Comparing Vegetation and Soils of Remnant and Restored Wetland Prairies in the Northern Willamette Valley

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Abstract

Most of the native wetland prairies once found in the Willamette Valley of Oregon, USA have been converted to agriculture, developed, or altered by disturbance and cessation of burning, especially in the northern portion of the valley. Mitigation efforts by Portland Metro and the NRCS have resulted in restoration of several wetland prairies, and the need for research to help assess restoration success. Here, data on vegetation and soils from three remnant wetland prairies and three restored wetland prairies in the northern Willamette Valley were analyzed to investigate whether differences among sites are related to site characteristics or management. Vascular plant species presence and percent cover data were collected from three 10 m x 10 m plots randomly located within study sites. Soil samples were collected adjacent to these plots and from nearby agricultural sites and analyzed for organic matter, moisture content, pH, and soil texture. Multivariate ordination techniques and ANOVA were used to assess differences among sites. Native species cover was higher in restorations than remnants, although remnant and restored sites did not differ in native species richness. However, NMS ordination distinguished restorations from remnants. Species such as *Deschampsia cespitosa*, *Carex densa*, *Juncus tenuis* and *Holcus lanatus* were associated with remnants, whereas *Anthemis cotula*, *Agrostis exarata*, *Plagiobothrys scouleri* and *Veronica perigrina* were associated with restorations. Soil moisture and organic matter are positively correlated with remnant status, while management attributes such as herbicide use, mowing, and cultivation of “clean crops” prior to restoration are correlated with vegetation assemblages of restorations. While some restoration goals are being met within a decade of restoration, plant communities in restorations differ from those of wetland prairie remnants.

Introduction

In their seminal paper on restoration ecology, Hobbs and Norton (1996) present a conceptual framework arguing for an approach to restoration that fosters planning, restoration, and evaluation of restoration outcomes at the landscape scale. They call for conservation planning not only at the site level but also at a regional scale and setting specific goals to enhance the conservation value of productive landscapes, such as increasing habitat overall, providing buffer zones and linking remaining fragments. Elements integral to such an approach include an improved understanding of the relative contribution made by components of working landscapes to the attainment of watershed restoration goals. Such landscape components often include agricultural fields as well as restorations and remnants of the natural systems that we are striving to restore. Because they support a unique set of plant species and provide important habitat including wintering sites for migratory waterbirds (Taft and Haig 2010), wetland prairies are an important part of a conservation network, and serve a different role in conservation of biodiversity at a landscape level than forest or savanna (Alverson 2005).

Here we present results of a study comparing native plant diversity, soil moisture and organic matter in agricultural fields, wetland prairie restorations, and wetland prairie remnants in an effort to provide information that could inform landscape-level planning for restoration (Metro 2000, Oregon Division of State Lands 2011).

Native wetland prairies of the Willamette Valley are among the rarest of Oregon's plant communities (Clark and Wilson 2001, Christy and Alverson 2011). These prairies are characterized by the presence of tufted hairgrass (*Deschampsia cespitosa* (L.) P. Beauv.), associated native grasses such as California oatgrass (*Danthonia californica* Bol) and native bentgrass (*Agrostis* L. spp..), as well as sedges (*Carex* spp.), rushes (*Juncus* spp.), and a diverse array of native forbs. Their soils have a high clay content and accumulatedorganic matter (Soil Survey Staff NRCS 2014). These poorly drained soils retain water well into the growing season, though by mid-July most wetland prairies are dry at the surface, a feature which makes it possible for managers to use fire for control of woody vegetation. The literature describes the historic use of fire by native peoples to keep prairies open and changes in land management practices since the 1850s (Johannessen et al. 1971, Titus et al. 1996). In the last 150 years native wetland prairies have experienced high rates of loss and conversion (Hulse et al. 2002). Presettlement extent of the vegetation designated as prairie by GLO surveys was about 31.4% of the Willamette Valley, and based on soil characteristics, over 137,000 hectares of the land area designated as prairie was wet prairie (Christy and Alvorsen 2011). Today, only about 2% (about 2047 ha) of these wet prairies remain, and most of those remaining occur in the southern portion of the valley. Many have been altered by surrounding development, changes in hydrology, natural succession to shrub lands and forests, and invasion by non-native species (Pendergrass et al. 1997, Taft and Haig 2003). While some efforts at mitigating loss have been successful (Wold et al. 2011), many have not. In this paper, we compare the most intact remaining northern Willamette Valley remnant wetland prairies to neighboring restored wetland prairies based on plant community composition and soil characteristics to assess the relative success of wetland prairie restorations in this area. In addition, we compare the soils of wetland prairie restorations and remnants to those of nearby agricultural sites. Numerous studies have shown that cultivation can result in loss of organic matter from soils (Schlesinger 1985, Reicosky 1997) , and that organic matter concentrations can influence moisture holding capacity, providing important ecosystem services (Costanza et al. 1997, Zedler and Kercher 2005).

While our remnant study sites are the best remaining examples of wetland prairies on public land and accessible for study (K. Pendergrass, personal communication), it should be noted that they are not high quality reference sites that should set the standard for future restoration management (E. Alverson, personal communication).

Willamette Valley wetland prairies support a high diversity of native vascular plants, and provide habitat for many native animal species. A rich body of research has been conducted on wetland prairies in the southern Willamette Valley around Corvallis and Eugene, where some of the most extensive areas of native wetland prairies remain, and many additional sites have been restored (Pendergrass 1995, Clark and Wilson 2001, Pfeifer-Meister et al. 2012a, 2012b). Studies conducted in the southern Willamette Valley have demonstrated that managed remnant prairie can be high in native plant diversity and native plant cover (Pendergrass et al. 1997, Taylor 1999, Wilson 2002, Norman 2008) and that management practices and techniques used to establish restored sites can have substantial influence on native plant species richness and cover abundance (Wold 2011, Pfeiffer-Meister 2012b, Highland et al. in press). In comparison, little has been published on the few remaining wetland prairies in the northern portion of the Willamette Valley. Very few native wetland prairie sites remain in the northern Willamette Valley in the Portland (OR) - Vancouver (WA) region, and the sites that do remain are relatively small. Recent work by Highland et al. (in press) found differences between wetland prairie communities in the southern and mid-Willamette Valley regions, indicating the importance of research on the vegetation of wetland prairies across regions. Research on the wetland prairies of the northern Willamette Valley is thus important in order to provide information on remaining wetland prairie sites in the region, and guide management efforts to increase their native cover and diversity.. In addition, the data collected on native plant diversity and soil attributes such as soil moisture retention, organic matter and carbon content points to the need for more extensive analyses and comparisons of soils in different land use in order to begin to quantify the potential ecosystem services these wetlands could provide.

This paper compares soils and vegetation in three remnant and three restored wetland prairies in the northern portion of the Willamette Valley Ecoregion of Oregon and Washington (Thorston et al. 2003). We ask:

- Does the vegetation of remnant and restored wetland prairies differ with respect to native species richness and abundance?
- What site characteristics, including soil texture and composition, hydrologic regimes and management practices, are associated with increased native species richness and increased native species abundance?, and
- How do soils differ among sites? and are there significant differences in soil attributes between the agricultural sites, restorations, and wetland prairie remnants in our study?

We hypothesized that native prairie remnants in our study would have greater richness and percent cover of native species than restored wetland prairies, because remnants retain the microtopography characteristic of native wetland prairies (Moser et al. 2007), have wellestablished native perennial plant species that resist weed invasion, and because soil and hydrologic conditions that promote growth of native wetland species are present in remnants and only developing in restorations. We considered as alternative hypotheses the possibility that no difference would be detected, or that restorations could have higher native species cover than remnants owing to the high investment of effort in establishing native species and intensive management to control introduced species and promote growth and abundance of native species. Restorations could also differ from remnants simply because they are at an earlier stage with respect to establishment of vegetation and soils characteristic of wetland prairies.

We hypothesized that the agricultural sites would have lower levels of organic matter owing to tillage compared to wetland prairie restorations and remnants (Schlesinger 1985, Reicosky et al 1995, Boman et al. 1996), and that soils from restorations that have been cropped and tilled in the recent past would have less organic matter than soils of remnants.

Methods

STUDY SITE SELECTION

Study sites were selected in consultation with agency professionals of the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS), The Nature Conservancy, Wetlands Conservancy, and regional experts to represent the best known remnants of wetland prairie vegetation in the northern Willamette Valley and restored sites comparable to the nearby remnants. In order to meet our selection criteria, remnant sites had to have at least 25% cover of tufted hairgrass and less than 25% cover of reed canarygrass (*Phalaris arundinacea* L.), which was determined by visual estimation on site during reconnaissance visits; silty clay loam hydric soils (identified from the web soil survey (Soil Survey Staff, 2012); and elevation below 100 m. Only three sites met these criteria and we used all three. Restored sites were selected to be similar in time since restoration (3 to 8 years), and land management objectives (high native plant diversity and cover). Also considered was geographic proximity to remnant sites, and similar soil type and elevation to remnant sites. The contract documents for the restorations state that restoration goals were to restore previously drained and altered wetlands within the flood plain areas of the Tualatin River System in order to improve surface water quality and ground water recharge, and to provide habitat for waterfowl, terrestrial amphibians, western pond turtle and other native species. Agricultural sites were required to be in crop production (two in grass seed and one in corn) at the time of sampling, similar in soil type, geographic location and elevation to the remnant and restored sites, with landowners willing to allow access. One agricultural site was chosen south of the Portland area because of the site's prior status as a wetland, landowner willingness to particpate, and to provide background data for this site which has since been restored to wetland prairie . Table 1 lists site attributes such as site size, location, elevation, soil type, and management practices. More detailed descriptions of sites and methods used can be found in Taylor (2011).

SAMPLING DESIGN

VEGETATION - At all sites, three 10 m x 10 m (100 $m^{2)}$ plots were located using random coordinates within areas designated as tufted hairgrass prairie. At the agricultural sites, random distances were marked along the field margin, then three 100 m^2 plots were placed 5 m into the field, to minimize crop disturbance.

Data on species presence/absence and visually estimated, absolute percent cover were recorded for all plots at each site. Visual percent covers were recorded to the nearest 1%. Plants that were not identified to species in the field were collected, pressed, and identified later in the Botany Lab at Oregon State University. Specimens lacking flower or fruit were identified only to genus. All sites were visited between June 16 and August 28, 2009 with the remnant and restored sites visited from middle June to late July. Data collection was timed based on the onset of dryness in each site and maximum peak bloom Plots were revisited in April 2010 to look for spring ephemerals such as Bradshaw's lomatium *(Lomatium bradshawii* (Rose ex Mathias) Mathias & Constance) and shortspur seablush *(Plectritis congesta* (Lindl.) DC). Data for species found in our plots in April 2010 were added to the data collected in 2009.

The USDA Natural Resources Conservation Service Plants Database (USDA NRCS 2011) was used as the authority for nomenclature and for traits of interest such as native status (native or introduced), duration (perennial or annual) and growth habit (graminoid or forb), except in the case of *Phalaris arundinacea*, a species that is native to parts of North America but is introduced in western Oregon.

SOILS - Soil samples were collected at four separate sampling periods; September 2009, November 2009, February 2010, and April 2010. Five soil cores, approximately 15 cm deep, were collected between 1 and 10 m from the outside margin of each 100 m^2 plot and bulked. . Bulk samples were placed in a cooler, and upon return to the lab analyzed for soil pH, percent moisture (gravimetric water content method), percent organic matter (loss on ignition method) and soil texture (% sand, % silt, % clay). Data on soil moisture and organic matter percent presented here are for samples collected in April 2010. Environmental characteristics of the site (such as presence or absence of standing water above the soil surface in each 100 m^2 plot) were noted at time of soil sample collection. .

MANAGEMENT – All sites- remnants as well as restorations -are managed to varying degrees. Data on site management were obtained from management documents and verified and augmented through interviews with agency staff Management practices included in the statistical analyses were mowing, fire, and herbicide applications; we also include the practice (used only in restorations) of sowing "clean crops" prior to restoring a site to help reduce presence of weeds, and time since restoration. Restorations tend to be managed more extensively than remnants, while management in remnantsfocuses on control of weeds and woody vegetation.

STATISTICAL ANALYSIS - Univariate analysis of variance (ANOVA) was used to investigate whether restored and remnant sites were different based on percent cover or richness of native species, and to test for differences between soil qualities of the restored, remnant and agricultural sites. Data used in the ANOVA were averages for the three plots at each site.

Ordination using Non-metric Multidimensional Scaling (NMS) (Kruskal 1964) with the software program PC-ORD (McCune and Mefford 2006) was performed to explore relationships among sites with respect to vegetation, soils, and environmental characteristics. Matrices used for data analysis using PC-ORD include:

- The species (main) matrix (18 plots x 117 species) with percent cover of all plant species for all 100 m^2 plots from remnant and restored sites
- The environmental (second) matrix (18 plots x 20 environmental/management categories) contained quantitative and categorical data for all plots, such as whether the

plot was at a remnant or restored site, native species richness, percent cover of native, perennial, and graminoid species, soil pH, organic matter percent, moisture percent, soil texture (percent sand, silt, and clay), whether plot was inundated in November, February, April, and/ or July, and use of specific management practices at a site such as burning, mowing, site preparation with growth of “clean” crops, yearly application of chemicals, and number of years in management.

- The traits (second) matrix (3 traits x 117 species) contained categorical data on native status (native or introduced), growth form (graminoid or forb), and life-cycle duration (i.e., annual or perennial) for all species

Vegetation data in the main matrix were relativized by species maximum and an arcsine square root transformation was used to improve normality (Sokal and Rohlf 1995, McCune and Grace 2002). To evaluate the effect of environmental variables in ordination species space, an enhanced environmental matrix was used with the main matrix for the NMS ordination. The enhanced matrix was generated by multiplication of the main matrix by the traits matrix and appending the resulting trait values matrix to the environmental matrix as three extra columns.

A multi-response permutation procedure (MRPP) with Sørensen distance was used to compare effect size of differences among site types in percent cover of native species. Presence or absence of remnant prairie was the grouping variable. Indicator species analysis (Dufrêne and Legendre 1997) was used to evaluate species separation between sites types, or with respect to environmental characteristics such as flooding frequency and management practices. Simpson’s index of diversity was also calculated for the data from the 100 m^2 plots in remnants and restorations.

Results

SOILS

Average soil organic matter content was marginally higher is remnants than restorations or agricultural sites (Table 2, P =0.092). Gotter Prairie South, which is the only remnant that is mowed annually, has the lowest percent organic matter of the three remnant sites at 6.8%, similar to that of the restored sites (Table 2). Soil moisture differed significantly among site types. Average percent moisture was significantly higher in remnants than in restorations (P=0.003). Soil moisture in agricultural sites was similar to that of restorations. No significant differences in pH were detected among site types (P=0.986), and sites were all similar with respect to soil texture.

VEGETATION

Most sites had the greatest proportion of cover in perennial species, and higher cover of native species than introduced species (Table 3). Exceptions were the Lovejoy restoration the Green Mountain remnant, for both sites cover of native species was similar to cover of introduced species. Plots in restorations had 23% higher native percent cover than those in remnant prairies (P =0.089).

A total of 117 species were recorded as present in all plots combined; 55 were native and 62 were introduced (Table 4). No significant difference in native species richness was found among sites (P=0.949). A total of 44 species was unique to remnants; 22 native and 22 introduced, whereas 24 species were found in both remnant and restored sites; 18 native and 6 introduced. Plots in restored sites contained 49 unique species; 15 native and 34 introduced. . The Green Mountain remnant has the highest number of native species and greatest perennial species richness, followed by the Gotter Prairie North restoration;the Lovejoy restoration has the highest number of introduced species (Table 4). Remnants tend to have more perennial than annual species, whereas restorations have a similar number of perennial and annual species. Sites with the highest species richness also have the greatest number of forb species. All species found at each site and their status as 'native' or 'introduced' are listed in Table 5..

The NMS ordination separated plots from different site types into different regions in species-space based on their similarities in species composition (Figure 1). The joint plot shows the relationship between the environmental variables and ordination scores; the angle and length of the line indicates the direction and strength of the relationship (McCune and Grace 2002). Remnant prairies are positively associated with Axis 1, and restored prairies are negatively associated with Axis 1. Percent soil moisture, percent organic matter, flooding in February and April are positively associated with Axis 1, whereas variables such as yearly mowing and use of chemicals, are negatively associated with Axis 1. Native species richness and percent cover of native species were positively correlated with Axis 2.

Results of MRPP comparison between remnant and restored prairie with N=6 showed a difference between groups at the 10% level (P=0.065) and small effect size (A=0.032) indicating some differences in species compositions between prairie types but little similarity in species compositions within prairie type. Values of Simpson's index of diversity (calculated using data for native plants only) ranged from 0.13 to 0.88, with average values of 0.??, 0.??, and 0.?? at

Hutchinson, Lovejoy and Gotter Prairie North restorations, respectively, and values of 0.88, 0.?? and 0.13 at Green Mountain, Knez, and Gotter Prairie South remnants, respectively.

Indicator species analysis identified many species with high indicator values (IVs) in remnant prairies. Velvetgrass (*Holcus lanatus* L.), tufted hairgrass (*D. cespitosa),* dense sedge (*Carex densa* (L.H. Bailey) L.H. Bailey), and poverty rush (*Juncus tenuis* Willd.) had the highest values as indicators of remnant status. Species with high IVs in restorations were stinking chamomile (*Anthemis cotula* L.), spike bentgrass (*Agrostis exarata* Trin.), Scouler's popcornflower (*Plagiobothrys scouleri* (Hook. & Arn.) I.M. Johnst.), and neckweed (*Veronica peregrina* L.). The species with highest IVs in plots associated with flooding at the different months of the year were as follows:

- November flooding - Queen Anne's lace (*Daucus carota* L.), annual bluegrass (*Poa annua* L.), and *Anthemis cotula.*
- February flooding – *Carex densa* and one-sided sedge (*Carex unilateralis* Mack.)
- April flooding – *Deschampsia. cespitosa*
- July flooding- bull thistle (*Cirsium vulgare* (Savi) Ten.), *Carex densa*, bay forget-me-not (*Myosotis laxa* Lehm.), and common rush (*Juncus effusus* L).

One species, small camas *(Camassia quamash* (Pursh) Greene), had a high IV associated with the use of fire for management.

Discussion

Agricultural fields and wetlands are common landscape elements in rural temperate regions worldwide. Comparison of the ecosystem services provided by agricultural fields compared to restored wetlands can assist efforts to evaluate the level of ecosystem services provided by restoration in rural landscapes, and help inform efforts to develop ecosystem services markets (de Groot et al. 2010). In addition, characterization of the vegetation occurring in native wetland prairie remnants can help inform efforts to restore these native plant communitiesand highlight the need for management of remnants to enhance the quality of these relatively degraded sites..

Agricultural fields, remnants and restorations in our study differed with respect to soil characteristics (Table 2). Soil organic matter and moisture content were positively correlated, and were highest in remnants, lower in restored sites, and lowest in the agricultural sites. Differences in organic matter content between remnant and restored sites might be even greater if the Gotter Prairie South remnant had not been hayed for many years. Our data indicate that soils of remnant wetland prairies and newly restored prairies are storing more carbon than soils of agricultural fields, and that cropping, mowing and haying affect soil organic matter content. Thus, restoring agricultural fields to wetland prairie could help sequester carbon, though more research is needed to better quantify this relationship, and to investigate the effect of management with fire as well as mowing on soil organic matter, to explore potential trade-offs between management for native species diversity and management for increasing oganic matter content of soils.

We focus our discussion of differences in vegetation on the comparison of remnant and restored sites, since the differences in vegetation between agricultural sites and the wetland prairie remnant and restored sites are obvious, and result from the intensive management of the agricultural sites for crop production (grass seed or corn). Differences between remnants and restorations with respect to vegetation are more subtle than differences in soils between site types. While ordination and MRPP clearly distinguish remnants from restorations based on the community composition of the vegetation, there is overlap among remnant and restored sites with respect to percent cover of native species, native species richness, and values of diversity indices. The three remnants and three restorations are not significantly differerent with respect to native cover at the 5% level of significance (P=0.089, N=6), and no significant difference was found in native species richness between remnant and restored prairies (P=0.949, N=6). These data suggest that by 4-8 years following restoration, managers have been able to restore native plant diversity in former agricultural areas that is similar to the best intact remnant prairies in the Northern Willamette Valley ecoregion. However, it is important to note that none of the wetland prairie remnants in our study are "pristine". All have been impacted by human activities, particularly historical livestock grazing , but also annual mowing to prevent invasion by woody species (Gotter Prairie South), urban development on adjacent property (Knez) or unsuccessful historic efforts at ditching and draining (Green Mountain) within the wetlands themselves. It is highly likely that the pre-settlement wetland prairie vegetation of these remnants had much higher native forb cover and richness than occur today. Despite their relatively degraded condition, however, we found that a set of more than 20 native species are unique to remnant prairies, whereas species composition of restored wetland prairies generally reflects the diversity of propagules used in establishing native vegetation.

With respect to our initial research questions, our data are most consistent with the hypothesis that native plant cover is higher in restorations than in remnants owing to intensive management efforts to reduce introduced species cover. The relatively high native cover in restored prairie wetlands suggests that management practices to limit introduced species have been effective at the sites we sampled, at least in the short term, however, the native species richness tends to be higher in the remnant sites than in restorations, which may reflect . In remnant wetland prairies, management of introduced, invasive species is an important concern. Introduced species in remnant wetland prairie habitats may result from a lack of management actions; time intervals between management actions conducted at remnant prairies in this project varied from 3 to 13 years. Patches of introduced species, including the invasive reedcanarygrass, were seen in all remnants and were mostly absent in restorations; except for the Lovejoy restoration. Increasing native cover and reducing invasive species cover remains a challenge at remnant wet praire wetlands and in the case of this study, remnants would not make ideal reference sites for restorations.

It is worth noting, however, that of 44 species found only at the remnant prairies, 50% were native, whereas only 30% of the unique species in restored prairies were native. Higher native species cover within remnant prairies is associated with microtopographic relief (Moser et al. 2007). Annual mowing and haying at the Gotter Prairie South remnant may be decreasing native species richness by suppressing bunchgrass expansion and destroying the microtopography associated with high native richness at the other remnant sites.

Native species richness in the restorations we sampled reflects the intensive efforts by managers to restore native species diversity. For example, the Gotter Prairie North restoration lies at the center of the ordination, closer to remnant sites than restorations. It appears that this site is becoming more like the remnants in species composition and in soil qualities. This tendency could be attributed to management for a longer period of time (8 years) compared to 3 and 4 years at the other restored sites. In addition, Gotter Prairie North has been consistently supplemented with propagules of native species, and is the only restoration in which wetland prairie microtopography is developing.

In summary, data from analysis of soils and vegetation at the sites we studied in the northern Willamette Valley indicate that native species abundance and richness comparable to that of the remaining remnant wet prairie sites in the region can be achieved at restored sites. Management practices such as mowing and haying or frequent burning were correlated with decreased organic matter content (and thus carbon storage) in soils at the sites we studied. Management practices may influence organic matter content of soils in remnants and restorations, and those differences, in turn, may influence soil moisture content and species composition of vegetation at the site.

While the remnant sites we studied are the best available sites remaining in the northern Willamette Valley, comparison of the species richness found in these sites to indicates that these remnant sites are not high-quality sites. All but one remnant (Green Mountain) and one restoration (Gotter Prairie South) score relatively low on native species richness as a key indicator (E. Alverson, personal communication). As a result, we caution that these remnant sites should not be used as the standard for restorations in the region, and we recommend increased efforts to increase native plant diversity at these sites.

The levels of native species richness that have been achieved at some intensively managed restorations (e.g., Gotter Prairie North, Table 4) indicate that time and effort expended on site management can contribute to richness and abundance of native species,. However, restoration alone is not sufficient to preserving existing native plant diversity in these wetlands. Because the highest numbers of native species unique to Willamette Valley wetland prairies are found only in remnants, it is important to conserve these rare sites. Also, because some species are unique to remnant sites, approaches which include both preservation and restoration will lead to the greatest native species diversity at the landscape scale (Hobbs and Norton 1996). Synergistic effects on landscape-level diversity could be achieved by enhancing native diversity at remnant sites and using restorations to link wet prairie remnants to other wetland and native vegetation types in the landscape (such as riparian forest or upland prairie and savanna). The relative success of wetland prairie restorations in establishing native cover, species richness, and diversity indicates that restoration can assist in the preservation of native species. Restorations can also help provide important ecosystem services such as carbon sequestration, soil moisture retention, and habitat for native wildlife species (Zedler and Kercher 2005). However, ecosystem response to various management practices may result in some tradeoffs among ecosystem sevices achieved. Further research to help quantify impacts of management on soils as well as native vegetation and wildlife, and the potential tradeoffs involved in achievement of different restoration goals will be an important next step in development of landscape-level conservation plans.

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Tables

Table 1. Study site name, site type (restoration, remnant, or agricultural), size, location, elevation and soil type

Site name	Type	Size (ha)	Lat. ° N, Long. °W	Elev. (m)	Soil type
Green Mountain	remnant	4.5	45.64299, 122.46092	58	Cove silty clay loam
Knez	remnant	4.0	45.43035, 122.75963	50	Verboort silty clay loam
Gotter Prairie S.	remnant	10.1	45.40441, 122.93529	35	Wapato silty clay loam
Hutchinson	restored	37.2	45.46940, 123.12998	51	McBee & Wapato silty clay loam
Lovejoy	restored	29.1	45.48526, 123.11220	50	McBee & Wapato silty clay loam
Gotter Prairie N.	restored	8.1	45.40742, 122.93274	40	Wapato & Cove silty clay loam
Zurcher	agriculture	80.9	45.50037, 123.10247	58	McBee silty clay loam
Westbrook	agriculture	80.9	44.96873, 123.22648	61	Bashaw silty clay loam & Woodburn silt loam
Gotter Prairie Ag	agriculture	~ 6.1	45.40184, 122.93258	61	McBee silty clay loam

Table 2. Comparison of soil characteristics from composite samples collected at remnant, restored and agricultural sites, based on percent organic matter (OM), moisture (measured as gravimetric water content), pH, and texture classes for soils collected in April 2010 with average and standard deviation (in parentheses) for each type of site. Soil moisture content at remnant sites differs significantly from that of soils at restored and agricultural sites; significant differences are denoted by lower case letters a and b.

Site type	Site Names	OM %	Moisture %	pH	Texture class	Soil Series
Remnant	Gotter Pr. S.	6.8	33.0	5.3	silty clay	Wapato
Remnant	Green Mountain	13.0	36.0	5.4	clay	Cove
Remnant	Knez	9.1	39.3	6.8	clay	Verboort
AVERAGE and ST. DEV.		9.6 (3.1)	36.1[a] (3.6)	5.8 (0.8)	na	na
Restored	Hutchinson	6.9	25.1	6.2	clay	McBee
Restored	Lovejoy	6.5	23.6	5.8	clay	McBee
Restored	Gotter Pr. N.	6.4	26.5	5.5	clay	Wapato
AVERAGE		6.6 (0.3)	25.0[b] (1.6)	5.8 (0.4)	na	na

Agriculture	Zurcher	6.4	22.3	5.9	clay	McBee
Agriculture	Westbrook	3.7	25.6	6.0	silty clay loam	Bashaw
Agriculture	Gotter Pr. Ag	6.0	18.1	5.4	silty clay	McBee
AVERAGE		5.3 (1.5)	22.0 [b] (4.3)	5.8 (0.3)	na	na

Table 3. Percent cover of bare ground and vegetated cover for plots in remnant and restored prairies, and percent cover (reported as the average of the three plots at each site, with standard deviations in parentheses) of species exhibiting the following plant traits: Native or Introduced (N/I), Perennial or Annual (P/A), and Graminoid or Forb (G/F). Vegetation sampling occurred between 6/28/2009 and 8/27/2009, and sites were revisited April 24, 2010 to collect data on the presence of spring ephemeral species. The sum of cover percent across categories can be greater than 100% owing to overlap of species canopies, and less than 100% when status of species as native or introduced is unknown, or when sites have high percent cover of bare ground.

Site name	Bare	Vegetated	N/I	P/A	G/F	
Remnants						
Gotter Pr. S.	9	95	83/ 12	95/ 0	93/ 2	
Green Mtn.	7	115	52/ 56	94/ 21	70/ 43	
Knez	4	109	76/ 25	96/ 10	94/ 15	
AVERAGE	7	107 (10)	70 (16)/ 31(23)	31 (23)/ 95(1)	10 (11)/ 86 (14)	/ 20 (21)
Restorations						
Hutchinson	17	128	101/ 26	101/ 27	108/ 21	
Lovejoy	8	166	82/ 81	44/ 119	44/ 123	

Gotter Pr. N.	4	117	102/	10	98/ 17	91		25		
AVERAGE	10	137 (26)	95 (11)/ 39 (37)		/ 81 (32)		54 (56)		81 (33)	56 (58)

Table 4. Average total species richness (standard deviations in parentheses) at each site (S) and average number of plant species in plots at these sites exhibiting the following traits: Native or Introduced (N/I), Perennial or Annual (P/A), and Graminoid or Forb (G/F) in each of the remnant and restored prairies studied. Data are not shown for species whose status as native or introduced is unknown. Species richness data for agricultural sites are not shown.

Site name	S	N/I	P/A		G/F	
Remnants						
Gotter Prairie S.	13	11/2	12/1		9/5	
Green Mountain	48	26/	18		34/14	16/30
Knez	23	13/	9		17/6	13/12
AVERAGE	28 (18)	17 (8) /10 (8)		21 (12)/7 (7)		13 (4)/16 (13)
Restorations						
Hutchinson	18	8/9	9/9		7/11	

Lovejoy	40	14/25	21/18	11/31	
Gotter Prairie N.	35	23/10	21/14	12/26	
AVERAGE	31 (12)	15 (8) /15 (9)	17 (7)/	14 (5)	10 (3)23 (10)

Figure Captions

Figure 1. NMS ordination of remnant (GM, GPS, KN) and restored prairies (GPN, HR, LJ) in species-space, with an overlaid joint plot showing strongest correlations with species traits and site attributes. The remnant sites (forming an envelope at right-hand side of the figure) are associated with higher % soil moisture and organic matter as well as flooding in February and April, whereas the restored sites (left side of figure) are negatively associated with soil moisture and organic matter, and positively associated with November flooding and managment practices such as clean crops, mowing, and chemical use. A list of these traits and attributes (and abbreviations used in the figure) follows: quantitative attributes of plots such as percent cover of native species (wt. native cover), native species richness (native sp. richness), % soil moisture, % soil organic matter, % silt, % sand, % clay, and soil pH; categorical attributes of plots (such as whether or not plot was flooded during site visits in a specific month (i.e., whether site was flooded in November (november H2O), February (february H2O), April (april H2O) and July (july H2O)); and categorical attributes describing whether a specific management practice was used at the sites (i.e., use of clean crops (clean crops), yearly application of chemicals (yrly-chemicals), mowing (yrly-mow), and years in management (yrs managed). Individual species are represented by a dot (•) within the ordination. The final stress of a 2-dimensional solution was 11.795; final instability was 0.0 and the Monte Carlo randomization test supported NMS in extracting stronger axes than expected by chance with P=0.020 for all axes. The proportion of variance represented by Axes 1 and 2 were calculated from r^2 values of 0.382 and 0.653, respectively.