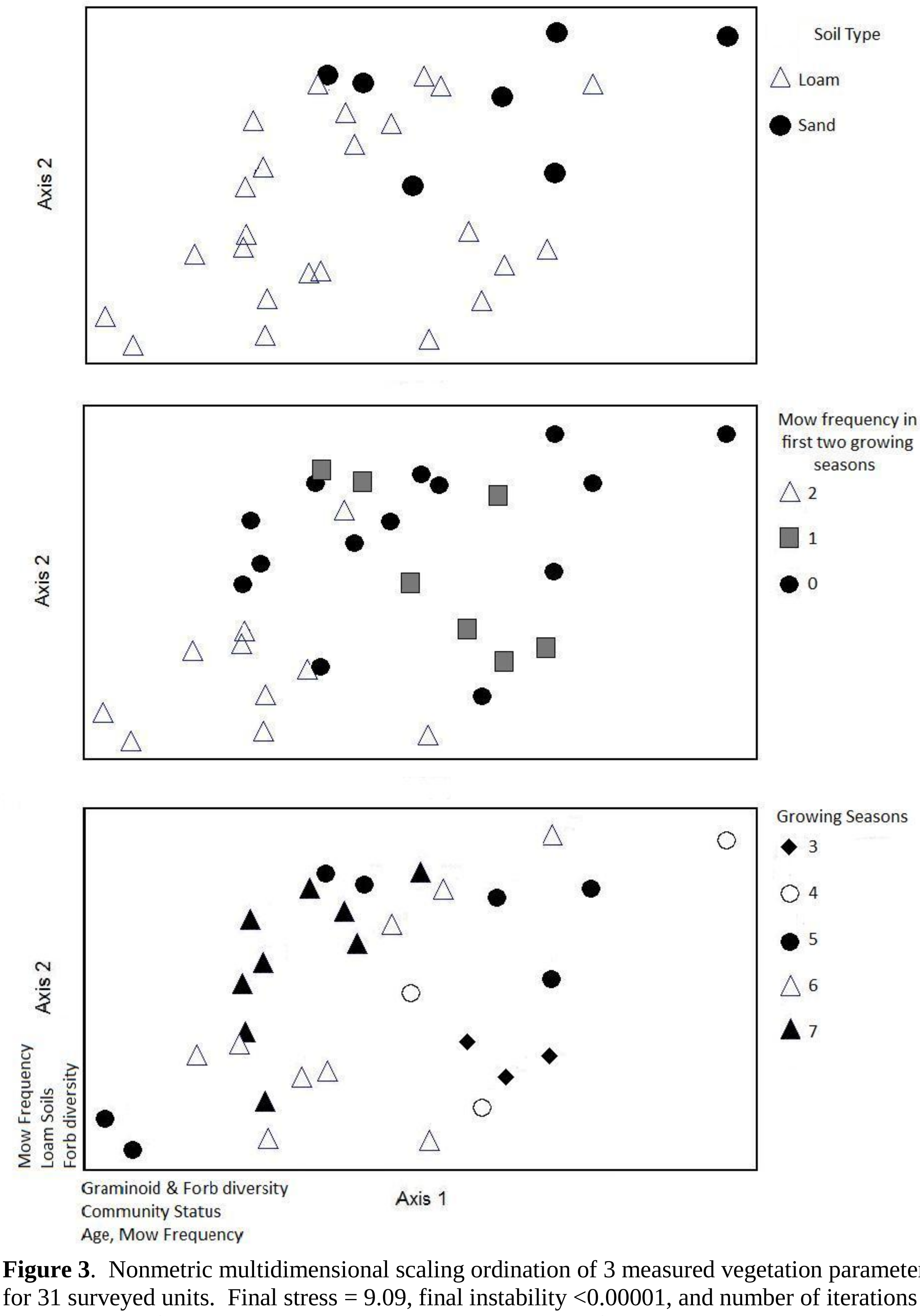

Figure 3. Nonmetric multidimensional scaling ordination of 3 measured vegetation parameters for 31 surveyed units. Final stress = 9.09, final instability <0.00001, and number of iterations = 65. Locations of variables along the axes indicate direction of positive correlation. Points in the graph represent sites.

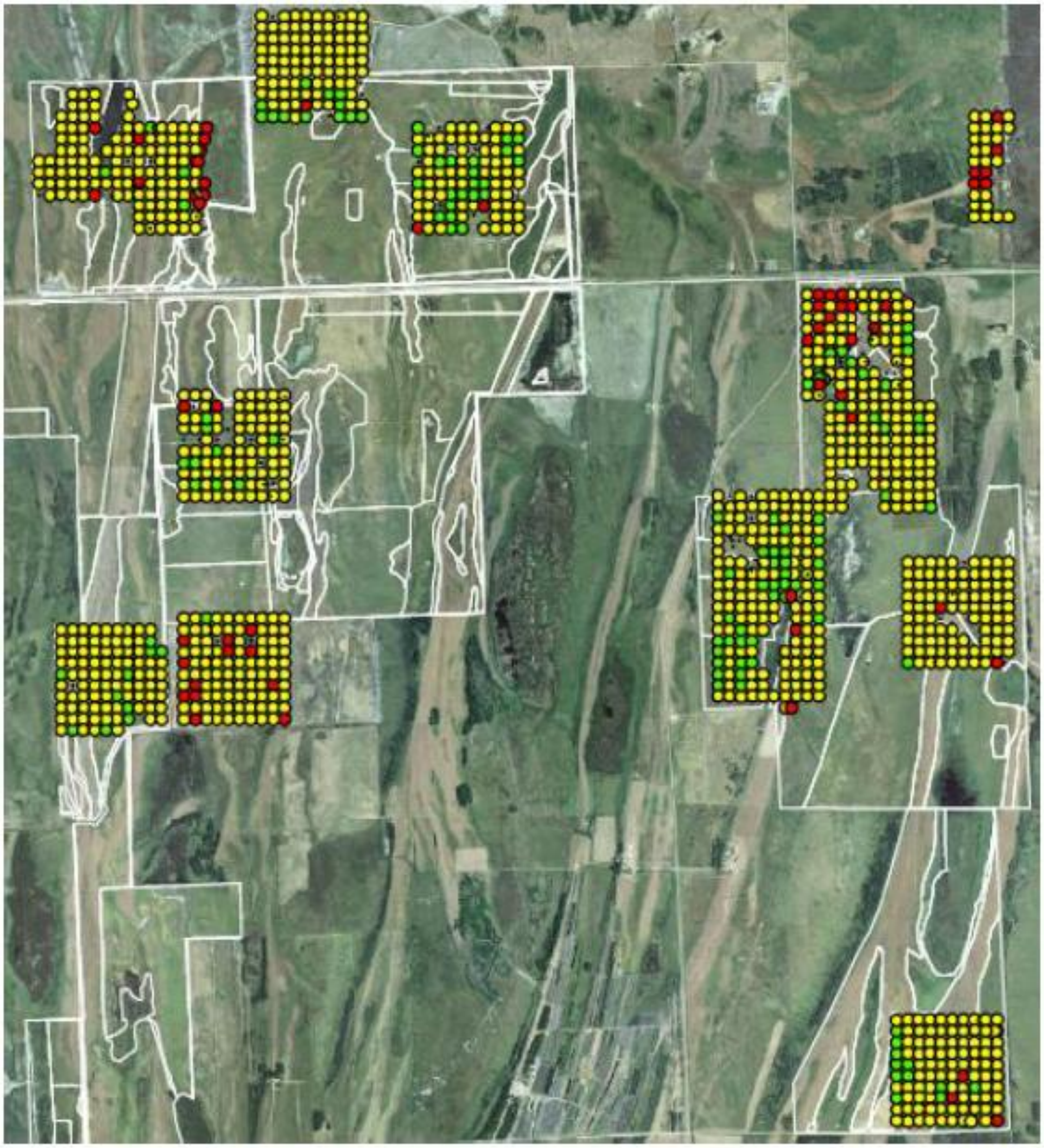

Figure 4. Example of status maps created for land managers from2008 monitoring data. Points assigned a community status of native are shown in green, yellow indicates mixed and red indicates weed communities. This same type of figure was created for graminoid and forb richness (high, medium, low).

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APPENDIX A: COMMUNITY CODE & DIVERSITY INDICATORS USED IN THE FIELD

Community Code

0) >80% bare
1) Dry Prairie
2) Mesic Prairie
3) Mixed Perennial Weed Upland
4) Mixed Annual Weed Upland
5) Wet Prairie
6) Wet Meadow
7) Mixed Perennial Weed Lowland
8) Mixed Annual Weed Lowland
9) Shallow Emergent Marsh
10) Fen
11) Mixed Perennial Weed Fen
12) Woody Veg.
13) Mudflat Annuals
14) Perennial Weed Upland
15) Perennial Weed Lowland
16) Open Water
17) Point of Interest

1,2,5,6 and 10 denote communities with >80% cover of native vegetation

3,4,7,8 and11 denote communities with 20-80% cover of native vegetation

13,14 and 15 denote communities with >80% cover of invasive vegetation

Diversity Indicators

Number of Essential Graminoids Present:

0-2 = L

3-4 = M

5+ = H

Number of Essential Forbs Present:

0-5 = L

6-10 = M

11+= H

APPENDIX B: ESSENTIAL SPECIES LISTS FOR NATIVE COMMUNITIES

Dry Prairie

FORBS

Achillea millefolium
Allium stellatum
Ambrosia psilostachya
Amorpha canescens
Anemone cylindrica
Anemone patens
Antennaria neglecta/neodioica
Antennaria plantaginifolia
Artemisia campestris/dracunculus
Artemisia frigida
Artemisia ludoviciana
Aster ericoides
Aster laevis
Aster sericeus
Astragalus adsurgens
Astragalus crassicarpus
Calylophus serrulatus
Campanula rotundifolia
Castilleja sessiliflora
Cerastium arvense
Chrysopsis villosa
Cirsium flodmanii
Comandra umbellata
Dalea candida
Dalea purpurea
Echinacea pallida/purpurea
Erigeron strigosus
Gaillardia aristata
Galium boreale
Geum triflorum
Helianthus pauciflorus
Heuchera richardsonii
Liatris aspera
Liatris punctata
Linum sulcatum
Lithospermum canescens
Lobelia spicata
Monarda fistulosa
Penstemon gracilis
Physalis virginiana
Polygala verticillata
Potentilla arguta
Prunus pumila
Psoralea esculentum
Rosa arkansana
Senecio plattensis/pauperculus
Solidago missouriensis
Solidago nemoralis
Solidago ptarmicoides
Solidago rigida
Symphoricarpos occidentalis/albus
Viola pedatifida

GRAMINOIDS

Andropogon gerardii
Bouteloua curtipendula
Bouteloua gracilis
Calamovilfa longifolia
Carex obtusata
Elymus trachycaulus
Koeleria pyramidata
Muhlenbergia cuspidata
Panicum wilcoxianium
Schizachyrium scoparium
Sorghastrum nutans
Sporobolus heterolepis
Stipa comata
Stipa spartea

Mesic Prairie

FORBS

Achillea millefolium
Agoseris glauca
Allium stellatum
Amorpha canescens
Amorpha nana
Anemone cylindrica
Apocynum sibiricum
Artemisia ludoviciana
Aster ericoides
Aster laevis
Campanula rotundifolia
Castilleja coccinea
Cirsium flodmanii
Comandra umbellata
Dalea candida
Dalea purpurea
Euthamia graminifolia
Fragaria virginiana
Galium boreale
Glycyrrhiza lepidota
Helianthus giganteus/grosseserratus
Helianthus maximiliani
Helianthus pauciflorus
Heliopsis helianthoides
Lathyrus palustris
Liatris aspera
Liatris ligulistylis
Liatris pycnostachya
Lilium philadelphicum
Lithospermum canescens
Lobelia spicata
Lysimachia quadriflora
Monarda fistulosa
Pedicularis canadensis
Phlox pilosa
Populus tremuloides
Potentilla arguta
Potentilla fruticosa
Prenanthes racemosa
Psoralea argophyllum
Pycnantheumum virginianum
Rosa arkansana
Rudbeckia hirta
Salix bebbiana
Senecio aureus/pseudaureus
Solidago canadensis
Solidago nemoralis
Solidago ptarmicoides
Solidago rigida
Thalictrum dasycarpum
Zigadenus elegans
Zizia aptera
Zizia aurea

GRAMINOIDS

Andropogon gerardii
Bromus kalmii
Calamagrostis stricta
Carex tetanica
Deschampsia cespitosa
Elymus trachycaulus
Koeleria pyramidata
Muhlenbergia glomerata
Muhlenbergia richardsonis
Panicum leibergii
Panicum virgatum
Schizachyrium scoparium
Sorghastrum nutans
Spartina pectinata
Sporobolus heterolepis
Stipa spartea

Wet Prairie

FORBS

Apocynum sibiricum
Asclepias incarnata
Aster ericoides
Aster lanceolatus
Aster novea-angliae
Aster umbellatus
Betula pumila
Cicuta maculata
Cirsium muticum
Comandra umbellata
Cornus sericea
Dalea pupurea
Equisetum laevigatum
Euthamia graminifolia
Fragaria virginiana
Galium boreale
Helenium autumnale
H. giganteus/grosseserratus/nuttallii
Helianthus maximiliani
Hypoxis hirsuta
Lathyrus palustris
Liatris ligulistylis
Liatris pycnostachya
Lobelia kalmii
Lycopus americanus
Lysimachia quadriflora
Pedicularis lanceolata
Plantago eriopoda
Potentilla anserina
Potentilla fruticosa
Pycnanthemum virginianum
Rosa woodsii
Rudbeckia hirta
Salix bebbiana
Salix discolor
Salix petiolaris
Senecio aureus/pseudaureus
Solidago canadensis
Solidago gigantea
Solidago nemoralis
Solidago ptarmicoides
Solidago riddellii
Solidago rigida
Thalictrum dasycarpum
Triglochin maritima
Viola nephrophylla
Zigadenus elegans
Zizia aptera
Zizia aurea

GRAMINOIDS

Andropogon gerardii
Calamagrostis stricta
Carex buxbaumii
Carex pellita
Carex praegracilis
Carex sartwellii
Carex tetanica
Deschampsia cespitosa
Distichlis spicata
Eleocharis compressa
Elymus trachycaulus
Juncus arcticus
Muhlenbergia glomerata
Muhlenbergia richardsonis
Panicum virgatum
Schizachyrium scoparium
Sorghastrum nutans
Spartina pectinata
Sporobolus heterolepis

Wet Meadow

FORBS

Apocynum sibiricum
Asclepias incarnata
Aster borealis
Aster lanceolatus
Aster puniceus
Aster umbellatus
Campanula aparinoides
Cicuta maculata
Cornus sericea
Epilobium leptophyllum/palustre/strictum
Equisetum arvense
Eupatorium maculatum
Eupatorium perfoliatum
Euthamia graminifolia
Helenium autumnale
Helianthus gig./gross./nuttallii
Helianthus maximiliani
Lathyrus palustris
Lathyrus venosus
Lobelia kalmii
Lycopus americanus
Lycopus asper
Lycopus uniflorus
Lysimachia quadriflora
Lysimachia thyrsiflora
Mentha arvensis
Pedicularis lanceolata
Polygonum amphibium
Potentilla anserina
Pycnanthemum virginianum
Salix bebbiana
Salix discolor
Salix exigua
Salix petiolaris
Senecio aureus/pseudaureus
Sium suave
Smilacina racemosa
Solidago canadensis
Solidago gigantea
Solidago riddellii
Spiraea alba
Stachys palustris
Teucrium canadense
Thalictrum dasycarpum
Triglochin maritima
Viola nephrophylla/spp.
Zizia aurea

GRAMINOIDS

Bromus ciliatus
Calamagrostis canadensis
Calamagrostis stricta
Carex atherodes
Carex buxbaumii
Carex emoryi
Carex haydenii
Carex pellita
Carex praegracilis
Carex rostrata
Carex sartwellii
Carex stricta
Carex tetanica
Eleocharis compressa
Elocharis palustris
Glyceria striata
Hierochloe odorata
Hordeum jubatum
Juncus arcticus
Muhlenbergia glomerata
Scirpus acutus/heterochaetus
Scirpus atrovirens/pallidus
Spartina pectinata