AN ABSTRACT OF THE THESIS OF

Sara M. Taylor for the degree of Master of Science in Environmental Science presented on June 1, 2011.
Title: Comparing Vegetation and Soils of Remnant and Restored Prairie Wetlands in the Northern Willamette Valley

Abstract approved:

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Native prairies of the Willamette Valley are considered among the rarest of Oregon's ecosystems (Clark and Wilson, 2001). As a result of agriculture conversion, urban development and cessation of native burning, Willamette Valley prairies have become highly fragmented and invaded by non-native species, leaving little room for native plant diversity. Even though wetland prairie conservation and restoration has been a priority for many government agencies there is a need for research on what restoration techniques and management are necessary for increasing native species richness and abundance in remnant and restored wet prairie sites.

In this research project, two studies were conducted. In the first study, data were collected on species presence and abundance from three $100m^2$ randomized plots within three remnant wet prairies (Green Mountain, Gotter Prairie South, Knez) and three restored wet prairies (Hutchinson, Gotter Prairie North, Lovejoy) to answer the following research question, 'Are there differences between remnant and restored prairie plant communities with respect to the diversity and abundance of native species?' Analysis of variance and multivariate ordination techniques were used to assess the ecological differences between uncultivated, minimally-managed remnant wet prairies and newly-restored, highly managed wet prairies. Data on soils collected from agricultural sites (Westbrook, Zurcher, Gotter Prairie Ag), as well as the remnant

and restored wet prairies mentioned above, were also used to compare soil quality and processes with the remnant and restored wetlands.

Restored wet prairie had 23% higher native species cover than remnant prairie (p-value=0.089, N=6). Remnant and restored sites did not differ in native species richness (p-value=0.949, N=6). The relatively high per cent cover of native species at restored sites, (significant at the 10% level), suggests that land managers have successfully restored agricultural properties with an abundance of native species. The lack of significant difference in native species richness between remnant and restored sites also suggests that land managers have also been able to restore native plant diversity into former agricultural properties equivalent to some of the best intact remnant prairies within the Northern Willamette Valley in a short period of time (8 years or less). However, a non-metric scaling (NMS) ordination of the species matrix separated the remnant sites from the restored sites, suggesting that community composition distinguishes restored sites from remnants. The NMS results, which include environmental data in the analysis, also suggest that there is a positive correlation of percent soil moisture and percent soil organic matter associated with the remnant prairies and a positive correlation of management practices such as yearly chemical use, mowing, and clean crops, associated with the restored prairies. The location of Gotter Prairie North restoration within the ordination, between the remnant and restored sites, suggests an intermediate plant composition and soil quality. This could be attributed to intensive weed suppression and soil organic matter build up over time (8 years) in comparison to younger restored sites (3 and 4 years). Indicator species analysis identified many species with high indicator values (IVs) in the remnant prairies; *Holcus lanatus, Deschampsia cespitosa, Carex densa* and *Phalaris arundinacea* being the highest. The use of fire as a management tool produced only one species with a high IV (*Camassia quamash).*

In the second study, three seeding treatments (Grass first, Grass and Forb together, Forb first) were compared within a 4 hectare experimental wet prairie unit to answer the research question 'Which of the three seeding treatments used leads to the highest native species abundance and species richness?' Results from an analysis of variance indicated significant differences between treatments in native species richness for 2009 and 2010 (p-values=0.002 & 0.004 respectively) at the 5% level and native species abundance in 2010 only (p-value=0.099) at the 10% level. The Grass and Forb and Forb first treatments were highest in native species richness for 2009 and 2010, whereas the Grass and Forb and Grass first treatments were highest in native species abundance in 2010. A NMS ordination suggests that *Juncus tenuis* is one of the dominant species, in all seeding treatments, after one year of growth.

Comparing Vegetation and Soils of Remnant and Restored Prairie Wetlands in the Northern Willamette Valley
by

Sara M. Taylor

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 1, 2011
Commencement June 2012

Master of Science thesis of Sara M. Taylor presented on June 1, 2011.

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Sara M. Taylor, Author

ACKNOWLEDGEMENTS

Foremost, I want to thank my friends and family who have supported me so much through my graduate study. Without them, I don't know if I could have finished. I also want to thank my advisor Mary Santelmann for allowing me to do such an interesting project and for her extensive help and advice throughout my writing and editing. My thanks also go out to David Myrold, who was the co-investigator in this project, and Betsy Leondar who both helped me with the soils component of the research. I want to thank my committee members Richard Halse, James Cassidy and Bruce Dugger, who have each helped me become more knowledgeable in plant taxonomy, soils and wetland ecology. And lastly, I would like to thank the following property managers and land owners who made this project possible; Kathy Pendergrass USDA NRCS, Dean Moberg USDA NRCS, Carlo Abbruzzese Washington DNR, Jennifer Wilson The Wetlands Conservancy, Curt Zonick Portland Metro, Elaine Stewart Portland Metro, Glen Westbrook, Elton Josey and Don Haynes. Thank you so much!

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

Table Page

LIST OF APPENDICES FIGURES

LIST OF APPENDICES TABLES

CHAPTER 1

GENERAL INTRODUCTION

Native prairies of the Willamette Valley are considered among the rarest of Oregon's ecosystems (Clark and Wilson, 2001). Maps of pre-settlement vegetation in the Willamette Valley (Figures 1 and 2) indicate that 456,119 hectares (1,127,071 acres) of wetland and bottomland habitat have been lost since 1850 (Titus et al., 1996) and the few remaining wetland prairies in the Willamette Valley are being threatened by development, changes in hydrology, natural succession to shrub lands and forests, and invasion by non-native plant species (Clark et al., 1993). Urban, rural, and agricultural development have caused the direct destruction of wetland prairie habitat (Clark et al., 1993); and while some efforts at mitigating wetland prairie destruction have been successful, most have not. Even without direct wetland prairie destruction, development can alter water flow and hydrologic conditions, and small changes in hydrology can cause dramatic changes in wetland vegetation (Magee and Kentula, 2005). This paper focuses on some of the ways land managers are maintaining and restoring present day wet prairie habitat; including comparisons between remnant and restored prairies in plant community composition and soil processes, as well as comparisons among different seeding treatments in the establishment of native species diversity and cover.

The climate and soil of Willamette Valley wetland prairies can support forests (Clark and Wilson, 2000) and natural succession occurs when the fires that keep the growth of trees and shrubs in check are prevented. Prescribed burning can be effective at reducing shrub and tree cover (Clark and Wilson, 2000; Pendergrass, 1995), although frequent burning is probably necessary (Clark and Wilson, 1998) to maintain high native herb cover (Wilson, 2002). Historically, wet prairies were used as hunting grounds and kept open by native burning practices. Now, prescribed burning is applied to only a small proportion of native wetland prairies due to governmental

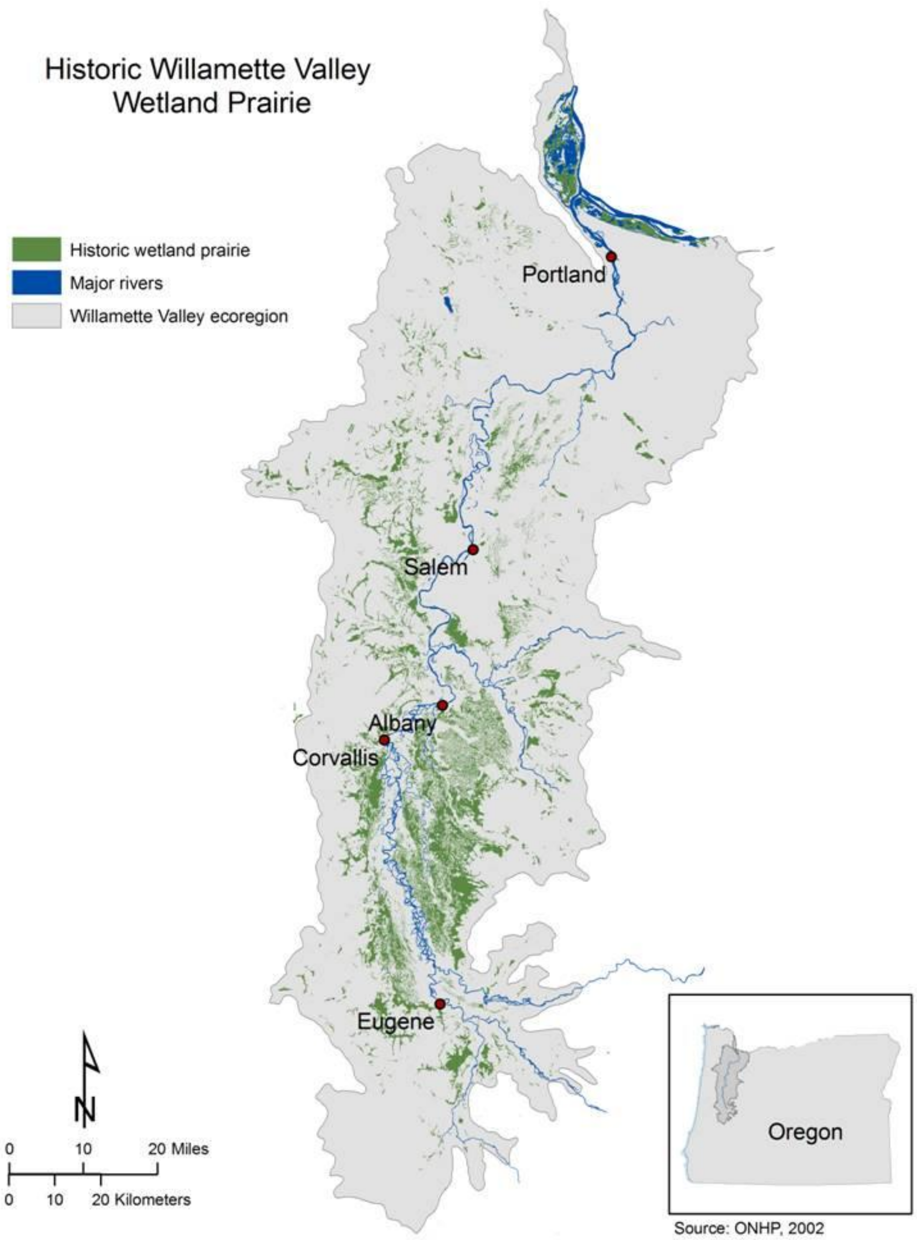

Figure 1. Pre-settlement, historical wet prairie habitat in the Willamette Valley reconstructed from soil and vegetation data. Photo courtesy of the Oregon Biodiversity Information Center, Portland State University, OR

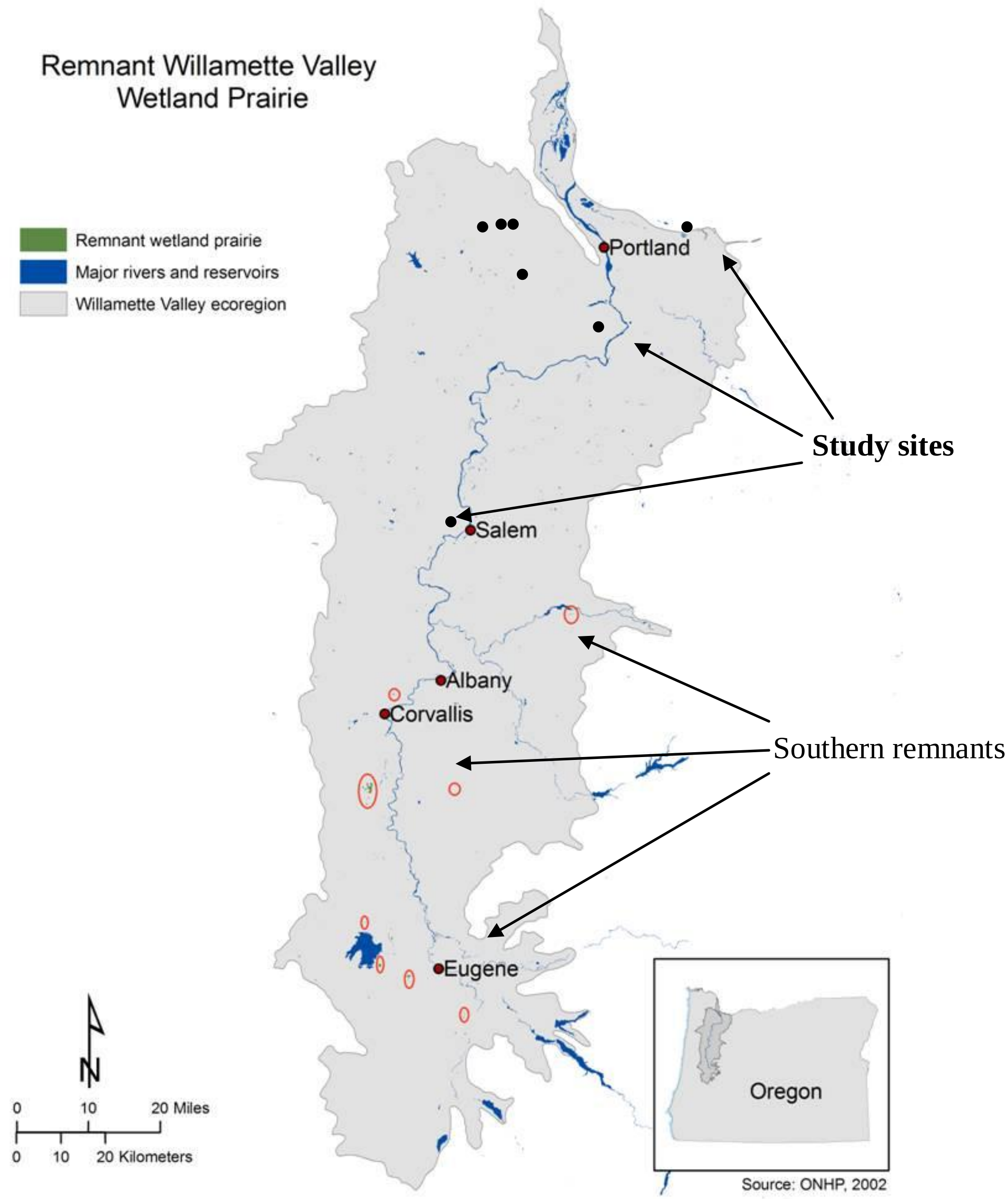

Figure 2. Current remnant wet prairie habitat in the Willamette Valley with black circles indicating areas used for the study and red circles indicating remnant patches of prairie in the Southern Willamette Valley. Photo courtesy of the Oregon Biodiversity Information Center, Portland State University, OR

smoke-management rules (Clark and Wilson, 2001) and threats to nearby farms (personal communication, Dean Moberg USDA NRCS); consequently, tree and shrub encroachment continues to threaten these habitats. This encroachment can essentially destroy the prairie characteristics of Willamette Valley wetland prairies which support very high native plant diversity. Competition for water and nutrients, and the deep shade cast by shrubs, in particular, are detrimental to the smaller and generally shade-intolerant native plants (Clark and Wilson, 1996). Loss of low-stature native herbaceous plant species and their inherent thatch cover could negatively affect small mammal populations which are largely reliant on percent cover and minimal bare ground (Slane, 2001).

Wetland prairies are dominated by tufted hairgrass (*Deschampsia cespitosa* (L.) P. Beauv.), sedges (*Carex* spp.), rushes (*Juncus* spp.), and a diversity of forbs. The physiognomy of wetland prairie vegetation is characterized by two major plant growth habits; graminoids and forbs. Graminoids are defined as grass or grass-like plants, including grasses (Poaceae), sedges (Cyperaceae), rushes (Juncaceae), arrow-grasses (Juncaginaceae), and quillworts (*Isoetes*) (USDA NRCS, 2011). Forbs are vascular plants without significant woody tissue above or at the ground and may be annual, biennial, or perennial but always lack significant thickening by secondary woody growth (USDA NRCS, 2011). Forbs provide the high plant diversity seen in this habitat and encompass the rarest and most threatened of species found in the prairies.

Wet prairies are considered seasonal wetlands that develop as a result of heavy clay soils, resulting in saturation and slight inundation of the soil surface from winter to spring (Titus et al., 1996). Dry summers desiccate the soil and vegetation, leaving the prairie susceptible to fire and discouraging growth of trees and shrubs. These prairies have a complex horizontal structure, with several types of microhabitats where well-developed wetland prairies have a small-scale pattern of raised “pedestals”

3 cm - 20 cm above a lower level of soil (Wilson, 1998) allowing for pedestal-interspaces (Appendix A). Most wet prairies are dominated by graminoids which tend to be tufted or bunched, forming tussocks which over time create pedestals. These pedestals can effectively exclude other species of grasses from growing within the bunches; however, pedestal-interspaces between tussocks can be habitat for a diverse array of forbs and smaller graminoids. This pedestal and interspace microtopography imposes spatial heterogeneity on the prairie, and enhances species diversity.

Microhabitats created by spatial heterogeneity within the wet prairie help generate environments that further enhance biodiversity. These microhabitats provide shelter for a variety of small, low lying herbs, fungi, and bryophytes. Specifically, vernally-flooded bare soils, between pedestals of *D. cespitosa* and on old animal excavations, are typically good sites for prairie bryophytes (Wilson, 1998). In the mud flats and around the clumps of *D. cespitosa* at the edge of vernal pools, a rich and endemic fauna of ground beetles (family Carabidae) occur. These beetles are largely unique to this type of semiaquatic prairie habitat, and are mostly absent from developed, agricultural fields in the Willamette Valley (Wilson, 1998). The tussocks formed by *D. cespitosa* are also habitat for the terrestrial mollusc community, which inhabits the perennial dry tops of the pedestals (Severns, 2005).

Currently, research studies on native bee occurrence in Willamette Valley prairies are being conducted. Native bees inhabiting the prairies could be an important natural resource for neighboring farms in need of pollinators for their crops. Since pollinator populations cannot be maintained by short-flowering crops alone, a continuous supply of nectar and pollen in the areas surrounding agricultural landscapes (Holzschuh, et al., 2007) such as prairies could be providing necessary habitat to maintain pollinator populations. In farming areas with perennial crops, remnant vegetation can provide nesting habitat and foraging resources when crops are not in bloom (Rao and Stephen, 2009). In one study, native bumble bees were identified as being principally responsible for high yields of blueberries in Oregon (Stephen et al., 2009). Increased forb diversity also allows for the possibility of a diversity of beneficial insects, a natural method against pests in nearby crops.

Important ecosystem services (UNEP FI, 2008) provided by wet prairies include not only conservation of native species diversity, but also carbon sequestration (Costanza et al., 1997), and denitrification (Zeoller and Kercher, 2005). Of the total storage of carbon in the earth's soils, anywhere from 20 to 30 percent is stored in wetland soils (Mitsch and Wu, 1995; Roulet, 2000; Hadi et al., 2005). Carbon sequestration occurs as a result of the process of photosynthesis, to the extent that carbon is retained in the plant biomass, living or dead. This carbon-laden dead material is slowly broken down by microbial activity and released again as CO_2 through microbial respiration. Favorable or unfavorable conditions regulate the amount of CO_2 respired, making certain habitats or conditions better for carbon sequestration. Loss of soil organic carbon following conversion of native prairie to agricultural uses has been a major source of anthropogenic CO_2, contributing to the historical rise in global levels of atmospheric CO_2 (Wilson, 1978; Flach et al., 1997).

The ability of wetlands to serve as sinks for nitrogen is also now being investigated as a solution to the nutrient pollution problems in our waterways. The anaerobic process of denitrification is particularly important in this effort. Denitrification is a process in the nitrogen cycle carried out by microorganisms under anaerobic conditions, where nitrate acts as a terminal electron acceptor, resulting in the loss of nitrogen as it is converted to nitrous oxide (N_2O) and nitrogen gas (N_2) (Mitsch and Gosselink, 2007).

Finally, native plant diversity is supported as an ecosystem service within the plant conservation community and has value for the genetic variability that relic, native species provide to our ecosystems. In fostering and maintaining native plant diversity a diversity of genetic plant resources are protected which may be of great importance during this time of global climate change. These native plant resources and their cover are also considered to be critical as both a food source and habitat for a number of federal and state listed animal species (USFWS, 2010).

Comparing vegetation and soils of remnant and restored wet prairie

CHAPTER 2

INTRODUCTION

The ecosystem service focused on in this study is the high native plant diversity provided by wet prairie habitats. The primary research interest was to investigate which site type (remnant or restored wetland) is best at providing native species diversity (richness) and which management strategies are playing a role in increasing the abundance and diversity of native species. Several studies have looked at plant diversity and composition of lowland prairie wetlands in the southern Willamette Valley, however, little plant community research has been conducted on the remaining lowland wet prairies in the northern half of the valley. Securing funds towards wetland prairie conservation and restoration has been a priority for many government agencies within the Portland area, but there is a need for guidance on the effectiveness of restoration techniques and management necessary to mimic the species diversity and composition of relic (remnant) wet prairie sites. One of the major assumptions that will be examined through this research is that the lowland remnant wet prairie sites still remaining in the northern Willamette Valley are high in native plant diversity and native plant cover. Research conducted in the southern Willamette Valley has demonstrated that managed, remnant prairie can be high in native plant diversity as well as in native cover (Taylor, 1999; Norman, 2008; Wilson, 2002).

Land managers within the Portland metropolitan area have become increasingly interested in restoring former agricultural properties, within the 100 year floodplain, into prairie wetlands, in hopes of providing the previously mentioned ecosystem services. However, research is lacking on the full benefits of Willamette Valley wet prairie restoration; from agriculture production to early restoration to long-term community establishment. To address the possible ecosystem services provided by the conversion of agriculture to wetland prairie habitat, data were collected on soil organic matter, moisture, and texture on three site types: 1) remnant prairie 2) restored prairie and 3) fields in agricultural production. A concurrent study looked more in depth at the soil qualities, denitrification processes (N_2O evolution), and statistical differences between these three site types (Leondar, 2011).

While this paper presents some of the soils data, the bulk of the paper focuses on the comparison of plant species and their abundance in remnant and restored wet prairies of the Tualatin River watershed and southwestern Washington (Figure 3). Understanding the differences between these two site types can provide land managers and ecologists with an assessment of the state of remnant prairies in the region, and whether or not they can be used as a reference for young restored prairies. The following research question and related hypotheses were the main topic of this study: Are there differences between remnant and restored prairie plant communities with respect to their native species cover abundance and native species richness?

Native species cover abundance

I hypothesized that when remnant wet prairies are compared to restored wet prairies then remnants will have higher percent cover of native species because remnants have well established native perennial plant species protecting them from weed invasion. I also hypothesized that when remnant wet prairies are compared to restored wet prairies, then remnants will have higher percent cover of native species because soil and hydrologic conditions that promote growth of native wetland species are present in remnants and only developing in restorations. Alternative hypotheses include the null hypothesis (H_0): There is no detectable difference between remnant and restored sites with respect to the percent cover of native species. In addition, another alternative hypothesis is that the restorations will have higher native species abundance than remnants because of the high investment of effort in establishing native species on these sites and management that is intended to foster growth of native species.

Native species richness

I hypothesized that when remnant wet prairies are compared to restored wet prairies then remnants will have higher native species diversity because remnants have microtopography that promotes a diversity of native plant species. I also hypothesized that when remnant wet prairies are compared to restored wet prairies then remnants will have higher native species diversity because soil and hydrologic conditions that promote growth of native wetland species are present in remnants and only developing in restorations. Alternative hypotheses include the null hypothesis (H_0): There is no detectable difference between remnant and restored sites with respect to native species diversity. In addition, another alternative hypothesis includes that restorations will have higher native species richness than remnants because of the high investment of effort in establishing native species on these sites and management that is intended to foster growth of native species.

The goal for this project was to sample and compare these rare plant communities using a community analysis program PC-ORD and the univariate statistical test ANOVA. These statistical programs helped assess the plant composition differences between uncultivated, minimally managed remnant wet prairies as compared to the younger, highly managed restored wet prairies.

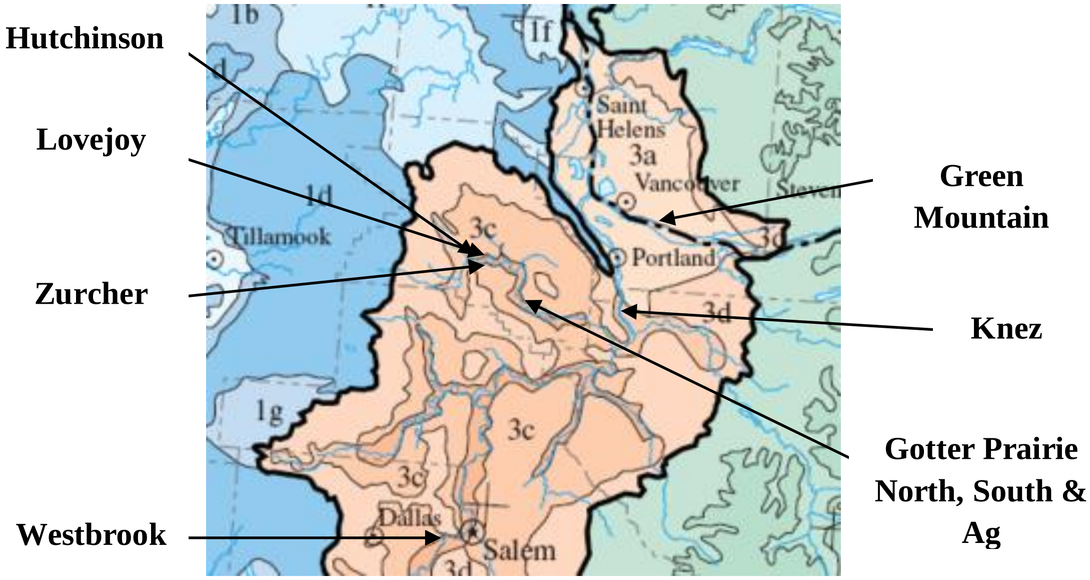

Figure 3. Location of remnant (Green Mountain, Knez, Gotter Prairie South), and restored wet prairies (Hutchinson, Lovejoy, Gotter Prairie North) and agricultural sites (Zurcher, Westbrook, Gotter Prairie Ag) used for data collection in the Northern Willamette Valley ecoregion. The Willamette Valley ecoregion is within the black lines.

METHODS

Site Selection

Remnants

Remnant wet prairie sites were selected based on 5 main criteria: 1) amount of invasive species 2) amount of tufted hairgrass (*Deschampsia cespitosa*) 3) soil type 4) elevation and 5) no historical tillage. The main invasive of concern during site selection was reed canary grass, *Phalaris arundinacea* L. Even though *P. arundinacea* has an ecotype that is native to North America, in this study *P. arundinacea* was viewed as an invasive within the wet prairie plant community and detrimental to native plant diversity (USFWS, 2011). However, due to the lack of remnant wet prairies in the Northern Willamette Valley Ecoregion, sites with a percent cover of 25% or less *P. arundinacea* on-site were allowed for the study and were determined by visual estimation during reconnaissance visits; even though standards set by the US Fish and Wildlife Service for recovery of prairie species within the study area were set to less than 5%.

The criterion that the site would have areas with at least 25% cover in *D. cespitosa* was used for site selection. Through historical literature and communications on the wet prairie habitat pre-1900s, *D. cespitosa* was known to be a dominant species in these prairies (Habeck, 1961). Soil type and elevation were also deciding factors for site selection of remnant, restored and agricultural sites. Soil types were identified based on maps from the web soil survey (Soil Survey Staff, 2011). From this website, sites that were in the family of silty clay loams and order mollisol were selected for the study. The reasoning behind this was to minimize soil differences that could impact nutrient availability and denitrification potential. We also tried to locate sites at similar elevations for the study, because differences in elevation could be reflected in different microclimates and affect plant community composition.

After reconnaissance visits for selecting remnant prairie sites, only three remnants fit the criteria defined above. Even though well-known high diversity remnants such as Sublimity and Kingston prairies exist east of Salem, OR, both of these remnants had soil types that were under the order of ultisol with very high bedrock at the surface layer of the soil. Other sites that were considered for selection were Yamhill Oaks owned by The Nature Conservancy and a private property west of Salem, OR. Both sites were in the foothills of the coastal mountains, with a higher elevation and slope in comparison to other remnant and restored sites. A difference between sites in elevation and slope was a concern due to the possible changes in plant community composition; since most of the restored prairies were in lowland floodplains.

Restored

Criteria for selecting restoration sites were: 1) age 2) similar land manager objectives such as high native plant diversity and cover 3) soil type and 4) elevation. Plant community structure can change over time, and in restorations, rapid changes can happen within the first few years (personal communication, Kathy Pendergrass). Because of this, restorations were chosen based on similarity in stage of the restoration. Monitoring a restoration one or two years after implementation may not be an adequate assessment of plant diversity and cover potential. Ideally, it would have been best to compare restorations that were the same age but that was not an option due to lack of restored prairie sites. Similarity in land manager objectives was important because many restoration projects focus primarily on invasive weed control and are managing for native cover but aren't necessarily managing for high native diversity.

Agriculture

Selection of the agricultural sites was dependent on private landowner approval. The other main criteria were 1) the site was in crop production at the time of sampling 2) soil type 3) location and 4) elevation similar to the remnant and restored sites. Having the agricultural sites in grass production was important for a comparison amongst site types in soil quality and processes. One of the project goals was to compare agricultural sites to restored and remnant grass dominated habitats. In the end, we were granted access to two perennial grass fields and one site in corn production.

Study Areas

The sites selected for study have unique attributes and variable management practices. Table 1 lists the site attributes; such as site size, location, elevation, soil type and site type and management practices are further discussed in this section.

Table 1. Study site summary including site type, size, location, elevation and soil type

Site name	Site type	Size (hectares)	Location		Location (nearest town)	Elevation (m)	Soil type
			Latitude ° N	Longitude ° W			
Green Mountain	remnant	4.5	45.64299	122.46092	Camas, WA	58	Cove silty clay loam
Knez	remnant	4.0	45.43035	122.75963	Tigard, OR	50	Verboort silty clay loam
Gotter Prairie S.	remnant	10.1	45.40441	122.93529	Scholls, OR	35	Wapato silty clay loam
Hutchinson	restored	37.2	45.46940	123.12998	Forest Grove, OR	51	McBee & Wapato silty clay loam
Lovejoy	restored	29.1	45.48526	123.11220	Forest Grove, OR	50	McBee & Wapato silty clay loam
Gotter Prairie N.	restored	8.1	45.40742	122.93274	Scholls, OR	40	Wapato & Cove silty clay loam
Zurcher	agriculture	~ 80.9	45.50037	123.10247	Forest Grove, OR	58	McBee silty clay loam
Westbrook	agriculture	~ 80.9	44.96873	123.22648	Rickreall, OR	61	Bashaw silty clay loam and Woodburn silt loam
Gotter Prairie Ag	agriculture	~ 6.1	45.40184	122.93258	Scholls, OR	61	McBee silty clay loam

Remnant prairies

Green Mountain

Green Mountain is an approximately 4.5 hectare wet prairie outside of Camas, WA and has been managed by the Department of Natural Resources of Washington state, The Nature Conservancy, and the Washington Field Office of the US Fish and Wildlife Service. The prairie is part of the Lacamas Creek watershed formed by the scouring of the Missoula floods (Habegger, 1998). In December of 1997, The Nature Conservancy and US Fish and Wildlife Service were approved to manage the site by the private landowners and onsite management started in 1998. The Department of Natural Resources has been managing the site since 2008. The site has had historical use of grazing and site hydrology has been changed by man-made drainage ditches and swales, which have undoubtedly altered patterns of surface water flow (Habegger, 1998). However, drainage ditches have been blocked to enhance the wetlands and a surface water flow barrier was implemented to separate the prairie from the nearby golf course. The site has a levee and pasture on its west side and roads on the north, east and south sides.

The prairie has large pedestaled bunchgrass topography with a diversity of native grasses and forbs and patches of introduced grasses and forbs including the invasive reed canary grass. A highlight species in this community is the population of the endangered species, Bradshaw's lomatium (*Lomatium bradshawii* (Rose ex Mathias) Mathias & Constance), which is the second largest population of *L. bradshawii* in the Willamette Valley wet prairie complex (Habegger, 1998). Sporadic management efforts at the site consist of weed suppression through brush cutting, digging, mulching and prescribed burning since 1997. More recently, spot treatments using the herbicides Garlon 3A and Roundup have been used on invasive shrubs (such as hawthorn) and reed canary grass. More specific site information and management can be found in Appendix B.

Knez

The Knez property is an approximately 4 hectare wetland located in Tigard, OR. The property was donated to the City of Tigard in 1992 by Knez Building Materials, Inc. (KBM) and in 1994 it was then donated to a non-profit organization, The Wetlands Conservancy (TWC), which now manages it. About 1.8 hectare is remnant wetland fed by Red Rock Creek (a tributary of Fanno Creek, which is a tributary of the Tualatin River). There is no record of crop cultivation on site, however, the area was grazed until KBM bought the property in 1979 (Shaich et al, 2006). Due to grazing, the site has had major hydrological changes and is also surrounded by development and impermeable surfaces which drain water onto the site. Large channels are on either side of the wetland funneling water away from the prairie, however, since the summer of 2007 a beaver has damned up the outlet of the wetland, keeping water onsite from late September to mid-August.

The site has relic prairie wetland micro-topography with large pedestaled tufted hairgrass, *Deschampsia cespitosa*, and a diversity of rushes and sedges but very little cover in forbs. In 2007 TWC decided to change the wetland prairie plant composition which was dominated by *D. cespitosa.* Native sedges and rushes were planted along with native forbs, such as *Plagiobothrys* sp., *Veronica peregrina* L. and *Myosotis* sp. in an effort to increase overall diversity on the site. Plantings started in 2007 and are still being inserted throughout the prairie in the form of seeds and plugs. Very little herbicide has been used on site but glysophate and 2,4 D have been used in blackberry removal on limited occasions. Solarization has been the main method for killing reed canary grass. Due to TWC's commitment to chemical free management, most of the labor has been done by volunteer work crews.

Gotter Prairie South

Gotter Prairie South is an approximately 10.1 hectare remnant prairie west of Scholls, OR. The property was purchased by Portland Metro in 2007 from a private landowner. The prairie is within the Tualatin River watershed and is influenced by the floodwaters of Baker and McFee Creek and the Tualatin River. The property has been managed annually for hay production of tufted hairgrass (*D. cespitosa*) since the mid-1930s until recently (Zonick, 2007). Drainage ditches have affected the hydrology on the site and it is unknown if a tile drain system installed prior to Metro's ownership still currently functions. However, a water control structure has been installed to mimic the historical hydrology regime and is primarily used to store water onsite until June for vegetation management and to enhance habitat for waterfowl and amphibians. The site is mostly surrounded by conventional agriculture practices and private farms.

The plant species composition on the site is dominated by *D. cespitosa* but this site lacks the relic micro-topography seen in the other two remnants, perhaps as a result of frequent mowing. There are occasional patches of sedges and rushes and an abundance of camas and brodiaea in the spring. Native forb diversity and cover is minimal and there are problems with reed canary grass on the southern end of the prairie. Management on site includes; prescribed burning, seeding of native forb species, mowing, haying, flooding and herbicide application on reed canary grass and other undesirable exotics.

Restored prairies

<u>Hutchinson</u>

Hutchinson is an approximately 142.5 hectare parcel of property under the Wetland Reserve Program. The USDA Natural Resources Conservation Service purchased a permanent easement in 2005 on the property for the purpose of restoring wetland habitat (Moberg, 2011). The Joint Water Commission owns the property and the City of Hillsboro manages the land. The site is three miles southwest of Forest Grove, OR at the confluence of O'Neil Creek and the Tualatin River. In 2008, the only active tile drain was destroyed so that site hydrology resembled historic hydrology more closely. Passive levee breeching was also allowed on three different spots along the Tualatin River. Beaver activity has created more soil saturation for a longer period of time (approximately 4-8 weeks) in the northern part of the wet prairie habitat. The site is surrounded by roads and conventional agricultural practices in the southern end.

Prior to restoration, crops such as red clover, cabbage, corn and some spring grains had been grown for decades. In 2006, 37.2 hectare of the agricultural field was restored to wet prairie. In preparation for restoration, the field was sprayed with Roundup ® in 2006 and no-tilled drilled with a clean crop of oats which was later hayed in the summer. The idea behind a clean crop is to grow a grass cover crop for a couple of years to clean up the weed seed bank. The oats will shade out a lot of other vegetation (especially broadleaves) and then herbicides can be used to kill the broadleaf weeds; thus reducing some of the weed seeds that would compete with the native seeds that were put down to establish a new plant community (personal communication, Kathy Pendergrass).

In Fall 2007, native grasses only were drilled in before planting forbs. Native forbs were then later seeded in Fall 2010. Management since restoration has consisted of mowing and spot spraying with 2,4 D. Prescribed burning is not allowed due to a highway and homes close by. Number of native seeds planted and seeds per acre are noted in Appendix B.

Lovejoy

Lovejoy is an approximately 99.1 hectare property purchased by Portland Metro in March 2000 to provide wildlife habitat and greenspace along the upper Tualatin River. The site is located in close proximity to Hutchinson prairie, south of the Tualatin River near Forest Grove, OR. The property has been subdivided into habitat units in which 29.1 hectares have been restored to wet and mesic prairie. The Tualatin River is the major waterway that floods this site. Hydrology has been restored by crushing and removing portions of tile drain and filling diversion ditches. The area is mostly surrounded by farms with one road running along the south end of the property.

Aerial photos taken since 1934 show that the site was still vegetated with wetland species but most of the site was extensively cropped with beets and clover (Stewart, 2009). Preparation for wetland prairie restoration included disking which took place in Fall 2004. It was farmed for another year to clean out weeds and then cultivated with oats in Spring 2006, for use as a clean crop. Broadleaf-specific herbicides were applied over the oat crop and the oats were harvested as hay in Summer 2007. Drilling of native grass and forb seed was implemented in Fall 2007. Problems with reed canary grass and blackberry are occurring along the periphery of the site. Ongoing management and maintenance include mowing, spot spraying and prescribed burning

Gotter Prairie North

Gotter Prairie North is a 44.5 hectare parcel owned by Portland Metro and is adjacent to Gotter Prairie South and Gotter Prairie Agriculture near Scholls, OR. The site is bounded by the Tualatin River to the north and McFee and Baker Creeks to the south and east. Tile systems have been plugged and minor surface grading has been implemented to restore the natural hydrology of the site. The same water control structure used in Gotter Prairie South manipulates water table levels on this property. The property is mostly surrounded by private farms and waterways. An 1851 land survey described Gotter North Prairie as wet prairie, forested wetland and white oak-fir savannah. Native plants found in less disturbed portions of the site are typical of these communities. The parcel has been farmed since the 1940s (Zonick, 2010). Potatoes and corn are among the crops that were cultivated until 2002 and the site had very little weeds before restoration. Restoration preparation started in Spring of 2002 on the 8.1 hectares designated as wet prairie with mowing, cutting and herbicide application on reed canary grass and other introduced plant species. Seeding of native grasses and forbs was completed in Fall of 2002. Management and maintenance of the prairie consists of mowing, spot spraying and prescribed burning. Additional native forbs, grasses and bulbs have also been planted since the initial seeding.

Agricultural sites

Zurcher

Zurcher property is an approximately 80.9 hectare agricultural field owned by Clean Water Services but is leased and farmed by a private landowner who owns the crops. The property is just south of Forest Grove, OR. Waterways that occasionally flood the site are Gales Creek and the Tualatin River. Flood waters flow via culverts out of the property into ditches which then drain into the river. Levees are built up along Gales Creek and the Tualatin River. Tile drains run through the property and the site is mostly surrounded by farms and agricultural land (personal communication Dean Moberg).

The site is agricultural with variety of agricultural practices such as grazing, cover cropping, crop rotation and no-till seeding being used. As of now, the site is in perennial rye grass and will be rotated with clover and corn when seed production wanes. The site is irrigated with water taken from Gales Creek for some of the fields and from the Tualatin for the others. Soils, percent cover and plant diversity data were taken in a field of tall fescue (*Schedonorus phoenix* (Scop.) Holub). Management of the perennial rye grass field includes herbicide application, fertilizers, mowing and haying. More specific information on site management can be found in Appendix B.

Westbrook

Westbrook is an 80.9 hectare private, agricultural property that is under conservation easement with Baskett Slough National Wildlife Refuge west of Salem, OR. The property is surrounded by refuge or agricultural properties with Hwy 99 running along its east side boundary. No major creeks or rivers impact the property, however there are ditches that seasonally flood which saturates the site at times. Tiles and ditches have maintained the property for agricultural use.

In the 1930s corn and hay were grown on the property and then after the 1940s it turned into a grass field, of fescues and rye grass (personal communication Glen Westbrook). As of now, the site is in tall fescue and some areas are grazed by cattle. Management on site consists of annual fertilizing and some minimal mulching. In the near future the site will be restored to upland and wetland prairie habitat and become part of the Basket Slough NWR.

Gotter Prairie Agriculture

Gotter Prairie Agriculture is an approximately 6.1 hectare private property adjacent to the Portland Metro properties, Gotter Prairie North and South. The main waterway affecting this site is McGee Creek and ditches and tile lines have been mostly plugged.

Agricultural crops grown on the property have included corn, cucumbers, pumpkins, pasture grass, oats and wheat. Corn has been grown for the last 6 years with wheat grown through the spring. The corn is mainly grown to attract waterfowl during the Fall and Winter. Management on site includes fertilizers and spot spraying of herbicide (personal communication Don Hayes).

Experimental Design

The criteria mentioned previously were used to select three remnant wet prairie sites (Green Mountain, Gotter Prairie South, Knez), three restored wet prairie sites (Hutchinson, Gotter Prairie North, Lovejoy) and three agricultural sites (Zurcher, Gotter Prairie Ag, Westbrook) for this study. The lack of remnant sites that met our criteria in the region meant that we selected every site that met our criteria, and we were able to find only three sites in the region.

Within each site, three 100 m^2 plots were randomly selected within areas designated as wet prairie. Nested within each 100 m^2 plot were two 1 m^2 microplots at the northwest and southeast corners, within the boundaries of the larger plot (Figure 4). Four 25 meter tapes were laid out to form the large plot starting from the northwest corner. Using a compass for directions, the tapes were run out to ten meters; east, south, west and north. Microplot frames were made of half inch PVC piping to form $1m^2$ and fit inside the corners of the 100 m^2 plot. Data on species presence/absence and cover abundance were collected for all plots (100 m^2 and $1m^2$). The smaller plot data were used to create species area curves, whereas the 100 m^2 plot data were used in comparisons of species richness and cover abundance among different site types.

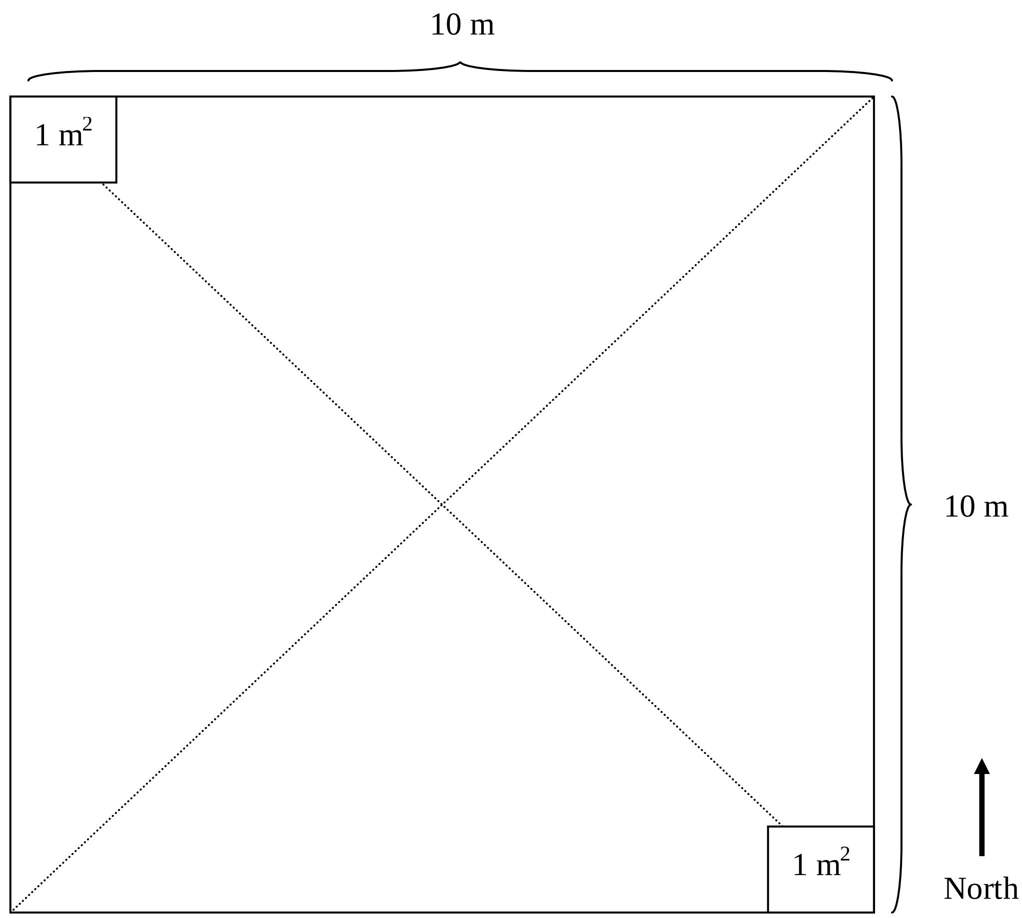

Figure 4. Plot design for $100m^2$ and $1m^2$ plots with diagonal lines for cover percent estimates

The methods used for plot selection varied from site to site. Although all plots were randomly selected based on stratification of vegetation types within the site and random selection of plots from wet prairie type vegetation, there were different techniques used to accomplish the random selection. Lack of information about vegetation on site prior to our visits, access issues, and patchiness of prairie with emergent vegetation required me to vary my methods for random location of sampling plots at the different sites.

For three restored sites and one remnant site, Gotter Prairie North, Lovejoy, Hutchinson and Gotter Prairie South, a grid was placed over the site maps and each grid cell that overlaid wet prairie was counted and given a number. Once all the grids were counted the first 10 numbers from a random number generator were used. GPS coordinates from the top left corner of each randomly selected grid were then recorded to be used for a possible plot location. Once in the field, these GPS coordinates were used if the plot looked homogenous to the rest of the surrounding prairie, if it did not, then that coordinate was thrown out and the next coordinate was used. Details that warranted a plot location to be thrown out was mostly due to vegetation variation such as; > 25% *Phalaris arundinacea*, swales or vernal pools with high percentage of forb only plant species, saturated soil with predominantly emergent plant species or > 25% woody species.

At Green Mountain, another remnant site, a different method of randomized plot location was used. I was unable to obtain information about vegetation at the site before I began data collection, so the plots were selected by running 100 meter tapes along one of the boundaries of the prairie. Three random numbers were then selected from a random number generator from the total length of the boundary. From these three numbers a perpendicular line of 50 meter tape went into the prairie and random numbers were then again generated to the northwest corner of the 100 m^2 plot. Starting from the northwest corner, the rest of the large plot was made with 25 meter tapes. Again, plots with vegetation atypical of wet prairie were rejected and another number along the 50 meter tape was then generated for a more homogenous plot location.

Another remnant site, Knez, was so small in acreage with a very high percentage of emergent wetland vegetation that only four approximate 100 m^2 plots met the conditions needed to be selected as sampling plots. Of these four plots, three were randomly selected and used.

Finally, the three agricultural sites were similar in experimental design for data collection. To respect the landowners who allowed access on their properties for data collection, plot locations were selected randomly from a set distance from the site boundaries as to not disturb their crops. At all of the sites, meter tapes were laid across one of the boundaries of the property and depending on the length of the boundary, three numbers were generated from the random number generator from the total length. From the three random numbers generated, perpendicular tapes ran into the field 5 meters in from which plots and GPS points were created at the northwest corner.

Measurements

Soil Data

Soil samples were collected at four separate sampling periods; September, November, February, and April. Five soil cores, approximately 15 cm deep, were collected on the outside of each 100 m^2 plot and then bagged and labeled. Analysis was done separately by me and an undergraduate student. The undergraduate looked at the dentrification activity of the soil microbial community and percent moisture content in the different soils between sites (See supplemental results, Figure 5 and Table 3). I was responsible for collecting data on pH, percent organic matter and soil texture for comparisons between sites on carbon sequestration potential and soil quality influences on the microbial community.

To get the pH of the soil samples 5 grams of air-dried, ground soil were put into 50 ml beakers. A 3:1 ratio of water to soil was needed for the pH meter to work property so 15 ml of distilled water was added to each beaker of soil and mixed thoroughly for 30 seconds with a glass rod stirrer. The mixture was left undisturbed for 10 minutes and then tested with the electrode until equilibrated. The pH values were then recorded.

Loss on ignition (LOI) was used to determine the percent organic matter at the Central Analytical Lab at Oregon State University. These data were collected by air-drying 10 grams of ground and sieved soil. Samples were then put in ceramic crucibles and oven dried at 105° C overnight, cooled in a desiccator and then weighed and recorded. Samples were then combusted at 360° C for 4 hours in a muffle furnace, cooled in a dessicator, weighed and the weights were recorded. The equation below was used to calculate percent organic matter.

LOI (g/kg) equation= ((oven dry soil wt – soil wt after combustion)/oven dry soil wt)) x 100

Soil texturing was obtained by finely grinding up 50 g of soil and mixing with 100 ml of hexametaphosphate into a cup for blending. Contents were blended in a soil mixer for 1 minute on slow and 4 minutes on the highest setting. The slurry was then dumped into a 1000 ml graduated cylinder where distilled water was added until the 1,000 ml mark. To obtain the first reading, the 1,000 ml cylinder was sealed and shaken until all of the soil was in suspension and then put upright. After 44 seconds a hydrometer was placed into the soil solution, read and recorded. This procedure was repeated for all soil samples, and after 2 hours of settling the readings were taken again with the hydrometer. The formulas below gave the percentages of silt, sand and clay after the temperature correction.

R_i (temp corrected density)=R (original density) + .36 (T-20° C)

1) % silt + % clay = (corrected reading at 44 seconds/mass of dry soil) x 100
2) % clay= (corrected 120 min reading/mass of dry soil) x 100

   % silt= 1)-2)

   % sand= 1) – 100%

Plant Data

The vegetation plots were sampled from mid-June to July in most cases, with one site (Knez) being sampled in August owing to the relatively wet nature of the site and the later time of flowering for the species that grew there.

Visual estimates were made of percent cover for each species present on the plot from 0.5% (or presence) to 100% was used for all plots. To help make these estimates more accurate, extra tapes were used to divide the plots into quarters to allow visualization of the size of a 25%, 50% or 75% amount of space (Figure 4). At all sites, species presence and absence as well as visual estimates of percent cover were first completed for the 1 m^2 microplots nested within the 100 m^2 plot to help the aid the eye in finding smaller species of plants. The 100 m^2 plots were used to gather cover percent information over a larger amount of area. Within the 100 m^2 plot, data were collected by walking a diagonal line between all four corners and using the laid out tapes to visualize the estimated percent cover of each species (Figure 4). GPS points were taken at the northwest corner of each 100 m^2 plot and recorded for revisiting the plots for soil collection and spring ephemerals (see Appendix C for GPS plot locations at each site and Appendix D for maps of each site).

For all sites, plants that were not identified to species in the field were collected in bags and labeled to be identified later. These plants were then dried between blotting paper and pressed to be classified during fall 2009 and spring 2010 in the Botany Lab at Oregon State University. Any species that were not in flower during data collection were recorded only to genus.

Genus and species were assigned to codes using the USDA Natural Resources Conservation Service Plants Database (USDA NRCS, 2011). Specific traits of interest such as native status (native or introduced), duration (perennial or annual) and growth habit (graminoid or forb) were also used from the database. The controversial status of *Phalaris arundinacea* within the wetland restoration community is recognized here; a decision was made to change the plant's USDA Plants Database status from 'native' to 'introduced' for this study. This choice was based on the plants status in the plant database maintained by The Burke Museum of Natural History and Culture at the University of Washington, where *P. arundinacea* is listed as 'introduced'. This decision was further supported by *P. arundinacea's* status as a listed noxious weed by Washington State (Washington Administrative Code, 2005.

Environmental data

Supplemental data that were collected during soil collection included the presence of flooding at each plot (Appendix B). This was used to understand individual site flooding periods throughout the year and how it may affect particular species and plant community composition. This information was based on the presence or absence of standing water above the soil surface in each 100 m^2 plot. If the plot had wet soil but there was no standing water, it was documented as dry.

Management data that were collected were based on management reports or verbal communication with the land owner or manager. Management information of most importance was whether or not land managers used chemicals, clean crops, mowing, a diversity of native seed or prescribed burning. Information on the length of time a site had been managed was also obtained (Appendix B).

Time of sampling

Plant data collection was primarily done in the summer from June 16th to August 28th 2009. Spring ephemerals such as *Lomatium bradshawii* and *Plectritis congesta* (Lindl.) DC., were identified the next spring in April 2010 and added to the data collected the previous summer in 2009. Most of the plant species at the remnant and restored sites were in full flower from late June to July and a majority of the collection happened during these months. However, one of the remnant sites, Knez, was particularly wet from beaver activity until late August and data collection was delayed at Knez until the site was dry and easily accessible.

Soil collection was done seasonally to get measurements of soil activity throughout the year. Four collections were made in total: September 2009, November 2009, February 2010 and April 2010. The collection times were selected to allow sampling at a range of site conditions, from the times during the year when the soil was at its driest to the time of increasing saturation, inundation, and then the time when soils were drying again, in an attempt to capture varying levels of activity by denitrifying microbes at different seasons.

Statistical analysis

Patterns in differences between native species abundance, richness and soil qualities

A univariate analysis of variance (ANOVA) was used to investigate whether significant differences occurred between the native cover percent (abundance) and native diversity (species richness) of the restored versus remnant sites. A univariate ANOVA was also used to test differences between soil qualities of the restored, remnant and agricultural sites. A univariate ANOVA is used to compare multiple treatments (sites) with a continuous response variable (percent cover, species richness, percent organic matter, percent soil moisture and pH).

Patterns in species abundance and the environment

PC ORD relates species abundance to environmental conditions which can be displayed through an ordination. The following are the main and second matrices used for data analysis using PC-ORD:

- The species (main) matrix (18 plots x 117 species) contained remnant and restored plant cover in percentages for all plots
- The environmental (second) matrix (18 plots x 20 environmental/management categories) contained quantitative and categorical data for both remnant and restored sites
- The traits (second) matrix (3 traits x 117 species) contained the categorical data of native status, growth form and duration for all species

Data collected for the second matrices were species traits, site information, quantitative soil information, categorical hydrology information, and categorical restoration management information (Table 2).

Table 2. Binary and quantitative information used in the environmental matrices and their acronyms

Species traits (binary)	**Site information (binary and quantitative)**	**Soil (quantitative)**	**Hydrology: flooding on site (binary)**	**Restoration management techniques (binary)**
native or introduced (native)	remnant or restored (remnant)	pH	November (nov.H_2O)	use of fire (fire)
perennial or annual (perennial)	% native cover (native sp. abundance)	% organic matter	February (feb.H_2O)	yearly chemical application (yrly.chem)
graminoid or forb (graminoid)	# of native species (native sp. richness)	% moisture	April (april.H_2O)	yearly mowing (yrly.mow)
		% sand	July (july.H_2O)	use of clean crops (clean.crop)
		% silt		years in management (yrs. managed)
		% clay		

We expected that when remnant wet prairies were compared to restored wet prairies, the remnants would have higher native species diversity and percent cover because soil and hydrologic conditions that promote growth of native wetland species are present in remnants and only developing in restorations. To assess whether or not remnant prairies had higher native cover and diversity due to their soil and hydrologic conditions, a non-metric scaling (NMS) ordination with Sørensen distance measure (Mather, 1976; Kruskal, 1964) was used; with random starting configurations and fifty runs with real and randomized data. An outlier analysis for plots was run with the distance measure, relative Sørensens which detected sample unit GPS 1 at 2.077 standard deviations and detected no outliers with Sørensens measure. Due to the low degree of problem with the standard deviation using the relative Sørensen measure, it was concluded that the sample unit would have little to no influence on the analyses.

Data transformations used on the main matrix were relativization by species maximum and arcsine squareroot, which supports the expression of rare species for plant community data sets. Relativization by species maximum was used to express a species raw percent cover as a proportion of the species maximum within a column (McCune and Grace, 2002) whereas the arcsine squareroot transformation was recommended for data to improve normality (Sokal and Rohlf, 1995). In this data set the final stress of a 2-dimensional solution was 11.795; and considered satisfactory for both Kruskal (1964a) and Clark (1993) evaluations for final stress. Final instability was very low at 0.0 and the Monte Carlo randomization test supported NMS in extracting stronger axes than expected by chance with p-value=0.020 for all axes. Lastly, the proportion of variance represented by axis 1 and 2 were calculated to an r^2 of 0.382 and 0.653 respectively.

To evaluate the effect of environmental variables in species space, an enhanced environmental matrix was used in combination with the main matrix for the NMS ordination. A matrix of sample unit by trait was obtained by the multiplication of the main matrix (18 sample units x 117 species) by the traits matrix (117 species x 3 traits). Multiplication of the species matrix by the traits matrix reveals how sites are related to each other in terms of species traits (McCune and Grace, 2002). The resulting trait values matrix (18 sample units x 3 traits) was then appended to the environmental matrix as three extra columns (18 sample units x 23 environmental/management categories).

To compare cover abundance and effect size between remnant and restored wet prairies, a multi-response permutation procedure, MRPP (Mielke, 1984; Bondini et al., 1988; McCune and Grace, 2002) with Sørensen distance was also chosen. Presence or absence of remnant prairie was used as the grouping variable. In this statistical test, a p-value tests the null hypothesis of no difference between groups whereas the A statistic describes within-group homogeneity, and between group differences compared to random expectation. In community ecology, values for A are commonly below 0.1 and an $A \geq 0.3$ is considered a very high value in distinguishing a strong difference between groups (McCune and Grace, 2002). However, the smaller the sample size, the larger the effect size is needed to achieve statistical differences.

Lastly, an indicator species analysis (ISA) with the Dufrêne and Legendre's (1997) method was used to evaluate how species separate between remnant and restored prairie, months of flooding occurrence and fire use. This method combines information on the concentration of species abundance in a particular group and the faithfulness of occurrence of a species in a particular group by providing indicator values (McCune and Grace, 2002).

RESULTS

Soils

The most obvious differences in soils between site types (remnant, restored and agricultural sites) are the percent organic matter and percent moisture (Table 3). Moisture and organic matter content are higher in remnant sites (9.6%) than restored (6.6%) and also higher in restored than agricultural sites (5.3%). Gotter Prairie South has the lowest percent organic matter of the three remnant sites at 6.8% and has a similar percentage to that of the restored sites. Zurcher has the highest percent organic matter of all the agricultural sites at 6.4%, similar to that of the restored sites. Overall, the percent moisture was 7% or higher in the remnants than the restored groups and agricultural sites were similar to restored sites. There were minimal differences between groups in regards to pH but the highest (6.8) and lowest (5.3) readings were seen in the remnant sites, Knez and Gotter Prairie South respectively. The most common texture class in both remnant and restored groups was clay. Only one site within those two site types was classified as silty clay, Gotter Prairie South. The agricultural sites were more variable, as seen in Table 3.

Supplemental data added into Table 3 includes bulk density, percent porosity, depth to water table and soil series types and were retrieved from the web soil survey (Soil Survey Staff, 2011). Bulk density depends on the mineral make up the soil and the degree of compaction. For all site types on average, the bulk density was 1.3 g/cm^3 which is relatively normal for most mineral based soils, however, if the soils were collected to measure bulk density at each plot, there may have been substantial differences between site type since accumulated organic matter content can substantially decrease the bulk density value. The percent porosity value is related to bulk density and explains the amount of pore space in a soil sample. Again these values were very similar between site types and their values (approximately 51% on average) are high but typical of clay based soils. Depths to the water table were variable within and between site types. These values explain some of the water resource availability during the dry months of April to September. Soil series types were most variable within the remnant sites and more similar in the restored and agricultural sites.

Table 3. Averaged percent organic matter, moisture (measured as gravimetric water content), pH, bulk density, percent porosity, depth to water table and texture classes for remnant, restored and agricultural sites. Greyed average sections were not used for statistical purposes. Asterisks refer to data that were obtained from the web soil survey.

Site type	Site Names	Percent organic matter	Percent moisture (April 2010)	pH	Bulk density (1/3 bar) g/cm³*	Percent porosity*	Depth to water table (cm)*	Texture class	Soil Series
Remnants	**Gotter Prairie S.**	6.8	33.0	5.3	1.3	50.9	15.0	silty clay	Wapato
	Green Mountain	13.0	36.0	5.4	1.3	52.1	15.0	clay	Cove
	Knez	9.1	39.3	6.8	1.3	52.8	31.0	clay	Verboort
AVERAGE		**9.6**	**36.1**	**5.8**	1.3	51.9	NA	NA	NA
Restored	**Hutchinson**	6.9	25.1	6.2	1.3	50.9	76.0	clay	McBee
	Lovejoy	6.5	23.6	5.8	1.3	50.9	76.0	clay	McBee
	Gotter Prairie N.	6.4	26.5	5.5	1.3	50.9	15.0	clay	Wapato
AVERAGE		**6.6**	**25.0**	**5.8**	1.3	50.9	NA	NA	NA
Agriculture	**Zurcher**	6.4	22.3	5.9	1.3	50.9	76.0	clay	McBee
	Westbrook	3.7	25.6	6	1.2	54.7	7.0	silty clay loam	Bashaw
	Gotter Prairie Ag	6.0	18.1	5.4	1.3	50.9	76.0	silty clay	McBee
AVERAGE		**5.3**	**22.0**	**5.8**	1.3	52.2	NA	NA	NA

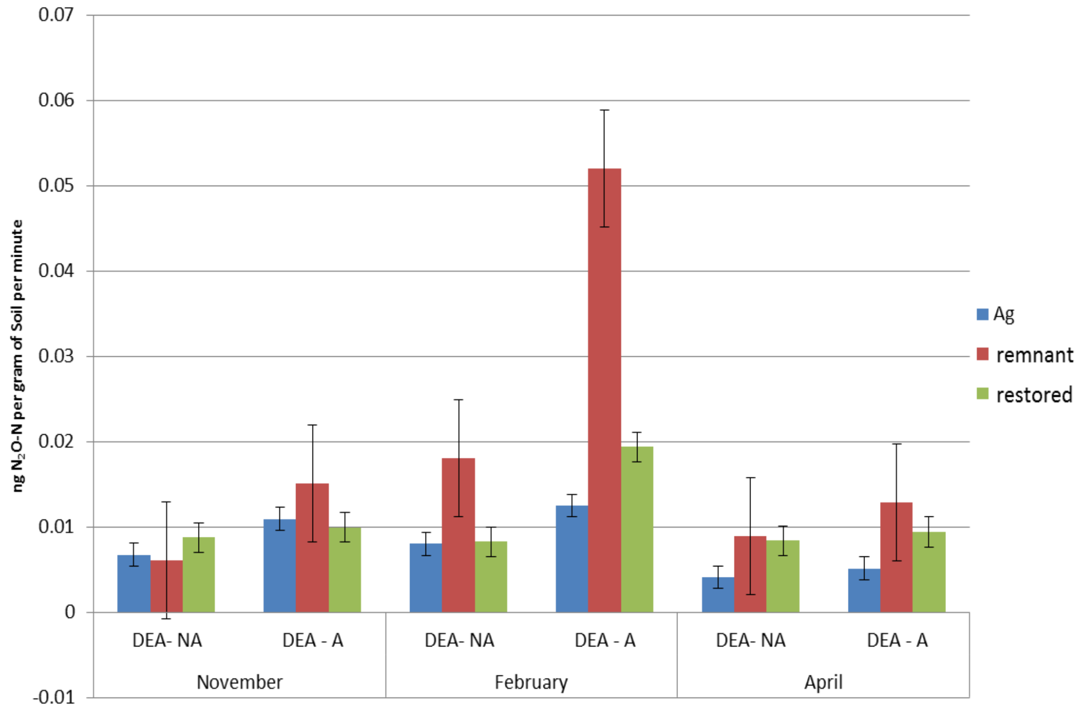

Figure 5. Denitrification rates using denitrification enzyme assays (DEA) with acetylene (A) and no acetylene (NA) between agricultural (Ag), remnant, and restored wetland sites sampled in November 2009, February 2010, and April 2010 (Figure courtesy of Betsy Leondar).

Figure 5 shows the denitrification rates of the agricultural, remnant and restored soils with and without the use of acetylene during three different sampling periods. The reason behind using acetylene in the assays is because the last step in denitrification is the reduction of N_2O to N_2 and not all denitrifiers have the enzyme that does this step and even for those that do, some environmental conditions (higher O_2, higher NO^{3-}, etc.) limit its effectiveness. Thus, there is usually some N_2O produced in a soil that is denitrifying. This last enzymatic step is inhibited by acetylene. So, when acetylene is added, only N_2O is produced (the N_2O that would have been denitrified further to N_2, is not). This is why acetylene is added to measure the total amount of denitrification.

In general, then, a sample with acetylene will produce more N_2O than one without (personal communication, David Myrold).

In this study, remnant prairie soils showed a higher rate of denitrification during the month of February without the use of acetylene and substantially higher denitrification rate with the use of acetylene. During November and April, soils showed similar denitrification rates with agricultural soils tending to have the lowest rates.

Vegetation

Abundance of plant cover

Comparison of the average plant cover in the remnant and restored sites revealed very little difference among sites, with the exception of the Lovejoy restoration site, which has approximately 30% more cover than the rest of the sites (Table 4). Overall, the average vegetated cover was high for all sites; however, comparing the percent cover of bare ground may be more informative, since bare ground can be occupied by weedy, introduced species (Table 4). One site that had a high percentage of bare ground was Hutchinson restoration, whereas Gotter Prairie North restoration had little bare ground exposed.

Comparison of the average percent cover of native versus introduced species in the remnant and restored prairie sites clearly shows that even though Lovejoy restoration has a high percentage of total cover; it also has the highest percent cover of introduced species of all the sites, restored or remnant (Table 4). Green Mountain remnant has nearly equal cover of native and introduced species, whereas the other remnants and restored sites have higher native cover than introduced. Gotter North had the highest cover of native species and also the lowest cover of introduced species.

Most of the sites have greater percent cover of perennial than annual plant species with Gotter Prairie South having the highest percentage cover of perennials at 95% and no annuals. Lovejoy restoration is the one site with low perennial cover at approximately 44% and high annual cover at 119% (Table 4).

Graminoid cover was substantially higher than forb cover at most remnant and restored sites with one exception. The high percentage of annual cover at Lovejoy restoration is comprised mostly of forbs (cover 123%) (Table 4). Gotter Prairie South has a high percentage of graminoid cover at 93% (2% forb), and Hutchinson has the highest percentage of graminoid cover at 108% (21% forb). Green Mountain, Knez and Gotter Prairie North are the only sites that had a shrub cover, and even at these sites shrub cover was a very small percentage of the total, thus, shrub cover is not shown in Table 4.

Table 4. Average percent cover of all plant traits: Status (Native or Introduced), Duration (Perennial and Annual) and Growth Habit (Graminoid and Forb) including bare ground and vegetated cover in remnant and restored prairies

Site type	**Project sites**	**Bare ground**	**Vegetated cover**	**Status**		**Duration**		**Growth Habit**	
				N	**I**	**P**	**A**	**G**	**F**
Remnant	Gotter Prairie S.	9	96	82	12	95	0	93	2
	Green Mountain	7	115	59	56	94	21	70	43
	Knez	4	109	81	25	96	10	94	15
AVERAGE		**7**	**107**	**74**	**31**	**95**	**10**	**86**	**20**
Restored	Hutchinson	17	128	102	26	101	27	108	21
	Lovejoy	8	166	83	81	44	119	44	123
	Gotter Prairie N.	4	117	106	10	98	17	91	25
AVERAGE		**10**	**137**	**97**	**39**	**81**	**54**	**81**	**56**

Plant species richness

A total of 117 species were recorded as present in areas occupied by the remnant and restored plots; 55 were native and 62 were introduced (Table 5). Of these, there were 24 species that were found in both remnant and restored sites; 18 of those were native and 6 were introduced. A total of 44 species were unique to the remnants only; 22 of those were native and 22 were introduced. In restored plots, there were 49 unique species; 15 of those were native and 34 were introduced. A list of all species for each site and their status of 'native' or 'introduced' are in Appendix E.

Table 5. Species common and unique to remnant and restored site types

Sites	**Native**	**Introduced**	**Total species**
Both remnant and restored	18	6	24
Remnant only	**22**	**22**	44
Restored only	**15**	**34**	49
TOTAL	55	62	117

The three sites with highest species richness are Green Mountain remnant, Lovejoy restoration and Gotter Prairie North restoration (Table 6). The Green Mountain remnant has the highest number of native species, Gotter Prairie North has the second highest number of natives and Lovejoy has the highest number of introduced species.

As seen in Table 6, the greatest richness of perennial species is found at the Green Mountain remnant. Also, Gotter Prairie South and Knez remnants have a high number of perennial species in comparison to annuals. The restored sites tend to have a similar number of perennial and annual species (Table 6).

Sites with the highest species richness are also the sites with the greatest number of forb species; Green Mountain remnant, Lovejoy restoration and Gotter Prairie North restoration (Table 6). Gotter Prairie South was one site that had a higher diversity of graminoid species than forb species.

Table 6. Average species richness of all plant traits: Status (Native or Introduced), Duration (Perennial and Annual) and Growth Habit (Graminoid and Forb) including total number of species in remnant and restored prairies

Site type	Project Sites	Total number of species	Status		Duration		Growth Habit	
			N	I	P	A	G	F
Remnant	Gotter Prairie S.	13	10	3	12	1	9	5
	Green Mountain	48	30	18	34	14	16	30
	Knez	23	14	9	17	6	13	12
AVERAGE		**28**	**18**	**10**	**21**	**7**	**13**	**16**
Restored	Hutchinson	18	9	9	9	9	7	11
	Lovejoy	40	15	25	21	18	11	31
	Gotter Prairie N.	35	25	10	21	14	12	26
AVERAGE		**31**	**16**	**15**	**17**	**14**	**10**	**23**

Species area curves

Species area curves explain the relationship between species richness and spatial scale. A comparison between site types indicates that restored prairies have more species per unit area (73 species at 900 m^2) than the remnant prairies (68 species at 900 m^2). Small increases in species richness occurring at 300, 500 and 700 m^2 areas in the restoration sites led to a higher final species richness at 900 m^2 (Figures 6 & 7).

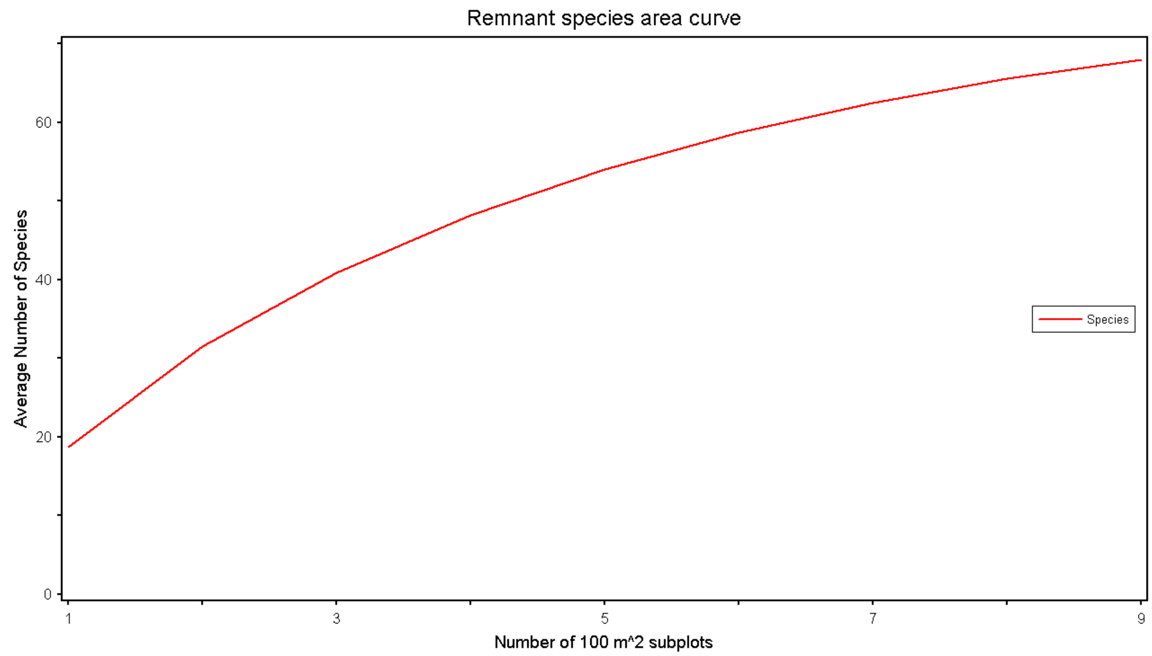

Figure 6. Species area curve for remnant subplots showing 68 species total at 900 m^2

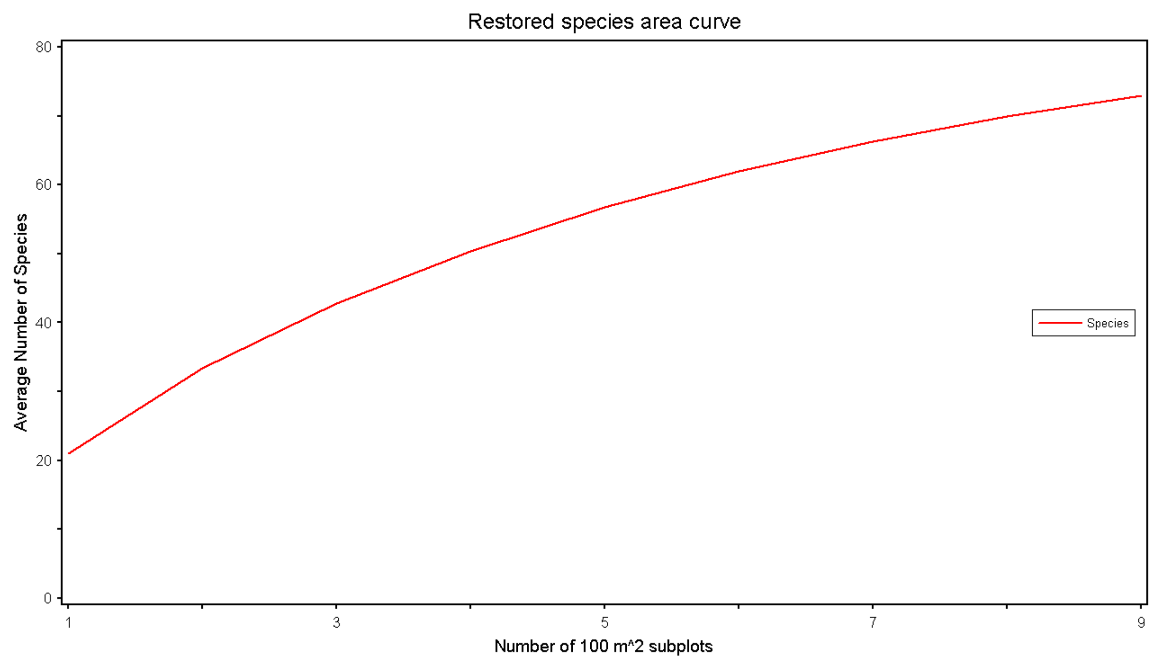

Figure 7. Species area curve for restored subplots showing 73 species total at 900 m^2

Data analysis

Soils

Soils from remnant wet prairie sites had an average of 3% higher organic matter than soils from restored prairie, and 4.3% higher organic matter than the agricultural sites (Table 3), with a significant difference at the 10% level using a single factor ANOVA (p-value= 0.092, Table 7). Remnant prairie also had 11.1% higher moisture content than the restored prairie and 14.1% higher moisture than the agricultural sites (Table 3), which was statistically significant at the 5% level using a single factor ANOVA (p-value=0.003, Table 8). No significant difference in pH was detected among site types (p-value= 0.986, Table 9).

Table 7. Statistical comparisons between remnant, restored and agricultural sites for percent organic matter using a single factor ANOVA

% Organic Matter

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	29.159	2	14.580	3.649	**0.092**
Within Groups	23.976	6	3.996		
Total	53.135	8			

Table 8. Statistical comparisons between remnant, restored and agricultural sites for percent moisture content using a single factor ANOVA

% Moisture

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	332.566	2	166.283	19.130	**0.003**
Within Groups	52.153	6	8.692		
Total	384.720	8			

Table 9. Statistical comparisons between remnant, restored and agricultural sites in pH using a single factor ANOVA

pH

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	0.009	2	0.004	0.014	**0.986**
Within Groups	1.860	6	0.310		
Total	1.869	8			

Comparison of observed outcomes with expected outcomes: Native species abundance and richness

Restored wet prairies had 23% higher native percent cover than remnant prairies, which was significant at the 10% level using a single factor ANOVA (p-value=0.089, Table 10), and native plant species richness did not differ between remnant and restored sites (p-value=0.949, Table 11).

Table 10. Statistical comparisons between remnant and restored sites for percent native species cover using a single factor ANOVA

% Native cover

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	816.667	1	816.667	5.021	**0.089**
Within Groups	650.667	4	162.667		
Total	1467.333	5			

Table 11. Statistical comparisons between remnant and restored sites for native species richness using a single factor ANOVA

Native richness

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	0.167	1	0.167	0.005	**0.949**
Within Groups	141.333	4	35.333		
Total	141.500	5			

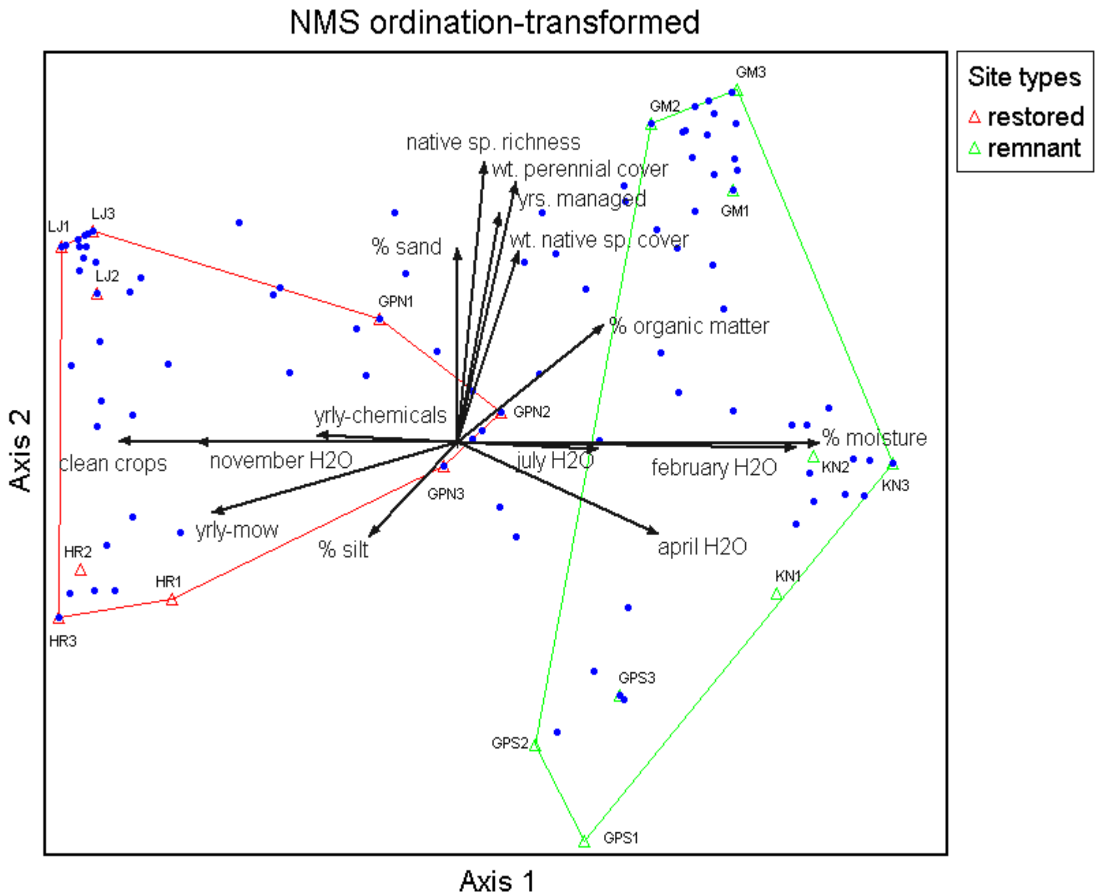

Figure 8. NMS ordination (with Sørensens measure) of remnant (GM, GPS, KN) and restored prairies (GPN, HR, LJ) in species space with an overlaid joint plot showing strongest correlations of species traits (native, perennial, graminoid), soil categories (% moisture, % organic matter, % silt, % sand), management (flooding, use of clean crops, yearly application of chemicals, mowing and years in management) and native species diversity and abundance. Each species is represented by a dot (•) within the ordination.

Comparison of observed outcomes with expected outcomes: Native species abundance and richness with environmental variables

The NMS ordination separated site types into different areas within species space, and plots within site type are grouped by their similarities in species composition (Figure

8). Species most highly associated with specific axes are represented as dots in the ordination. Joint plots show the relationship between the environmental variables and ordination scores where the angle and length of the line indicates the direction and strength of the relationship (McCune and Grace, 2002). Remnant prairies are positively associated along Axis 1 with a range of separation between negative and positive associations along Axis 2 with species most highly associated with those axes. Restored prairies are negatively associated along Axis 1 with Gotter Prairie North being the center point within the ordination. Lovejoy shows slight positive associations along Axis 2 whereas Hutchinson shows slight negative associations along Axis 2. The NMS ordination also showed that serial variables (% soil moisture and February through July flooding) were positively associated with the remnant prairie at Knez (Figure 8). Other positive associations were % organic matter, % sand, native species richness, weighted species abundance, years in management and weighted perennial cover in between Green Mountain remnant and Gotter Prairie North restoration. Weighted categories are a result of relativizaion by species maximum and arcsine squareroot transformations, giving unique and/or rare plant species higher values. Lovejoy and Hutchinson had negative associations with % soil moisture and positive associations with November flooding and management categories (use of clean crops, yearly mowing and chemical application).

Highest Pearson and Kendall correlation (R) values with species in the main matrix were: *Anthemis cotula* L., an introduced, annual forb (-.744 on Axis 1); *Deschampsia cespitosa*, a native, perennial graminoid (-.764 on Axis 2); and *Veronica perigrina* L., a native, annual forb (-.770 on Axis 1). Another noteworthy species that had a relatively high correlation (R) on Axis 2 (.644) was the endangered species, *Lomatium bradshawii*, a native, perennial forb (Table 12). Highest (R) correlations with the second matrix were: % soil moisture (.931 on Axis 1), native species richness (-.803

on Axis 2), use of clean crops (-.900 on Axis 1), February flooding (.901 on Axis 1) and November flooding (-.790 on Axis 1) (Figure 8).

Table 12. Species with highest Pearson and Kendall correlations (R values) and species traits (native/introduced, perennial/annual, graminoid/forb) on Axis 1 and 2 in the NMS ordination N=18

Genus and Species	**N/I**	**P/A**	**G/F**	**Axis 1**	**Axis 2**
Anthemis cotula	I	A	F	**-.744**	.281
Carex densa	**N**	P	G	**.641**	.430
Daucus carota	I	A	F	**-.636**	-.251
Deschampsia cespitosa	**N**	P	G	.351	**-.764**
Deschampsia elongata	**N**	P	G	**-.630**	.038
Holcus lanatus	I	P	G	**.669**	.044
Juncus tenuis	**N**	P	G	**.665**	.099
Lomatium bradshawii	**N**	P	F	.391	**.644**
Myosotis laxa	**N**	A	F	**.654**	.042
Plagiobothrys scouleri	**N**	A	F	**-.631**	.387
Veronica perigrina	**N**	A	F	**-.770**	.275

MRPP results for the comparison between remnant and restored prairie with N=6 showed statistical significance between groups at the 10% level (p-value=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. Varying results were calculated for the significant difference between groups and effect size during periods of flooding in November (p-value=0.016; A=0.057), February (p-value=0.016; A=0.057) and April (p-value=0.304; A=0.009); and significant differences in management with yearly chemical use (p-value=0.633; A=-0.010), yearly mowing (p-value=0.209; A=0.016), use of fire (p-value=0.057; A=0.033) and use of clean crops (p-value=0.016; A=0.057).

Indicator species analysis identified many species with high indicator values (IVs) in the remnant prairies, with *Holcus lanatus* L., *Deschampsia cespitosa*, *Carex densa* L.H. Bailey) L.H. Bailey and *Juncus tenuis* Willd. being the highest (Table 13). However, species with even higher IVs in the restored prairies were *Anthemis cotula*, *Agrostis exarata* Trin., *Plagiobothrys scouleri* (Hook. & Arn.) I.M. Johnst. and *Veronica perigrina*. The highest IVs in the plots with presence of flooding during the year were: November flooding, *Daucus carota* L., *Poa annua* L. and *Anthemis cotula;* February flooding, *Carex densa* and *Carex unilateralis* Mack.*;* April flooding, *Deschampsia cespitosa* and July flooding, *Cirsium vulgare* (Savi) Ten.*, Carex densa, Myosotis laxa* Lehm. and *Juncus effusus* L. The use of fire as a management tool produced one species with a high IV *Camassia quamash* (Pursh) Greene (Table 14). Species with high IVs as a result of no fire were *Daucus carota* and *Deschampsia elongata* (Hook.) Monro.

Table 13. Indicator species analysis and Monte Carlo test (p-value) of observed maximum indicator value for species with native (N), introduced (I), perennial (P), annual (A), graminoid (G) and forb (F) traits in remnant and restored prairies and the presence (+) and absence (-) of flooding in November and February. Indicator values and associated significant p-values at the 5 to 10% level are in bold.

Genus and Species	**N/I**	**P/A**	**G/F**	**Rem.**	**Rest.**	**p-value**	**Nov. H_2O**		**p-value**	**Feb. H_2O**		**p-value**
							+	**-**		**+**	**-**	
Agrostis exarata	**N**	P	G	0	**89**	**.0034**	**70**	4	**.0092**	2	**75**	**.0038**
Anthemis cotula	I	A	F	0	**78**	**.0006**	**81**	3	**.0030**	0	**100**	**.0002**
Camassia quamash	**N**	P	F	43	5	.2663	0	54	.1006	46	2	.1348
Carex densa	**N**	P	G	**57**	3	**.0326**	0	**62**	.0620	**73**	0	**.0114**
Carex unilateralis	**N**	P	G	45	4	.1780	0	**54**	.0900	**64**	0	**.0194**
Daucus carota	I	A	F	0	**67**	**.0120**	**98**	0	**.0006**	0	**86**	**.0004**
Deschampsia cespitosa	**N**	P	G	59	41	.1958	33	**67**	**.0350**	**63**	37	.0732
Deschampsia elongata	**N**	P	G	0	**67**	**.0120**	**77**	2	**.0030**	0	**86**	**.0004**
Elymus glaucus	**N**	P	G	0	33	.2028	**60**	0	**.0122**	0	**43**	**.0424**
Galium trifidum	**N**	P	F	**56**	0	**.0280**	0	38	.2322	**45**	0	.0882
Holcus lanatus	I	P	G	**67**	0	**.0092**	0	46	.1610	**55**	0	**.0396**
Hordeum brachyantherum	**N**	P	G	2	**62**	**.0318**	18	25	.8348	16	32	.5065
Juncus tenuis	**N**	P	G	**67**	3	**.0174**	0	**69**	**.0274**	**68**	**1**	**.0286**
Myosotis laxa	**N**	A	F	**56**	0	**.0286**	0	38	.2406	**45**	0	.0922
Phalaris arundinacea	I	P	G	**56**	0	**.0262**	0	38	.2356	**45**	0	.0994
Plagiobothrys scouleri	**N**	A	F	0	**100**	**.0002**	**85**	5	**.0044**	1	**94**	**.0002**
Plantago major	I	P	F	0	33	.2134	**60**	0	**.0160**	0	**43**	**.0412**
Poa annua	I	A	G	0	**67**	**.0114**	**93**	1	**.0008**	0	**86**	**.0008**
Veronica perigrina	**N**	A	F	0	**100**	**.0002**	**83**	5	**.0046**	2	**90**	**.0002**

Table 14. Indicator species analysis and Monte Carlo test (p-value) of observed maximum indicator value for species with native (N), introduced (I), perennial (P), annual (A), graminoid (G) and forb (F) traits in the presence (+) and absence (-) of flooding in April and July and with the use of fire as a management tool. Indicator values and associated significant p-values at the 5 to 10% level are in bold.

Genus and Species	**N/I**	**P/A**	**G/F**	**April H_2O**		**p-value**	**July H_2O**		**p-value**	**Use of fire**		**p-value**
				+	-		+	-		+	-	
Agrostis exarata	**N**	P	G	4	**54**	**.0592**	0	**53**	.2314	7	43	.2044
Agrostis stolonifera	I	P	G	19	3	.7197	**64**	0	**.0252**	3	19	.7157
Alopecurus geniculatus	I	P	F	**56**	0	**.0264**	12	17	.8966	40	1	.1270
Anthemis cotula	I	A	F	0	**78**	**.0022**	0	47	.3417	0	**64**	**.0076**
Camassia quamash	**N**	P	F	30	11	.5211	0	47	.3223	**78**	0	**.0030**
Carex densa	**N**	P	G	**53**	5	**.0848**	**73**	9	**.0390**	36	12	.3843
Cirsium vulgare	I	A	F	33	0	.2006	**100**	0	**.0020**	0	33	.1976
Daucus carota	I	A	F	0	**67**	**.0094**	0	40	.4757	0	**67**	**.0076**
Deschampsia cespitosa	**N**	P	G	**70**	30	**.0022**	55	45	.6427	62	38	.1000
Deschampsia elongata	**N**	P	G	0	**67**	**.0094**	0	40	.4469	0	**67**	**.0076**
Juncus effusus	**N**	P	G	33	0	.2006	**100**	0	**.0020**	0	33	.1976
Juncus tenuis	**N**	P	G	**58**	4	**.0484**	**87**	5	**.0046**	28	19	.7892
Leontodon taraxicoides	I	P	F	2	**83**	**.0030**	0	67	.1536	37	18	.5699
Lotus corniculatus	I	P	F	22	0	.4665	**67**	0	**.0230**	0	22	.4723
Myosotis laxa	**N**	A	F	38	2	.1260	**95**	1	**.0014**	5	26	.3565
Phalaris arundinacea	I	P	G	**56**	0	**.0328**	43	7	.1590	24	6	.5149
Plagiobothrys scouleri	**N**	A	F	2	**71**	**.0254**	0	60	.1734	4	**58**	**.0976**
Poa annua	I	A	G	0	**67**	**.0092**	0	40	.4105	2	46	.1086
Typha latifolia	**N**	P	F	22	0	.4725	**67**	0	**.0244**	0	22	.4619
Veronica peregrina	**N**	A	F	3	**67**	**.0178**	0	60	.1942	8	**52**	**.0796**

DISCUSSION

Soils

The largest differences in soil characteristics observed between sites were for soil organic matter content and moisture content. The difference between remnant and restored sites with respect to organic matter content might be even greater if the Gotter Prairie South remnant had not been hayed and grazed for many years (Table 3). At the two other remnant sites, Knez and Green Mountain, the organic matter content was higher than the restored sites, with Green Mountain having six percent higher organic matter content than the Hutchinson site (the restoration with the highest soil organic matter content). These results suggest that remnant wet prairies are effective at storing carbon, that newly restored prairies are quickly accumulating carbon, and that management practices such as mowing and haying can affect soil organic matter content. These results support the theory that agricultural soils are carbon sources (Wilson, 1978; Flach et al., 1997) and that by restoring former agricultural fields with perennial native cover, carbon can be sequestered.

Overall soil moisture content was significantly higher in the remnant sites, allowing for a longer period of available moisture for later and longer season of flowering for annuals and perennials. Moisture may have an effect on the high diversity of natives seen in one of the remnant sites, Green Mountain, which also had one of the highest soil moisture contents amongst the sites at 36%.

The denitrification data in this study are consistent with past wetland research on the effectiveness of wetlands in removing nitrates from surface water. However, in this study, denitrification in the remnant prairie soil was highest only during one season, the middle of winter (February); whereas fall and spring denitrification rates in soils of wet prairie remnants resembled the rates observed for the agricultural and restored prairie soils. Since restored sites did not show a large difference in denitrification compared to agricultural sites, I can hypothesize that restored sites are still accumulating organic matter which facilitates soil aggregation and then soil moisture retention. The ability of remnant soils to retain more water for longer may be facilitating microbial processes such as denitrification.

Comparisons between remnant and restored prairies: native species abundance

Based on comparison of native percent cover between remnant and restored prairies, we cannot reject the null hypothesis at the 5% level; there seemed to be no significant difference among site types with respect to native cover. However, at the 10% level, the null hypothesis can be rejected (p-value 0.089, N=6). Continued monitoring of these sites with additional sampling would provide a more powerful test for rejection of the null hypothesis.

The data were also consistent with the alternative hypothesis that native plant cover would be higher in restorations than in remnants owing to management efforts to enhance native species cover. Total native perennial cover for all restored sites was 50% higher than in remnant sites. Higher native cover, specifically perennial cover, in restored prairie suggests that management practices to keep cover of introduced species low have been effective at the sites we sampled, and that in remnant prairies, management of introduced, invasive species is an important concern. Weediness in remnant wet prairie habitats may also result from a lack of conservation management actions over many years; time intervals between management actions conducted at the remnant prairies in this project varied from 3 to 13 years. Large patches of introduced species, including the invasive *P. arundinacea*, were seen in all of the remnant sites and were mostly absent in the restored prairies; except for Lovejoy. Increasing native cover and reducing invasive species cover in a remnant prairie that has not been managed for many years is the main challenge at the remnant sites; especially with an invasive species that is not controlled well by many management techniques, such as flooding or by competition with native grass species such as *D. cespitosa*.

Comparisons between remnant and restored sites: native species richness

No statistically significant difference was found in native species richness between remnant and restored prairies (p-value 0.949, N=6), which is consistent with the null hypothesis. This suggests that land managers have been able to restore native plant diversity into former agricultural areas equivalent to the best intact remnant prairies within the Northern Willamette Valley ecoregion in a relatively short period of time (8 years or less). However, as was discussed earlier, there is a set of more than 20 native species that are unique to remnant prairies, whereas species composition of restored prairies generally reflects the diversity of propagules used in establishing native vegetation on the site.

Of the unique 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 variability within remnant prairies may be associated with the developed microtopography and the presence of native species in the seed bank within those sites whereas microtopography is only developing in restorations, and the seed bank for native species has been depleted over time. Heterogeneous environments created by mature bunchgrass pedestals may be providing habitat for a diversity of native species that show distinct habitat preferences for hummocks. The presence of microtopographic relief has been shown to foster more rare species in experimental wetland communities (Vivian-Smith, 1997). Temporal variation in hydrologic conditions may result from relatively small fluctuations in water levels (9-12 cm). Variation in hydrologic conditions present in the pedestaled microtopography may be creating a mosaic of anoxic and oxic conditions at the sites. These conditions may influence both vegetation and microbial processes, and reinforce the differing spatial and temporal patterns of soil nutrient availability (Vivian-Smith, 1997).

Species area relationships

Species area curve relationships indicate that restored sites have a slightly higher number of species per unit area than remnant sites, which is consistent with the overall species density results between site types. However, the assumption that developed wet prairie microtopography (seen in remnants) would increase species density is not supported by the species area curve relationships. What was noticed was that one of the remnant sites, Gotter Prairie South, was lacking in microtopographic variability, and had lowe species density for a remnant whereas the restoration Gotter Prairie North had developed microtopography and exhibited relatively high species density. This suggests that differences in environmental conditions and management within site types have a strong influence on species richness and community composition at the study sites, as illustrated in the NMS ordination (Figure 8). Even though Gotter Prairie South was considered a remnant, because it has never been plowed, the mowing and haying of the site maybe the reason for minimal pedestal formation and lack of wet prairie microtopography on the landscape. Minimal pedestal formation may also be a result of pedestal flattening from the farming equipment. In contrast, Gotter Prairie North restoration showed signs of pedestal formation after 8 years of restoration and management with minimal mowing and no haying. These differences in management practices for remnant and restored sites may have influenced the minimal differences in species per unit area between site types, causing the Gotter Prairie South remnant to have lower species richness than one would expect, and the Gotter Prairie North restoration to have higher species richness than expected.

Comparisons between remnant and restored sites in respect to management and soils: native species abundance and richness

Remnant and restored sites, with respect to management and soils, showed a fairly strong separation within the ordination; and produced subtle differences in species composition between site types (Figure 8). The ordination indicates a strong association of weighted native species abundance, weighted perennial cover, and native species richness for both remnant and restored sites (mainly Green Mountain remnant and Gotter Prairie North). The ordination clearly depicts a different picture in respect to native species richness and abundance between site types, partially contradicting the results from the ANOVA. This difference in results between the two methods is best explained by the ability of the ordination to rescale species abundance by species maximum throughout the data set, equalizing weight given to common and uncommon species. Because of this relativization, a site such as Green Mountain which contains more native species (including native perennials) but at relatively low abundances, will have more weight for these categories within the matrix. Gotter Prairie North, on the other hand, showed the highest 'actual' native species abundance and richness in the results; which also supports the alignment of the vector for those categories towards that site.

Other categories associated with remnant prairies were percent organic matter at Green Mountain and February through July flooding and percent moisture at Knez. The association of high percent organic matter and percent moisture with weighted native species abundance, perennial cover and native species richness partially supports the second hypothesis that soil characteristics are influencing native plant composition in remnant sites. Correlations between native perennial cover and flooding from February through July are also associated with remnant prairies as shown in the indicator species analysis.

Restored prairies have the highest associations with management (chemicals, mowing and clean crops) and November flooding, and plant community composition is also more similar than in the remnant sites. As mentioned before, the restored prairie, Gotter Prairie North, lies at the center of the ordination and is closer to the remnant sites. It appears that this site is becoming more like the remnants in species composition and in soil qualities. This could be attributed to higher amounts of management for a longer period of time (8 years) in comparison to the other restored sites (3 and 4 years old). Along with a longer time in management, Gotter Prairie North has been supplemented with native seeds and bulbs since the original seeding and is the only restoration that exhibited the development of wet prairie microtopography, comparable to the wet prairie remnants Knez and Green Mountain.

Additional multivariate statistical analyses with MRPP distinguished a significant difference between the remnant and restored sites at the 10% level but showed little within-group homogeneity with the effect size. This means that species composition within the same site type is slightly more similar than species composition across site types. Results from the MRPP also suggest that November and February flooding and the use of clean crops are shaping the plant communities. However, the presence or absence of flooding in April, yearly mowing and chemical use did not show large differences between groups, therefore suggesting little impacts on plant community composition. From the results of this analysis, impacts of seasonal variation in flooding on site type and the native plant community response are research topics that should be further investigated.

Plagiobothrys scouleri and *Veronica perigrina* were the indicator species with the strongest association to restored prairies, and were not found in the remnants. Both of these native, annual forbs are excellent at providing ground cover and contribute to the high proportion of native cover found at restored sites. Species with the highest indicator values for remnants were the native, perennial graminoids *Deschampsia cespitosa*, *Juncus tenuis* and *Carex densa*. Species of interest that were unique to sites with flooding in November were weedy annuals. These results suggest that weedy annuals are favored by flooding earlier in the winter but drier in the spring, as do the high indicator values for common weeds such as *Anthemis cotula*, *Daucus carota*, *Leontodon taraxicoides* and *Poa annua* in the absence of April flooding. Longer saturation periods might help suppress these weeds. Although *L. taraxicoides* can survive spring flooding, it has been reported to die off during intense and long-lasting floods when totally submerged (Grimoldi, et.al, 1999). Finally, the one indicator species associated with prescribed burning in prairies was *Camassia quamash*, which is consistent with historical accounts of the native tradition of burning prairies associated with harvesting *Camassia* sp. for food (Storm and Shebitz, 2006) as well as the research on the native species response in wetland prairies to burning (Pendergrass, 1995).

Remnant wet prairies

Remnant prairies varied greatly in management practices and in species composition, however, presence of unique species at these sites make these remnants important for conservation and maintaining regional levels of plant diversity. Even though Green Mountain had the lowest native cover and fairly high introduced cover, it had pedestaled microtopography and the highest native species richness of perennials, graminoids and forbs. This site has been managed the longest to maintain high native diversity and the endangered species populations of *Lomatium brawdshawii* that still thrive there and is clearly the highest quality remnant in the Northern Willamette Valley ecoregion. See Appendix E for the species list of all sites.

Knez had the highest soil moisture of all the sites and minimal bare ground. Like Green Mountain, the topography on the site was typical of the Southern remnant prairies with high pedestaled microtopography from *D. cespitosa*. Even though native species diversity found in my plots was not high, there were multiple native graminoid species identified in this site that were not found in any of the other prairies. The presence of these unique wetland species can be attributed to the high amounts of water on site creating more perennial, emergent vegetation with little forb cover or diversity. Managers have struggled with incorporating forb diversity on site due to the long period of wetness that leaves little time for forb maturation.

Gotter Prairie South had low introduced cover due to high amount of graminoid, perennial cover that existed on this site. Species diversity was also lowest in this site compared all other sites. No annual cover existed in the plots and the most abundant perennial forb was *Camassia quamash*. The recent management practices of mowing and haying seem to have suppressed the establishment of forbs and smaller graminoids, leaving the site a monoculture of mostly *D. cespitosa*. Management to control the invasive *P. arundinacea* through longer periods of flooding and herbicide use has been the main management priority, making the establishment of native diversity on site a difficult task.

Restored wet prairie sites

Vegetation and soils of restored wet prairies in the Northern Willamette Valley are variable due to differences in site conditions prior to restoration and management practices that have impacted the establishment of native species. Amount of management and methodology for seeding has also played a role in the species composition of the restorations. However, species composition of restorations is more similar than that of the remnants, mostly due to the limited available native seed sources for plantings. Hutchinson and Lovejoy are the closest in resemblance to one another in composition. yet differences in seeding technique have created variations in these plant communities. Due to the high amount of native grass seed used initially in restoring Hutchinson, there is a relatively high percentage of bare ground. Very little native diversity exists on this site but there is very high native cover of perennial graminoids. Establishment of forb diversity is now a challenge due to the competition from the perennial graminoids early in the summer and restrictions on the use of prescribed burning as a practice to suppress the dominant native graminoids.

Lovejoy, on the other hand, had a very high weedy seed bank making this site a challenge to restore in native cover and diversity. This site had the highest amount of introduced cover and diversity compared to other sites and is the only site with more annual forb cover than graminoid cover. However, if intensive management for weed control continue, the annual weed seed bank should eventually die out allowing for the native perennials to establish and expand.

Lastly, Gotter Prairie North had higher native species richness and native cover than any of the other sites included in this study. The efforts at careful site preparation, high seeding rates, intensive management and maintenance have made this restoration into a success story. Although it is a success story in meeting the goals and objectives for most management plans, the amount of management and time spent developing the diversity and cover at this site over a period of 8 years may not be realistic for other properties or for entities that lack the resources for long term, intensive management. However, where feasible, the management regime used for Gotter Prairie North appears to be ideal. From the results of this study, it can be concluded that this site is being managed into a high quality prairie with the fairly rapid development of grass pedestals and microtopography, and soil organic matter approaching that found in remnant prairies. The relative isolation of this site maybe its one drawback for long term management, because this limits the opportunity for dispersal of relic, native seeds to the site.

CONCLUSIONS

The major finding for this study was that restoration of wetland prairie has been successful in providing sites with high native species abundance and richness. However, a simple analysis of variance of the vegetation data is insufficient to distinguish differences observed between remnant and restored sites. By using multivariate analyses, such as an NMS ordination and MRPP, patterns in species composition that vary between site types and along environmental gradients could be distinguished.

Results of this study suggested that higher soil organic matter and time and effort expended on site management can contribute to high species richness, native abundance and abundance of perennials. In addition, our results indicate that management practices can have a strong influence on organic matter content soils of remnants and restorations, and that those differences influence soil moisture content and species composition of vegetation at the site. Sites that were associated with higher organic matter content and soil moisture and long-term management were Green Mountain (remnant) and Gotter Prairie North (restored). Furthermore, the restoration that has been managed for the longest period of time, Gotter Prairie North, has developed soil qualities and a plant species composition most similar to that of the remnants. However, it is also important to note that the highest numbers of unique native species were found in remnant wet prairies. The opportunity to preserve species which are found only in wet prairie remnants is an important reason for the conservation of these rare site types in the Northern Willamette Valley.

Restoring retired agricultural land to a diverse wet prairie: A seeding comparison study

CHAPTER 3

INTRODUCTION

Wetlands have been identified as critically important for provision of a number of ecosystem services such as water quality improvement, flood protection, and conservation of native plant and animal diversity (Mitsch and Gosselink, 2007). Wetland restoration is being considered as a watershed-scale tool for assisting in the provision of these ecosystem services (Costanza et al., 1997). Several recent reviews have discussed the need to incorporate information concerning provision of ecosystem services into tools that help decision makers evaluate alternative policies for land use and management (Kentula, 2007). One such service is the provision of habitat for native plant and animal species.

Several studies have looked at plant diversity and species composition of restored wetlands in the Portland area (Magee and Kentula, 2005), and prairie wetlands in the southern Willamette Valley (Schwindt, 2006; Norman, 2008; Clark and Wilson, 2003, Jancaitis, 2001; Clark and Wilson, 2001; Pendergrass et al., 1999; Taylor, 1999) but little research has been done to investigate the effectiveness of different seeding treatments for achieving restoration goals of high native plant diversity and cover in restored wet prairie habitats. Even though natural area conservation and restoration of wet prairie has been a priority for many government agencies within the Portland area, there is a need for research on the effectiveness of restoration techniques and management practices necessary to attain high native plant species richness and abundance.

Currently, restoration professionals are debating the best techniques to use in order to restore diversity into the prairie plant communities and specifically, whether grasses or forbs should be seeded first with annual over-seedings (multiple seeding method) or whether grasses and forbs should be seeded together (single seeding method) . The single seeding method is the most attractive since many land conservation agencies have little money and limited time within a contract period for funding initial project implementation, post-seeding management and monitoring, all of which are important for the success of a wetland restoration project.

Here, I describe the results from two years of monitoring a seeding experiment established by the USDA Natural Resources Conservation Service (NRCS) on a 142 hectare previously farmed wetland near Forest Grove, Oregon (Figure 9). The wetland was restored as part of a Wetland Reserve Program project. To compete with the annual and perennial weeds present on site, a high density native grass seed mix was sown over approximately 37 hectare of designated wet prairie. In addition to this, a 4 hectare parcel was set aside for an experiment on the effectiveness of three seeding treatments: 1) Grass First (G1), 2) Grass and Forb (G&F), and 3) Forb First (F1). The objective of the experiment was to determine which treatment would be cost-effective, yet produce the most diverse plant community over time, and to help provide land managers with an effective seeding and establishment protocol for implementing wet prairie restoration.

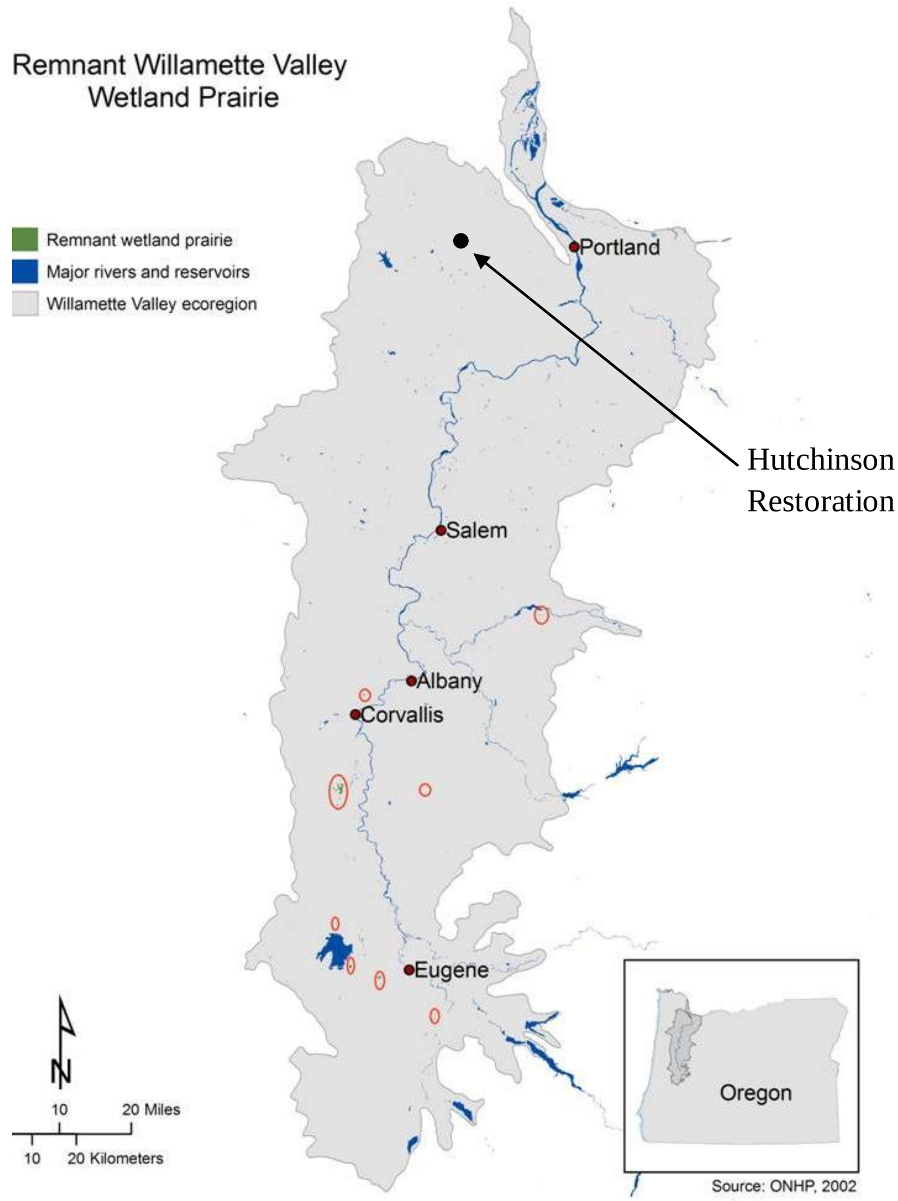

Figure 9. Location of Hutchinson restoration along with remaining remnant wet prairie in the southern Willamette Valley (circled in red). Photo courtesy of the Oregon Biodiversity Information Center, Portland State University, OR

The primary research question addressed by this study is; which of the three seeding treatments used (and subsequent management practices) leads to the highest native plant abundance and species richness?

The null hypothesis, (H_0), is that there will be no difference between treatments in regards to native plant species richness and cover. Alternative hypotheses (H_A) are that the seeding treatments will differ significantly with respect to native plant species richness and/or cover abundance of native species. At the outset of this experiment, I hypothesized that the Forb First (F1) seeding treatment would have the highest native species richness, and that the Grass First (G1) seeding treatment would have the highest native plant cover.

The expected outcomes consistent with these two hypotheses would be that:

(1) when different seeding treatments are compared in restored wet prairie, the F1 treatment will have the highest native plant diversity because many species of forbs can coexist in a plot whereas grasses tend to compete more intensely with other grass species and exclude one another from the plot, and

(2) when different seeding treatments are compared in restored wet prairie, the G1 treatment will have the highest native plant cover because native grasses establish early in the growing season and can outcompete non-native species.

The secondary research question addressed by this study is; will treatments change in native species abundance and richness over a period of one year?

The null hypothesis, (H_0), is that there will be no difference between treatments in native species abundance and richness between years. Alternative hypotheses (H_A)

are that the seeding treatments will differ significantly between years in respect to native species abundance and richness. I hypothesized that the Grass first (G1) treatment will have the biggest increase in native species abundance over one year and the biggest decrease in native species richness.

The expected outcomes consistent with this hypothesis would be that:

(1) when different seeding treatments are compared in restored wet prairie over one year period the G1 treatment will have the greatest increase in native species abundance and decrease in native species richness because perennial grasses get larger over time while shading out many forbs.

METHODS

Site description

Hutchinson Restoration is located east of Highway 47 at the confluence of O'Neil Creek and the Tualatin River, 1.6 kilometers south of Forest Grove, Oregon at the latitude of 45.46940° N and longitude 123.12998° W; in Washington County, Oregon (T 1S, R 4W Section 24). Soils at the site are primarily McBee silty clay loam and Wapato silty clay loam (Soil Survey Staff , 2011). The site is roughly triangular in shape, and has been restored to include riparian shrub, wetland forest, oak savannah, emergent wetland, vernal pools and upland and wetland prairies. The experimental study was conducted only in the restored wet prairie. Before its purchase as a wetland restoration, the site had previously been cropped in 8-16 hectare fields of corn, perennial ryegrass, cauliflower, barley and red clover.

Site preparation

The entire area was disked and seeded to spring wheat during spring of 2006 and no-till seeded to spring wheat during spring of 2007. This clean-cropping approach was an attempt to reduce recruitment of broadleaf weed seeds into the soil seed bank. The entire area was then broadcast sprayed with a 2% glyphosate solution during the fall of 2007. During October 2007, most of the wet prairie portion of the site (approximately 37 hectares) was seeded to grass-only seed mixes which was deemed the best restoration approach to a weedy site.

For the seeding experiment, nine rectangular treatment plots (18 x 221 meters) were established and no-till seeded (soil surface to 0.6 cm depth) to three different treatments randomly assigned, with three replications of each seeding treatment (Figure 10). Due to continued weed problems at the site, broadcast broadleaf herbicide spraying was conducted on all of the G1 plots each fall through October 2010. The F1 and G&F plots have received no herbicide or other weed control.

The G1 treatments had a total of 25 native species no-till drill seeded over 3 years. Six native grass species were seeded in October 2007, 9 native forb species were seeded in October 2008 and 10 native forb species were seeded in 2009. The G&F treatments had 23 species of herbs seeded together in October 2007; 6 native grass species and 17 native forb species. In the F1 treatment, 17 species of forbs were seeded in October 2007. This is the only treatment that was not monitored with the full seeding regime completed in the course of this thesis research project, since grass seed was sown into the treatment during fall of 2010 whereas the plots were monitored in the summer of 2009 and 2010. See Appendix F for the percent cover for all species per treatment.

Data collection

During the first year of establishment, Spring 2008, observation of the seeding experiment plots by NRCS staff indicated that native grass species were abundant only in the G1 treatment plots. The ground cover of the F1 and G&F plots was dominated by non-native weed species, including pineapple weed (*Matricaria discoidea* DC.), sharpleaf cancerwort (*Kickxia elatine* (L.) Dumort.), mayweed (*Anthemis cotula*), wild carrot (*Daucus carota*), hairy hawkbit (*Leontodon nudicaulis* (L.) Banks ex Schinz & R. Keller), false dandelion (*Hypochaeris radicata* L.), broad-leaf plantain (*Plantago major* L.), annual bluegrass (*Poa annua* L.), prostrate knotweed (*Polygonum aviculare* L.), sow thistles (*Sonchus* sp.) and prickly lettuce (*Lactuca* sp.).

In July of 2009 and 2010, native plant species richness and cover abundance were monitored by identifying each plant species present and recording visual estimates of the percent cover of each species in 1 m^2 microplots that were randomly selected within each treatment. Meter tapes were placed in a west to east direction along the boundaries of each treatment plot and three random numbers were generated along the boundary for placement of the plot x-coordinate. At the x-coordinate, another randomized number was generated for the distance perpendicular to the plot boundary as the y-coordinate of a one 1 m^2 plot to be placed within the treatment plot (Figure 10). GPS points were taken at the northwest corner of each microplot and all species of plants found in the plot plus their cover percent were recorded. See Appendix G for GPS locations.

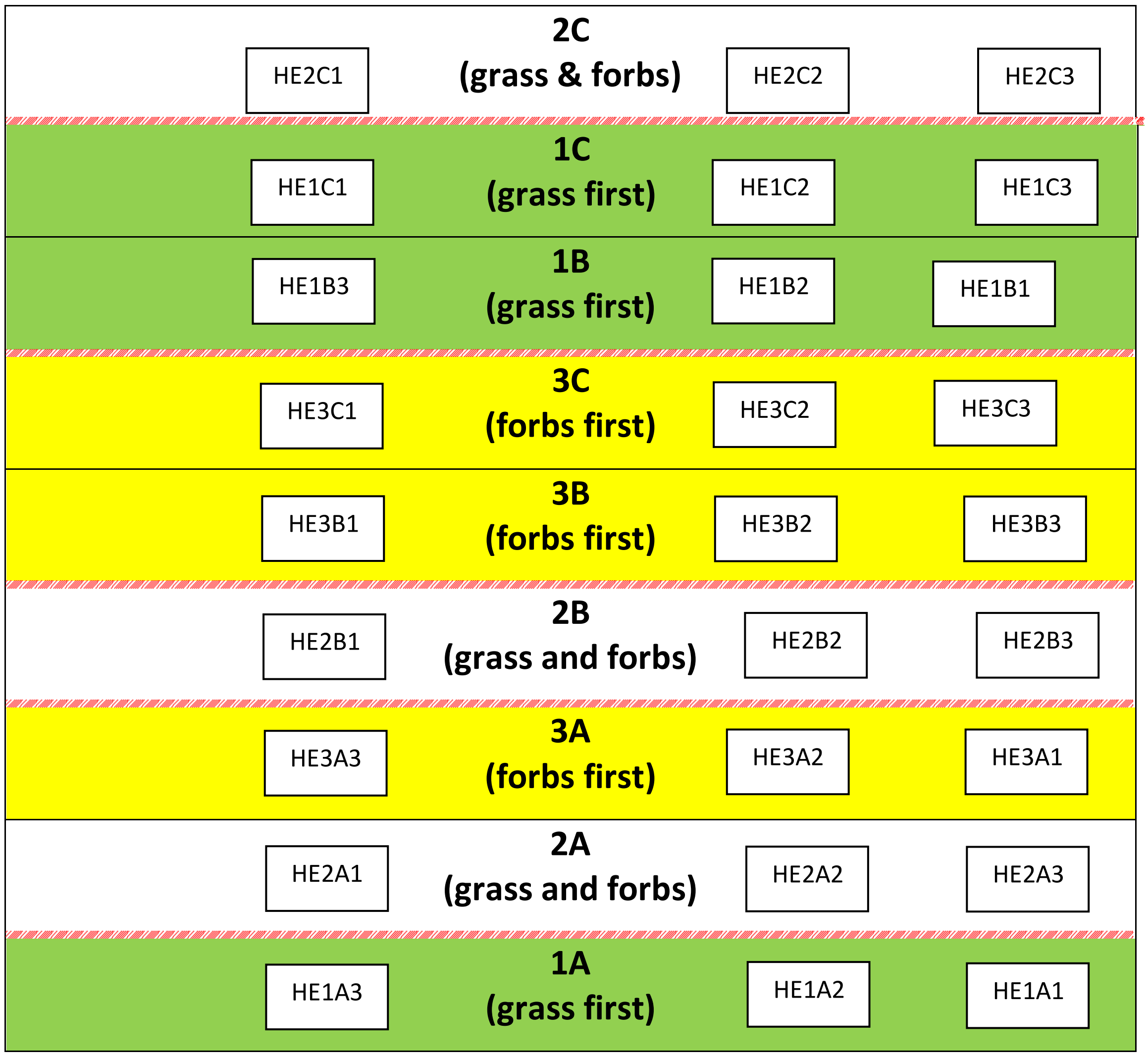

Figure 10. Hutchinson experiment layout of three treatments (grass first, grass and forbs, forbs first), three replicates and three 1m^2 plots with GPS code (ie. HE1A3). The dashed line indicates where the meter tape was placed for locating randomized plots in adjoining treatments.

Data analysis

Hypotheses concerning differences among treatments were tested by obtaining p-values and effect size from the statistical program R version 2.11.0 and PC ORD version 6.0, respectively. Treatment differences were also graphically displayed by year and between years using R and PC ORD. The PC ORD multivariate statistical analysis program was specifically used for its ordination method, nonmetric multidimensional scaling (NMS), and its capability to relate species abundance to environmental conditions and/or species traits. The Sørensen distance measure (Mather, 1976; Kruskal, 1964) was used in the NMS ordination for all analyses with random starting configurations and fifty runs with real and randomized data. An outlier analysis for plots was run and detected no outliers with Sørensens measure for 2009, 2010 or both years.

Data transformations used on all main matrices were relativization by species maximum and arcsine squareroot. Relativization by species maximum was used to express a species raw percent cover as a proportion of the species maximum within a column. Arcsine squareroot transformation was recommended for data to improve normality (Sokal and Rohlf, 1995), which in the 2009 data set decreased the final stress of a 2-dimensional solution to 4.504. In 2010, this transformation decreased the final stress of a 2-dimensional solution to 5.446 and in 2009 to 2010 it decreased the final stress of a 3 dimensional solution to 7.945; all of which are considered robust ordinations with low risk of drawing false inferences Kruskal (1964a) and Clark (1993). Final instability was very low at 0.0 for all analyses and the Monte Carlo randomization test supported NMS in extracting stronger axes than expected by chance with p=0.020 for all axes. The proportions of variance represented by the axes are listed in Table 15.

Table 15. NMS ordination results for dimensional solution, final stress, instability and percent variance for each axes in 2009, 2010 and 2009-2010

Analysis year	Dimensional solution	Final stress	Instability	Percent Variance		
				Axis 1	Axis 2	Axis 3
2009	2	4.504	0.0	76%	92%	
2010	2	5.446	0.0	77%	94%	
2009-2010	3	7.945	0.0	63%	79%	90%

To evaluate the effect of environmental variables in species space, an enhanced second (environmental) matrix was used with the main matrix for the NMS ordination. A sample unit by trait matrix was obtained by the multiplication of the main matrix (9 sample units x 55 species) by the traits matrix (3 traits x 55 species). Multiplication of the species matrix by the traits matrix reveals how sites are related to each other in terms of species traits (McCune and Grace, 2002). The resulting trait values matrix was then appended to the environmental matrix (native cover, native species richness, bare ground and treatment) as three extra columns for a final second matrix of 9 sample units x 7 environmental variables (Table 16). For the 2009-2010 data set, successional vectors were used to show the trajectory of a sample unit in species space over a one year period.

Table 16. Binary and quantitative information used in the second (environmental) matrices

Species traits (binary)	Treatment groups	Sample unit information (quantitative)
Native or introduced	Grass first (1)	% native cover
Perennial or annual	Grass and Forb (2)	% bare ground
Graminoid or forb	Forb first (3)	Native species diversity

To test for any differences in effect size between treatments a multi-response permutation procedure, MRPP (Mielke, 1984; Bondini et al., 1988; McCune and

Grace, 2002) with Sørensen distance measure was chosen. For the 2009 and 2010 data sets, each seeding treatment was used as its own grouping variable. When using MRPP a p-value tests the null hypothesis of no difference between groups whereas the A statistic describes within-group homogeneity or 'effect size', compared to random expectation. In community ecology, values for A are commonly below 0.1 and an $A \geq 0.3$ is considered a very high value, distinguishing a strong difference between groups (McCune and Grace 2002). However, the smaller the sample size the larger the effect size needed to achieve statistically significant differences.

RESULTS

A total of 65 species were recorded as present in area occupied by the experimental treatment plots over the two year monitoring period; 53 species were recorded in 2009 and 55 species were recorded in 2010. Of these, there were 17 species that were seeded into the F1 treatment and 23 species seeded into the G&F treatment. Twenty five species were seeded into the G1 treatment, of which 2 were unique to the G1 treatment only. Data on patterns of native species richness and cover abundance of native species are presented below.

Bar graphs and tables

As seen in Figure 11, increased cover in native plant species was present in both the G1 and G&F treatments after one year of monitoring. However, in the F1 treatments a slight decrease in native plant cover was observed between 2009 and 2010. Cover of introduced species decreased in all treatments after one year. The highest native cover after one year of monitoring was in the G1 and G&F treatments, with native cover percentages at 94 and 97 percent respectively. The F1 treatment had the lowest native plant cover at 74% in 2010. Introduced cover was highest in the G&F treatments and F1 treatments in 2009 with both at 81%.

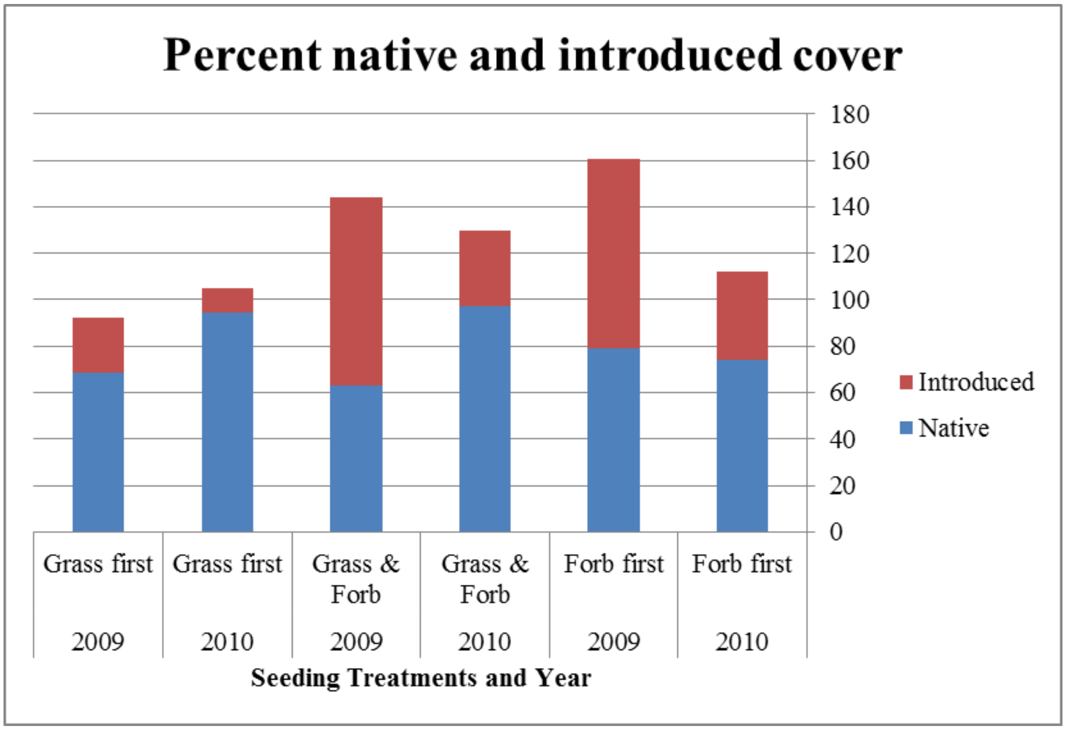

Figure 11. Percent native and introduced cover in all seeding treatments in 2009 and 2010

The data presented in Table 17 document a noticeable difference in perennial cover from 2009 to 2010 in the G1 treatment, but little change in perennial cover in the other treatments. Cover of annual species decreased in all treatments after one year, with greatest decreases (~50%) in the F1 treatment. Graminoid cover increased and forb cover decreased in all treatments from 2009 to 2010.

Differences among treatments in species richness are shown in Table 18. The greatest species richness of native, introduced, perennial, annual, graminoid and forb species occurred in the G&F and F1 treatments. Very little difference was seen between the two treatments from 2009 to 2010.

Table 17. Categories and traits of species percent cover in all seeding treatments from 2009 to 2010; including Native (N), Introduced (I), Perennial, Annual (A), Graminoid (G), Forb (F) and Shrub (S) cover

Year	Seeding type	Bare ground	Vegetation	Status		Duration		Growth Habit		
				N	I	P	A	G	F	S
2009	Grass first	16	98	69	23	68	24	73	19	0
2010	Grass first	15	105	94	11	98	7	100	5	0
2009	Grass & Forb	5	148	63	81	106	38	33	111	0
2010	Grass & Forb	9	130	97	33	106	24	83	47	0.1
2009	Forb first	6	162	79	81	75	86	19	142	0
2010	Forb first	5	112	74	38	78	34	39	73	0

Table 18. Categories and traits of species richness in all seeding treatments from 2009 to 2010; including Native (N), Introduced (I), Perennial, Annual (A), Graminoid (G), Forb (F) and Shrub (S) species

			Status		Duration		Growth Habit		
Year	**Seeding type**	**Total number of species**	**N**	**I**	**P**	**A**	**G**	**F**	**S**
2009	Grass first	27	12	15	11	16	9	18	0
2010	Grass first	16	8	8	7	9	8	8	0
2009	Grass & Forb	40	20	20	20	20	10	30	0
2010	Grass & Forb	42	22	20	25	17	11	30	1
2009	Forb first	37	18	19	14	23	8	29	0
2010	Forb first	42	21	21	23	19	11	31	0

Species area curves

In Figure 12 the species area curves for the different seeding treatment plots in 2009 show that the G1 treatment is lower in overall species richness and as area sampled increases, there is a steady increase in species richness which does not stabilize after the largest area sampled (9 m^2). If area sampled were to increase beyond 10 m^2, then it is possible that species richness would continue to increase. However, the species area curves for both the grass and forb and forb first treatments show a leveling off of species richness of 39 and 35 species, respectively, at 8 m^2 of area sampled.

In Figure 13, the treatment species area curves in 2010 show some changes in species richness with area after one year of growth. The G1 treatment shows much lower species richness per area sampled, with species richness stabilizing at 17 species in a 5 m^2 area, whereas in 2009, species richness appeared to be increasing with area sampled in the G1 treatment, with 26 species at 9 m^2. The species area curves for the G&F and F1 treatments remain similar in 2010, and species richness for both seeding treatments appears to stabilize at 43 species after sampling of 9 m^2 area for both treatments.

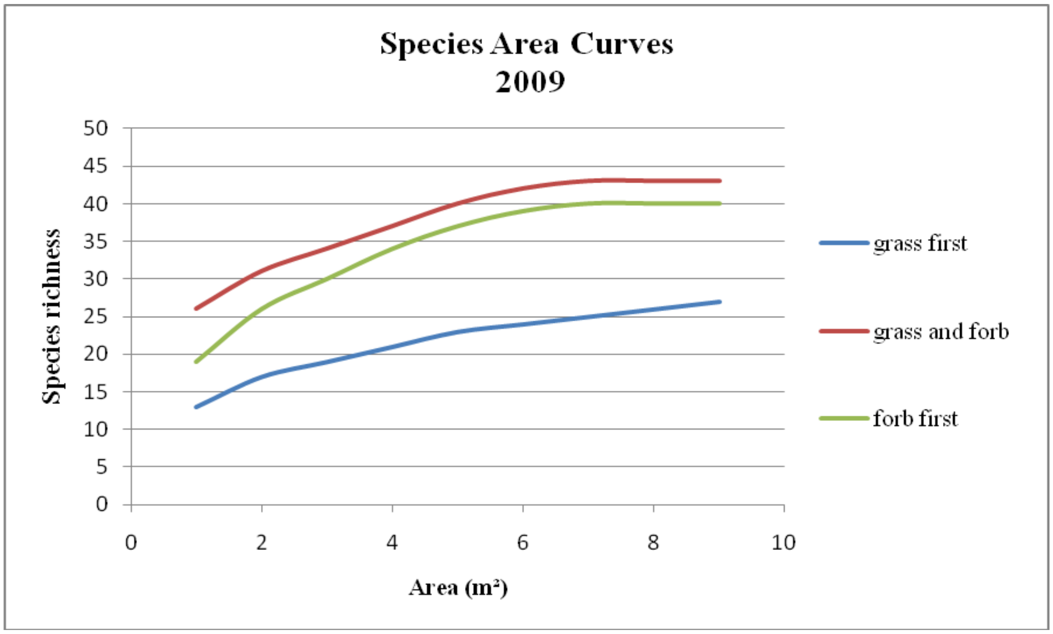

Figure 12. Plot area and associated species richness for all treatments in 2009

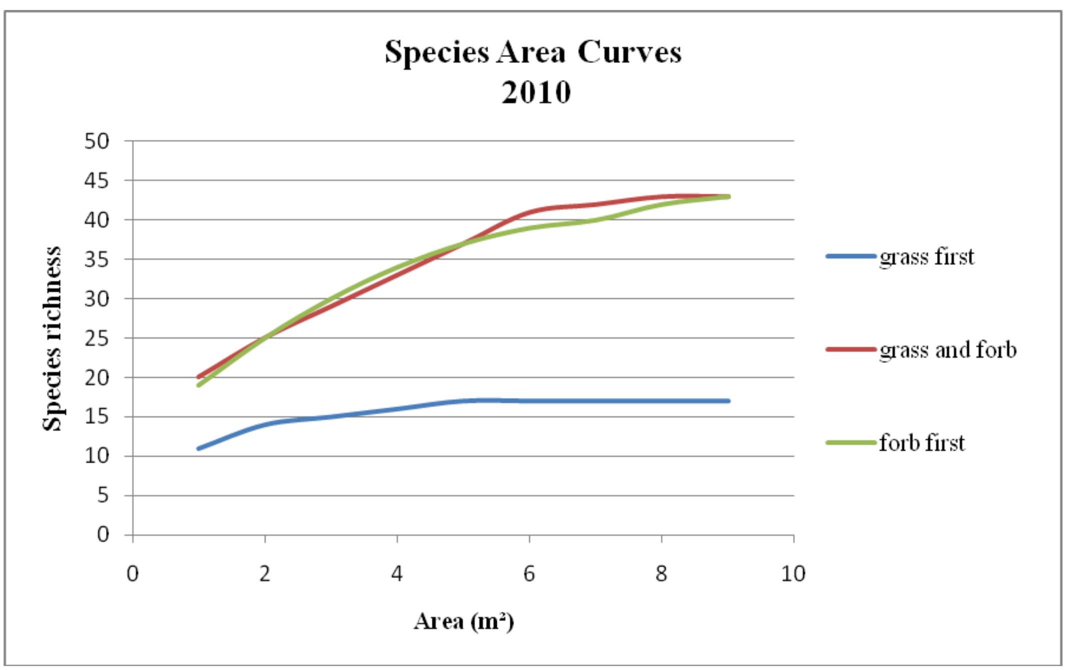

Figure 13. Plot area and associated species richness for all treatments in 2010

Data analysis

In Figures 14 and 15 respectively, differences in native plant cover abundance are shown for 2009 and 2010. There was no significant difference between treatments in regards to native plant cover in 2009 (p-value=0.464) (Table 19). In data from 2010, a larger separation between treatments is noticeable with significance at the 10% level (p-value=0.099) (Table 20).

Table 19. Statistical comparisons between treatments for native species abundance in 2009 using a single factor ANOVA

2009 % native cover

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	435.340	2	217.670	0.868	**0.464**
Within Groups	1504	6	250.667		
Total	1939.340	8			

Table 20. Statistical comparisons between treatments for native species abundance in 2010 using a single factor ANOVA

2010 % native cover

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	1022.296	2	511.148	3.313	**0.099**
Within Groups	925.759	6	154.293		
Total	1948.056	8			

Figures 16 and 17 show large treatment differences in both years with the G1 treatment having low native species richness compared to the other treatments. Differences at the 5% level of significance among treatments in native plant richness for both 2009 and 2010 were p-values of 0.002 and 0.004 respectively (Table 21 & 22).

Table 21. Statistical comparisons between treatments for native species richness in 2009 using a single factor ANOVA

2009 native richness

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	84.667	2	42.333	22.412	**0.002**
Within Groups	11.333	6	1.890		
Total	96	8			

Table 22. Statistical comparisons between treatments for native species richness in 2010 using a single factor ANOVA

2010 native richness

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***
Between Groups	169.556	2	84.778	16.587	**0.004**
Within Groups	30.667	6	5.111		
Total	200.222	8			

Trends in native cover and native species richness for each treatment between 2009 and 2010 can be seen in Figures 18 and 19. Over a one year period, large increases in native percent cover occurred in the G1 and G&F treatments (p-values= 0.048 & 0.023 respectively) whereas the F1 treatments had a slight decrease in native cover (p-value=0.092). However, little change occurred in native plant species richness for the G&F and F1 treatments (p-values=0.374 & 0.547) and the G1 treatment had a slight decrease in native diversity (p-value=0.091). Statistical comparisons using an ANOVA for each treatment between years can be seen in Appendix H.

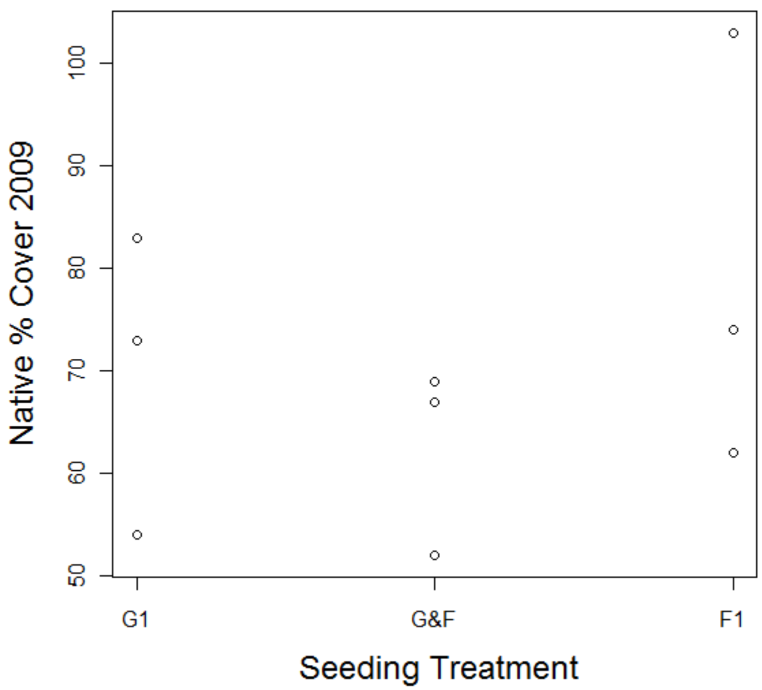

Figure 14. Scatterplot showing the averages of native cover percent in all treatments in 2009 (p-value=0.464, N=9)

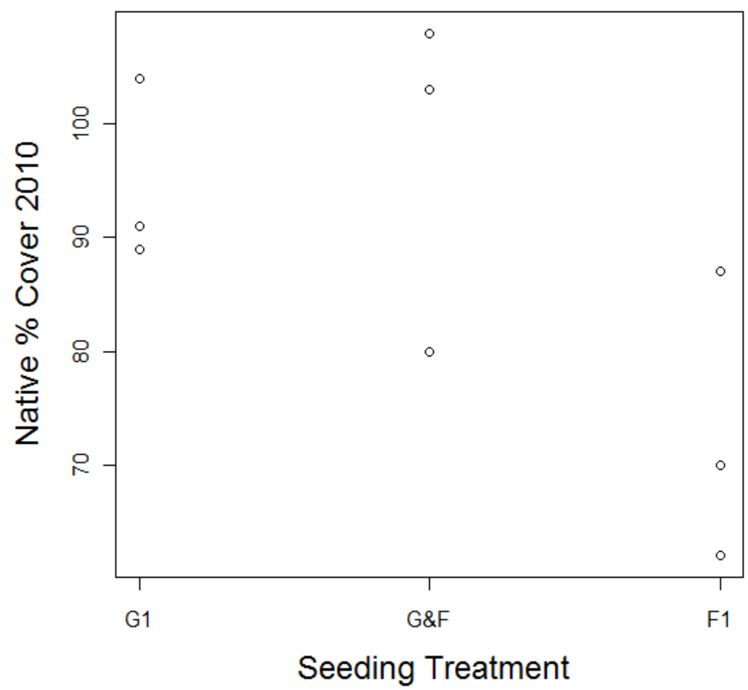

Figure 15. Scatterplot showing the averages of native cover percent in all treatments in 2010 (p-value=0.099, N=9)

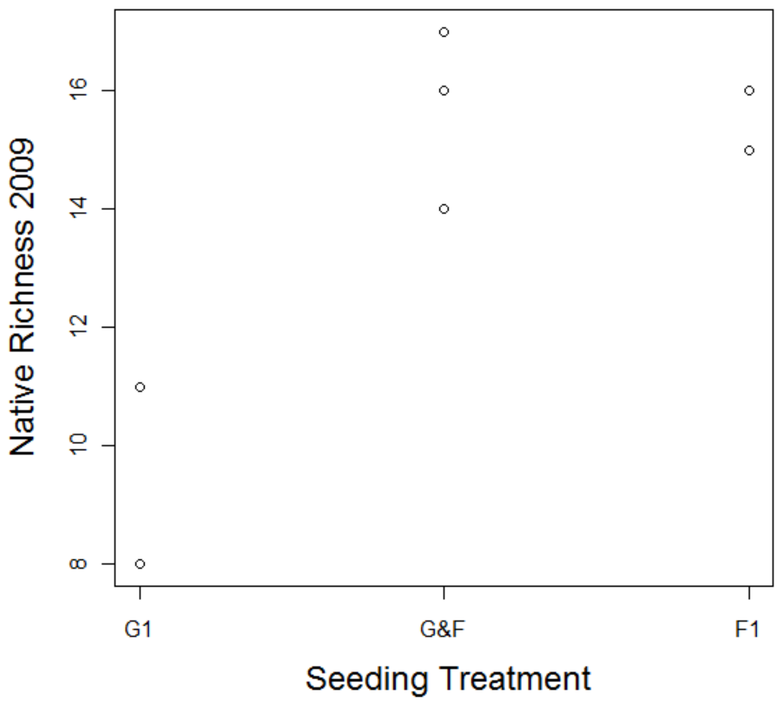

Figure 16. Scatterplot showing the averages of native species richness in all treatments in 2009 (p-value=0.002, N=9)

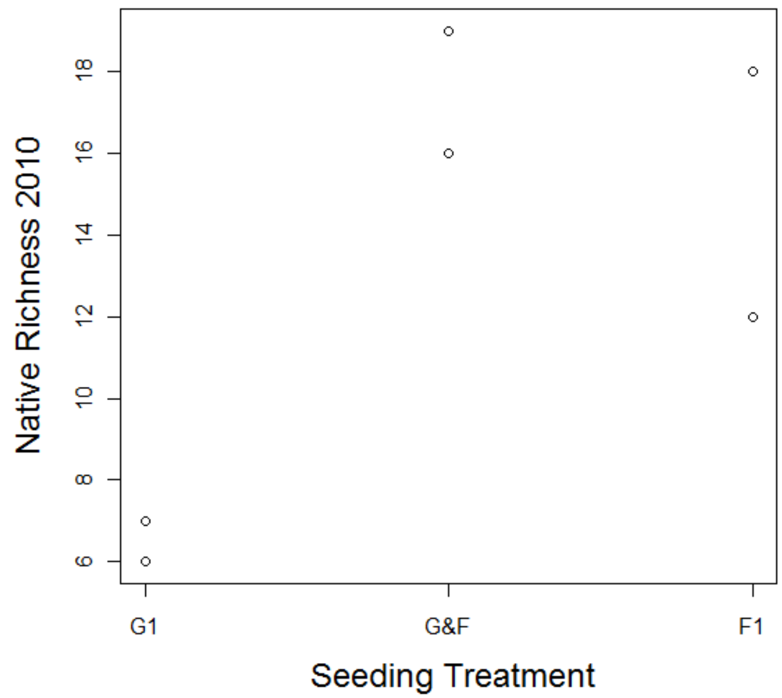

Figure 17. Scatterplot showing the averages of native species richness in all treatments in 2010 (p-value=0.004, N=9)

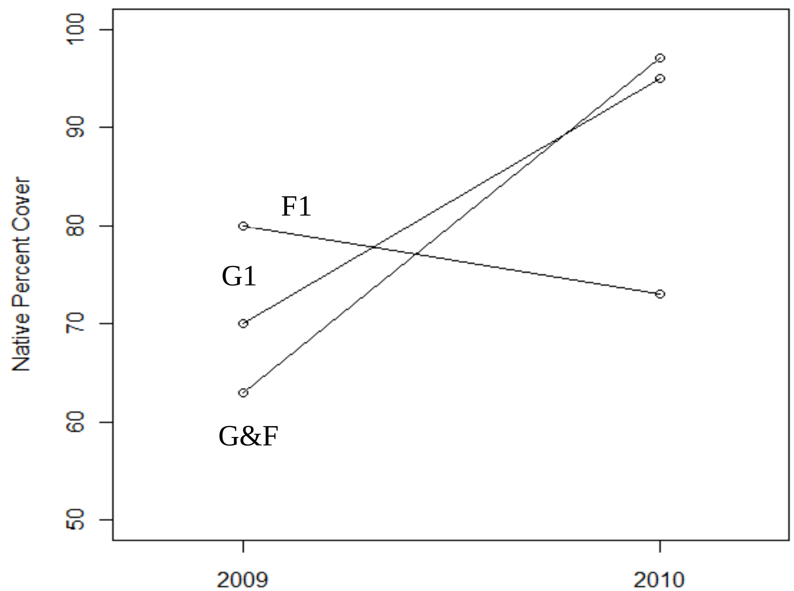

Figure 18. Changes in average native percent cover in treatments from 2009 to 2010 (F1: p-value=0.092, G1: p-value=0.048, G&F: p-value=0.023, N=18)

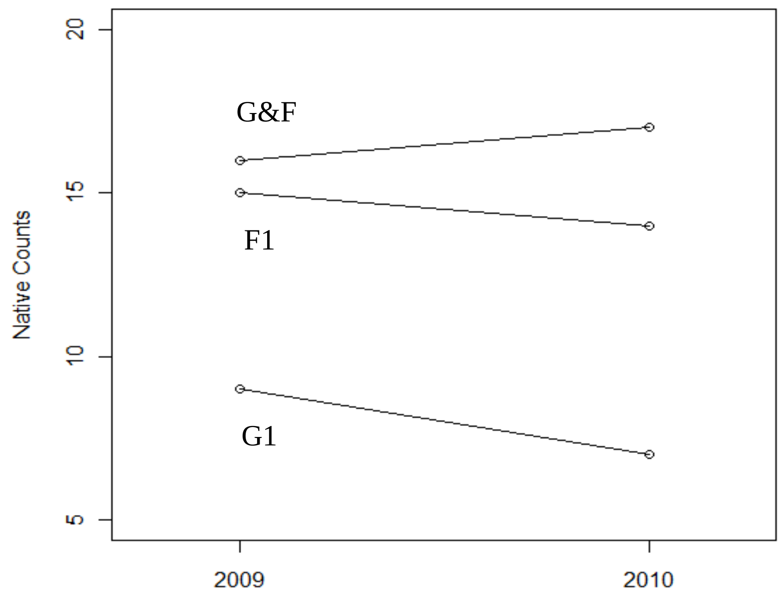

Figure 19. Changes in average native species richness in treatments from 2009 to 2010 (G&F: p-value=0.374, F1: p-value=0.547, G1: p-value=0.0913, N=18)

Figures 20 and 21 show an NMS ordination of data from 2009 and 2010, respectively, using the community analysis program PC-ORD, in which treatments and plots within treatments are grouped by their similarities in species composition. Joint plots show the relationship between the environmental variables and ordination scores where the angle and length of the line indicates the direction and strength of the relationship (McCune and Grace, 2002). In 2009, the variables related to plant species composition were the percentage of graminoids in the plot and native species richness (Figure 20). Native species richness is highly associated with the F1 and G&F treatments and negatively associated with the G1 treatment. Native species richness is also negatively associated with Axis 1, whereas low species richness is positively associated with Axis 1. The plant trait 'graminoid' is positively associated with the G1 treatment and Axis 1. Many species were highly associated with both Axis 1 and 2 (Appendix I), but the species with positive correlations above a 0.650 R value included *Agrostis exarata, Danthonia californica* and *Deschampsia cespitosa.* Species with negative associations to Axis 1 include *Downingia elegans* (Douglas ex Lindl.) Torr., *Eriophyllum lanatum* (Pursh) Forbes, *Juncus tenuis*, *Plagiobothrys figuratus* (Piper) I.M. Johnst. ex M. Peck, *Plantago major, Potentilla gracilis* Douglas ex Hook, *Psilocarphus elatior* (A. Gray) A. Gray, *Rorippa curvisiliqua* (Hook.) Besser ex Britton and *Trifolium pretense* L. Species positively associated with Axis 2 include *Anthemis cotula* and *Hypochaeris sp.* whereas negative associations include *Crepis* sp., *Lolium perenne* L. and *Phleum pratense* L.

In the ordination of data from 2010, graminoids are still positively associated with the G1 treatment (Axis 1) along with % bare ground. Perennials, native diversity, F1 and G&F are all negatively correlated with Axis 1 (Figure 21). Percent native cover and two of the F1 plots are positively correlated with Axis 2 whereas graminoids and one G&F plot are negatively associated with Axis 2. Species positively associated with

Axis 1 and above a .650 R value include *Agrostis exarata, Danthonia californica, Deschampsia cespitosa* and *Kickxia elatine* (L.) Dumort. whereas *Downingia elegans, Juncus tenuis, Plantago major, Plagiobothrys scouleri, Prunella vulgaris* L. and *Psilocarphus elatior* are negatively associated. Species positively associated with Axis 2 include *Equisetum arvense* L., *Fraxinus latifolia* Benth, *Hypochaeris* sp., *Juncus bufonius* L., *Lythrum hyssopifolium* L., *Mentha pulegium* L., *Poa palustris* L. and *Sonchus asper* (L.) Hill whereas *Anthemis cotula, Cerastium glomeratum* Thuill., *Navarretia squarrosa* (Eschsch.) Hook. & Arn., *Rumex conglomeratus* Murray, *Trifolium pretense* L. and *Trifolium repens* L. were negatively associated with Axis 2 (Appendix I).

From 2009 to 2010 an obvious trend in vegetation change over time towards higher proportion of graminoid species can be seen, from treatments having high positive correlations with Axis 2 in 2009 to negative correlations with Axis 2 in 2010 (Figure 22). Native species richness and perennial species maintained negative associations with Axis 1. Species also negatively correlated with Axis 1 include *Downingia elegans, Juncus tenuis, Plagiobothrys scouleri, Potentilla gracilis, Prunella vulgaris and Psilocarphus elatior*. Positive correlations with Axis 1 include *Agrostis exarata, Danthonia californica* and *Deschampsia cespitosa*. Positive associations with Axis 2 include *Anthemis cotula* and *Cerastium glomeratum* whereas negative associations include *Juncus tenuis* (Appendix I).

MRPP results showed significant differences between treatments in the 2009 and 2010 data sets (p-values 0.006 and 0.005 respectively) and some significant effect size between treatments (A-values 0.129 and 0.226 respectively). With an A=0.226, the 2010 data set is showing a relatively high within-group homogeneity for ecological data; whereas the 2009 data set is showing slightly lower within-group homogeneity at A=0.129.

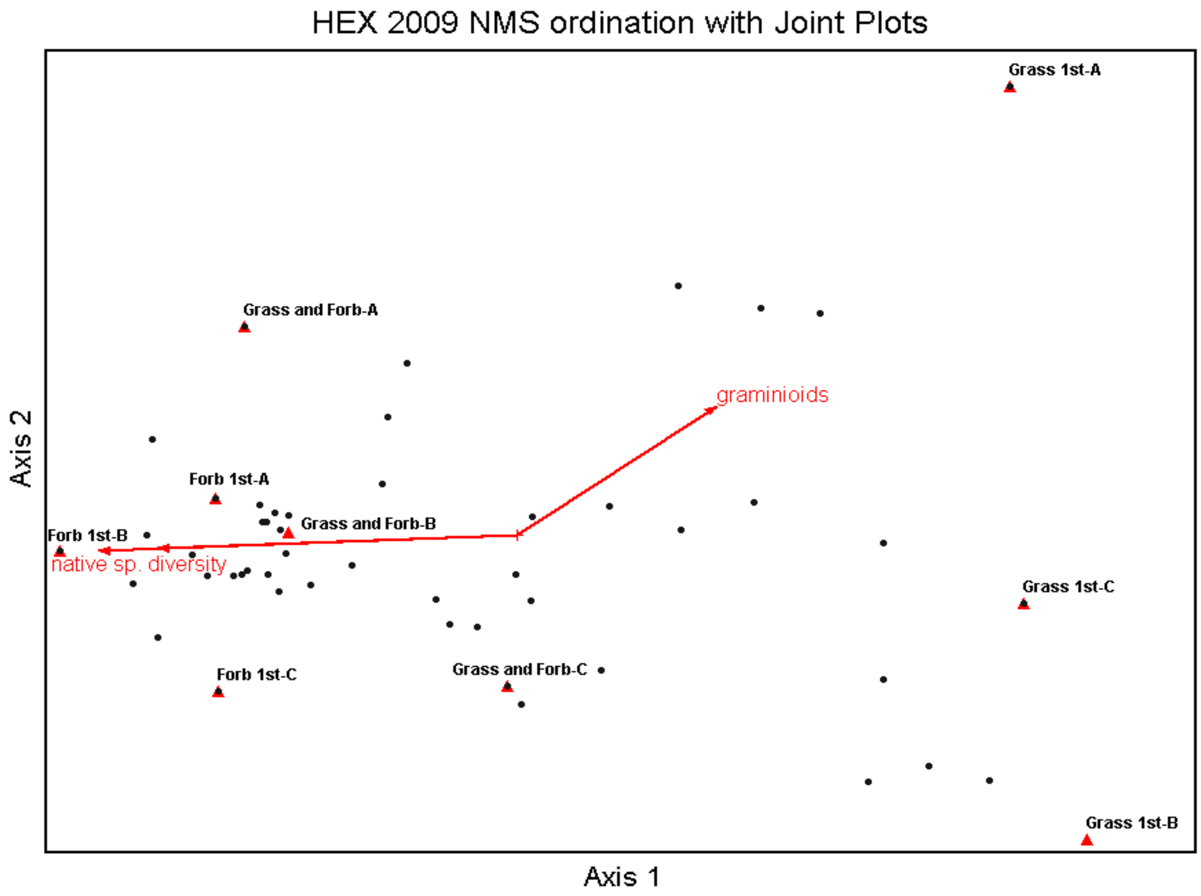

Figure 20. HEX 2009 NMS ordination (with Sørensens measure) measure showing treatment plots (Δ) in species (•) space with the strongest plant variable associations (graminoids) and categories (native species diversity).

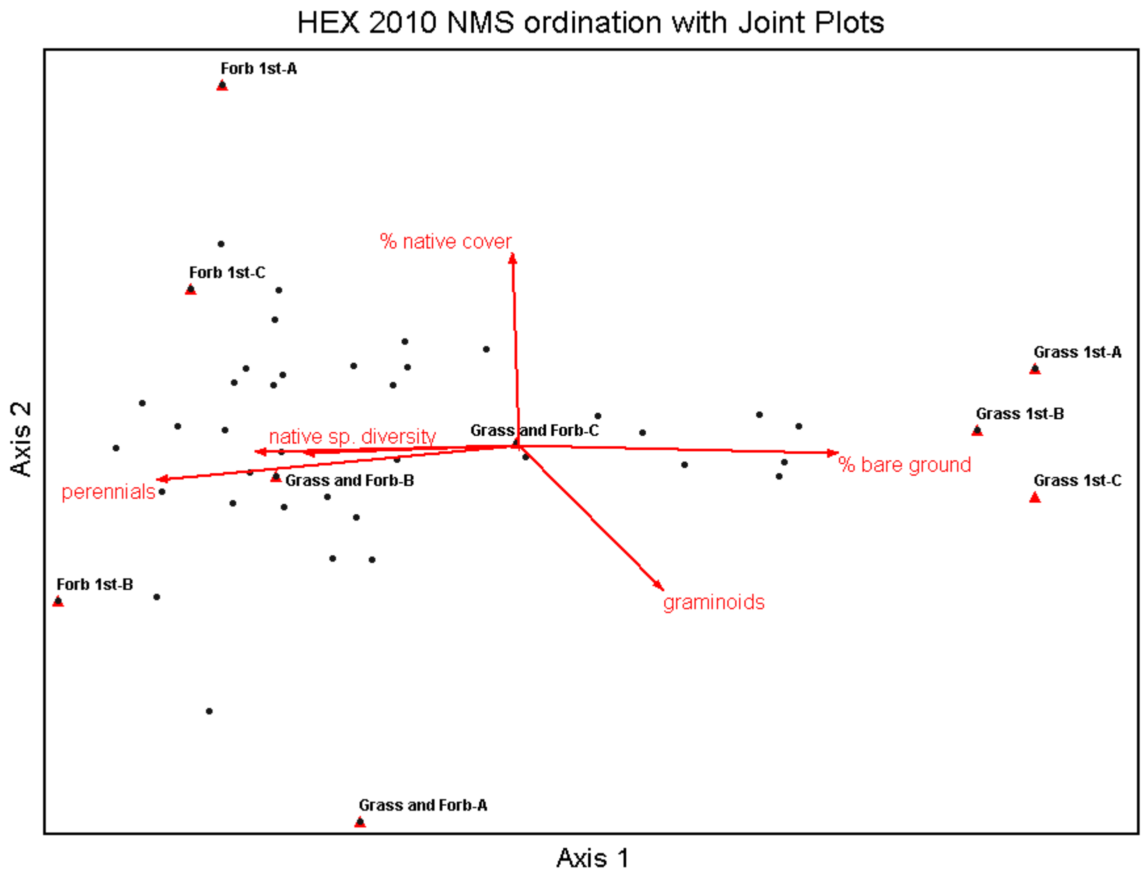

Figure 21. HEX 2010 NMS ordination (with Sørensens measure) showing treatment plots (Δ) in species (•) space with the strongest plant variable associations (graminoids and perennials) and categories (native species diversity, % native cover and % bare ground).

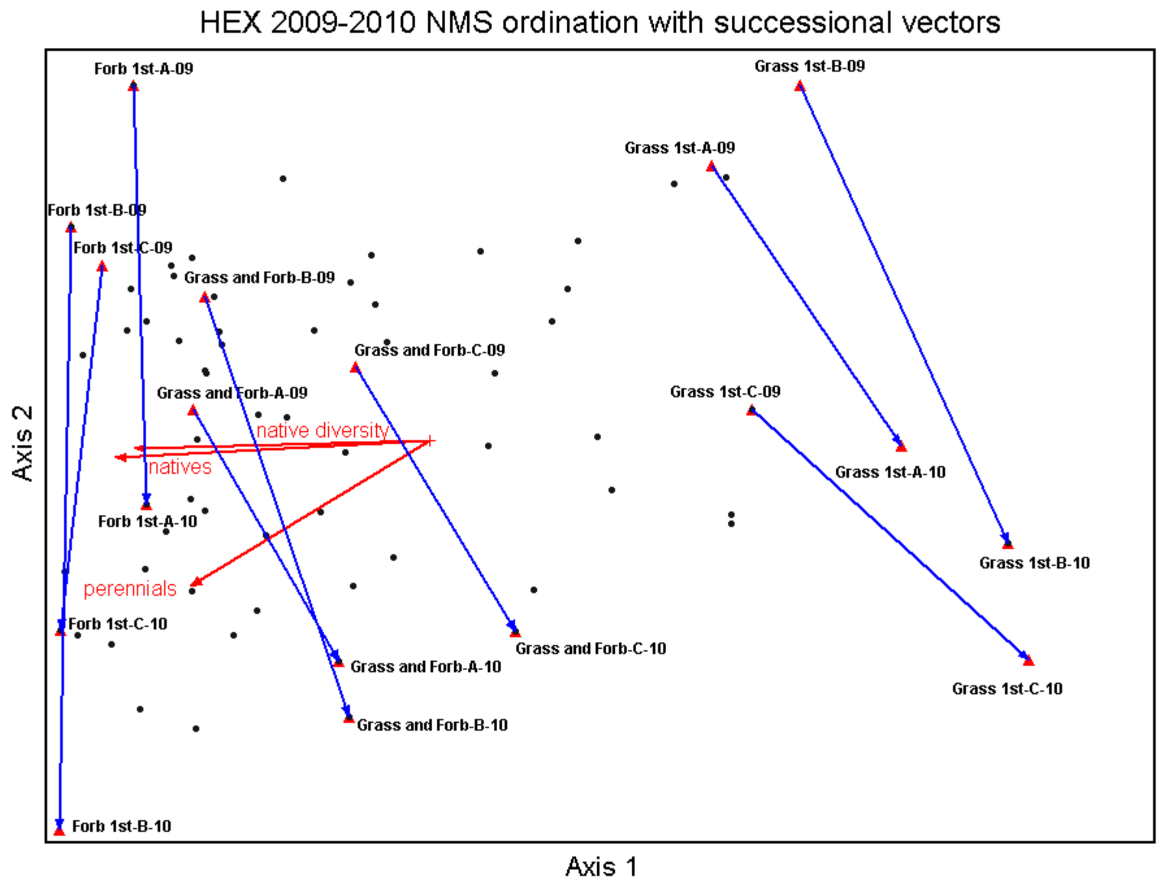

Figure 22. HEX 2009-2010 NMS ordination (with Sørensens measure) showing treatment (Δ) changes over time (2009-2010) with successional vectors in species (•) space; including the strongest plant variable associations (natives and perennials) and categories (native species diversity).

DISCUSSION

From the results of two years of monitoring the Hutchinson wet prairie seeding experiment, I can conclude that the G&F treatment shows the highest in native plant species abundance and species richness. However, results may change after a couple more years since native grasses were not incorporated into the F1 treatment during the time of data collection (See Appendix J for all native species seeded into treatments). Drilling grasses in first results in high native cover but lower species richness in comparison to the other treatments. Low species richness in the G1 treatment is most likely a result of early, rapid grass emergence that creates shading and therefore retards forb emergence.

The results from this experiment indicate that high native plant species richness can be obtained by seeding in native grasses and forbs at one time instead of sowing in grasses and forbs one year after the other. Substantial decreases in introduced plant species cover from 2009 to 2010 were observed in all seeding treatments, which indicates that native plant species can compete successfully with introduced species for space within the wet prairie community, at least over a two-year time period. Established native perennial grasses limit space available for exotic annual seeds to germinate and limit light available to exotics reducing exotic productivity and shifting competitive interactions in favor of natives (Corbin and D'Andonio, 2004).

Species area curves show that samples of a relatively small total area (9 m^2) can capture a high proportion of the total species present at a site, and that many species can coexist in a relatively small area on the order of 1 m^2. Higher species richness occurred with the G&F or with F1 treatments which, again can likely be attributed to grasses shading out many forb species early in the spring, decreasing the diversity. It is also possible that the herbicide treatments used in the G1 plots decreased overall species richness in the plots by selecting against broad-leaved forbs. It may be that

that a higher diversity of forbs can coexist in a smaller area due to the small structure and size of many forb species. The species area curves suggest that data collected in the first year following restoration (2009) may not provide a good indication of the species richness that can be sustained over time, particularly for the G1 treatment. The F1 and G&F treatments maintained the same level of species richness from 2009 to 2010, whereas the G1 treatment had large changes in species diversity projection within one year. Again, this may be the result of management for weeds in the G1 seed treatment, which was treated with broad-leaf herbicides in 2008 and 2009.

The alternative hypotheses we proposed concerning the effect of seeding treatment on native species richness and native cover; specifically, that the F1 seeding treatment would have the highest native species richness and that the G1 seeding treatment would have the highest native plant cover, were not consistent with the observed data. Both the F1 and the G&F treatments had similarly high native plant richness in both years, and species richness was significantly greater in the F1 and G&F treatments than the G1 treatment (p-value=0.002) even though G1 was seeded with more natives (25 species) than either the F1 (17 species) or G&F (23 species) treatments.

The statistical tests for significant differences between treatments for data collected in 2010 indicated that there was a significant difference at the 10% level in native plant cover abundance (p-value=0.099) and a significant difference in native plant richness (p-value=0.004) at the 5% level. This lowered p-value of 0.099 in 2010 for native abundance (2009 p-value=0.464) suggests that after one year of growth and change between treatments a larger difference between treatments was occurring. The large increase of native percent cover between treatment years, specifically between the G1 and G&F treatments, suggests again the high potential for increased native cover by these treatments over a short period of time. In plots where grasses were not seeded in, as seen in the F1 treatment, there was actually a decrease in cover abundance of native species from 2009 to 2010.

The MRPP analysis supports the idea that plant community composition within treatments is changing over time. Effect size indicated large differences between treatments for 2009 but lower differences in 2010. Variability within treatments can be attributed to the arrangement of treatment replicates within the 4 hectare parcel. Some F1 and G&F strips had more grass cover because they neighbored a G1 treatment. These influences contributed to the lowered homogeneity within groups after the second year following plot establishment.

Ordination of the ecological community data in PC-ORD shows that there was an increase in cover of graminoids and perennials in a majority of the plots from 2009 to 2010. All treatments showed a shift towards the negative end of Axis 2 from 2009 to 2010 along Axis 2. The species with the highest negative correlation along this axis was *Juncus tenuis*, the one graminoid that was seeded in all treatments. There is also a noticeable trend in the grass seeded treatments with an increase in positive correlation along Axis 1 over one year. The species with the highest positive correlations to Axis 1 are *Agrostis exarata*, *Deschampsia cespitosa* and *Danthonia californica*. It can be concluded that these 4 species (*J. tenuis*, *A. exarata*, *D. cespitosa* and *D. californica*) are the dominants within this habitat and are responsible for most of the vegetation change in this plant community over time.

CONCLUSIONS

The major finding from this seeding experiment, and one that is readily applicable to management, is that seeding grasses and forbs together can result in high native cover and native species richness. It seems that seeding more forbs or grasses at a later time may increase the chances of soil disturbance during the seeding process increasing the chances of noxious weed establishment, since seeds of noxious weeds such as *Phalaris arundinacea* are easily transported through floodwaters. Studies on *P. arundinacea* concluded that invasibility of a wet prairie assemblage by *P. arundinacea* almost always increased when multiple disturbances or disturbances plus nutrients were combined (Kercher and Zedler, 2003). Furthermore, much of the land being restored to prairie is retired agricultural land with varying histories of cropping and weed compositions. Seeds of many agricultural weeds can persist for decades in the soil seed bank. A commonly used approach to restoration is to seed grass first in order to allow for continued use of broadleaf-specific chemicals to control broadleaf weed infestations. This practice has led to prairie habitats that are exceptionally grass-dominated, making it difficult to establish a diverse forb component in subsequent years, as seen in this experiment. A restoration approach in which forbs are seeded first, allowed establishing, and then grasses are over-seeded in light doses one to two years after the forb seeding maybe effective in situations where broadleaved weeds have been controlled for many years, such as in grass seed production fields.

Management practices will continue to play a key role in maintaining native species diversity and cover of native species in the Hutchinson restoration and wet prairie landscapes in general. Since the Hutchinson restoration is close to many farms, a major highway and a rail line, prescribed burning cannot be used as a management tool. The benefits of fire are graminoid suppression which allows openings for forbs to establish and in some cases certain forbs are stimulated by fire. Without this management tool the long term management for maintenance and enhancement of diversity will be a challenge. Other management tools, such as mowing, maybe a substitution for suppressing graminoids. However, research literature suggests that while mowing can encourage establishment of native communities by decreasing cover of exotic grasses (Dyer & Rice 1997, Hayes & Holl 2003, Hofmann & Isselstein, 2004) it can also favor exotic forbs (Hayes & Holl, 2003).

Future monitoring will be essential to document the long term trends in native species abundance and richness within the Hutchinson seeding experiment. If yearly monitoring continues, valuable information could be obtained on plant community changes among the different treatments. One critical piece of information will be whether the differences among seeding treatments will persist over time, decrease, or increase. With further monitoring it would also be interesting to study the changes in the wetland surface microtopography between treatments. Microtopography within a grassland habitat adds the structural component necessary for many organisms to live and thrive. Increasing microtopography within the site could possibly lead to the increase of wildlife biodiversity. Such increases in biodiversity are one of the main ecosystem services that are of value for protecting and restoring the wetland prairie habitat.

CHAPTER 4

FINAL CONCLUSIONS

Very few examples of wet prairie wetlands remain in the Northern Willamette Valley ecoregion, and the remnants that are left have been impacted by human activities, so that not all remnants exhibit high native diversity and cover. Our results are consistent with findings of other studies on the importance of microtopography in wet prairies, in that remnants that have retained their historic microtopography and restorations with incipient microtopography seem to provide the best sites for native species diversity and that soil conditions that enhance native species richness are associated with microtopographic variability (graminoid pedestals) and variability in hydrologic conditions within the site. However, even with the micro-environmental variability that microtopography provides, wet prairie remnant and restored sites can and have been invaded by invasive perennial graminoids such as *Phalaris arundinacea* which overtime can suppress the biomass of native communities (Martina and vonEnde, 2008). Various strategies to manage such invasions have been used for the different sites within this study; including longer term flooding into the summer, mowing and haying, solarization, burning, and chemical applications. Intense management strategies to suppress invasive species may have negative impacts on the establishment or persistence of sensitive native species in remnant habitats. Therefore managing for high cover abundance of native species in a remnant prairie may make it difficult to meet management objectives for high native species richness and diversity. Even though burning has been reported through the literature (Pendergrass et al., 1999; Taylor, 1999; Clark and Wilson, 2001; Jancaitis, 2001; Wilson 2002) as one of the better management techniques for maintaining relic, native wetland species, such as *Lomatium bradshawii*, in many cases this practice is not allowed due to smoke hazards or threats to urban developments in the Portland area.

The results of the seeding experiments presented here indicate that native plant species sown into newly restored wet prairie can outcompete non-natives when starting from bare soil or a clean cover crop, at least in the first few years following restoration. Depending on the former management of the property before restoration, a restored wetland can have over 100% native cover with up to 50+ species in one year. Costs of seed and propagules, as well as the cost of labor to plant native species and combat weeds at these sites are likely the biggest obstacle to achieving high levels of native cover and diversity over a large area. Yet, drilling of native grass and forbs together can achieve management objectives without the costs of multiple seedings.

A longer-term study would be required to determine how resilient these highly diverse restorations are to invasion. Monitoring is essential to understanding the succession of wetland prairie plant composition over time. The results presented here indicate that consistent, long-term management that takes into account key processes such as increasing organic matter content and moisture content in the soil and the establishment and maintenance of microtopography is likely the only way to maintain native diversity and cover.

Significance of research

Preservation of native species diversity, carbon sequestration and denitrification are important ecosystem services that can be provided by wet prairie ecosystems. As seen in this research, over time soil organic matter decreases when remnant prairie is converted tto agriculture, while restoration of native prairie vegetation can help increase organic matter. Soils of restored wetland prairies may be a carbon sink, which is a relevant service considering our growing concern with increased global carbon and its affect on the earth’s warming. Denitrification of surface waters is another potential benefit of wet prairies. Preliminary results presented here indicate that denitrification tends to be higher on remnant wet prairie sites relative to nearby agricultural areas.

Nitrogen leaching is a common concern for farmers and ecologists. Excess nitrates are one of the largest problems in aquatic systems within agricultural regions. Wetlands and wet prairies can provide buffers to remove nutrients that would otherwise enter our waterways. Owing to the reducing environment in wetland soils and a lack of available oxygen in wetlands, nitrite and nitrate (NO_2 and NO_3) are used for microbial processes resulting in production of nitrogen gas, N_2. Nitrogen gas is less soluble in water and unavailable for aquatic plants, so, denitrification can reduce algal growth and mitigate some of the alterations of the trophic relationships in aquatic systems that result from algal blooms. Nutrient pollution and resulting algal blooms can affect the quality of water we drink and the diversity and species composition of aquatic communities.

As part of the US Fish and Wildlife Service recovery plan for endangered, rare and threatened plant species, wet prairie restoration and protection of wet prairie remnants have become high priority actions for genetic plant diversity conservation throughout the Willamette Valley. Thus far, the endangered species, *Lomatium bradshawii*, was identified during the survey and its survival and proliferation is of importance, especially since this species population has only recently been known to exist in the Northern Willamette Valley Ecoregion (US Fish and Wildlife Service, 2010).

Other specific issues highlighted by this project are the alarming extent of deterioration and loss of wet prairie in the region, and the need for protection of wetland resources by enhancing our understanding of practices that lead to effective restoration. Wetland restoration is being considered as a watershed-scale tool for assisting in meeting societal needs for the ecosystem services mentioned (Willamette

Partnership, 2008). By quantifying the potential level of ecosystem services such as carbon sequestration, denitrification and native plant diversity that could result from wetland prairie restoration, it may become possible to incorporate the value of wetland ecosystem services into credit trading programs. The work presented here is a first step towards that goal, additional research at more sites will help further quantify these relationships.

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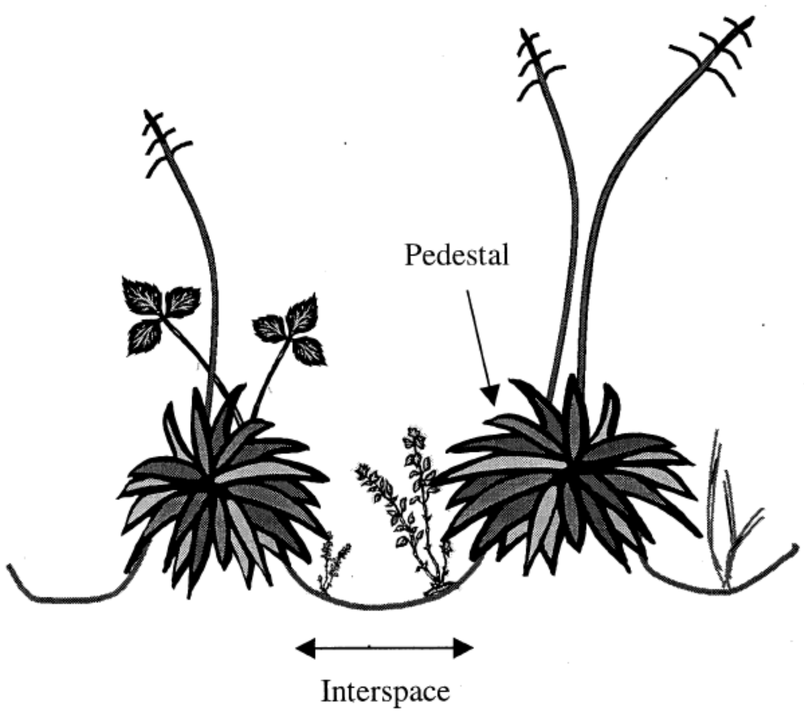
APPENDICES

Appendix A. Pedestal-Interspace microtopography of Willamette Valley wet prairie



Appendix B. Site management information-soils and hydrology

	Soil						Hydrology				
	pH	% OM	% moist	% clay	% silt	% sand	Sept	Nov	Feb	April	July
HR1	6	6.8	26.6	64	32	4	N	Y	N	N	N
HR2	6	6.9	24.3	62	34	4	N	Y	N	N	N
HR3	6	7.2	24.4	64	32	5	N	Y	N	N	N
LJ1	6	6.7	24.2	56	36	9	N	Y	N	N	N
LJ2	6	7.2	23.3	57	34	9	N	N	N	N	N
LJ3	6	5.5	23.2	40	35	24	N	Y	N	N	N
GPN1	6	6.3	25.0	54	38	8	N	N	N	N	N
GPN2	5	6.1	25.7	54	38	8	N	N	Y	Y	N
GPN3	6	6.7	28.7	54	36	10	N	N	Y	Y	N
GPS1	5	7.3	32.4	45	44	11	N	N	Y	Y	N
GPS2	5	7.0	32.4	43	50	6	N	N	Y	Y	N
GPS3	6	5.9	34.3	50	46	5	N	N	Y	Y	N
GM1	5	13.2	36.4	62	22	16	N	N	Y	Y	N
GM2	5	13.4	35.3	57	24	19	N	N	Y	N	N
GM3	6	12.4	36.4	56	20	24	N	N	Y	N	N
KN1	6	8.9	39.6	82	16	2	N	N	Y	Y	Y
KN2	7	8.7	35.4	81	17	2	N	N	Y	Y	Y
KN3	7	9.8	43.1	81	18	1	N	N	Y	Y	Y
Z1	6	6.3	22.2	54	38	8	N	N	N	N	N
Z2	6	6.4	21.6	52	38	10	N	N	N	N	N
Z3	6	6.3	22.9	57	40	2	N	N	N	N	N
WE1	6	4.3	24.5	44	48	8	N	N	Y	N	N
WE2	6	3.2	26.9	40	48	13	N	N	Y	N	N
WE3	6	3.6	25.3	40	50	10	N	N	Y	N	N
GPA1	5	5.8	17.9	49	42	9	N	N	N	N	N
GPA2	5	6.4	18.5	48	44	8	N	N	N	N	N
GPA3	6	5.7	17.8	54	40	6	N	N	N	N	N

Appendix B (cont.). Site management information-restoration management and seeds

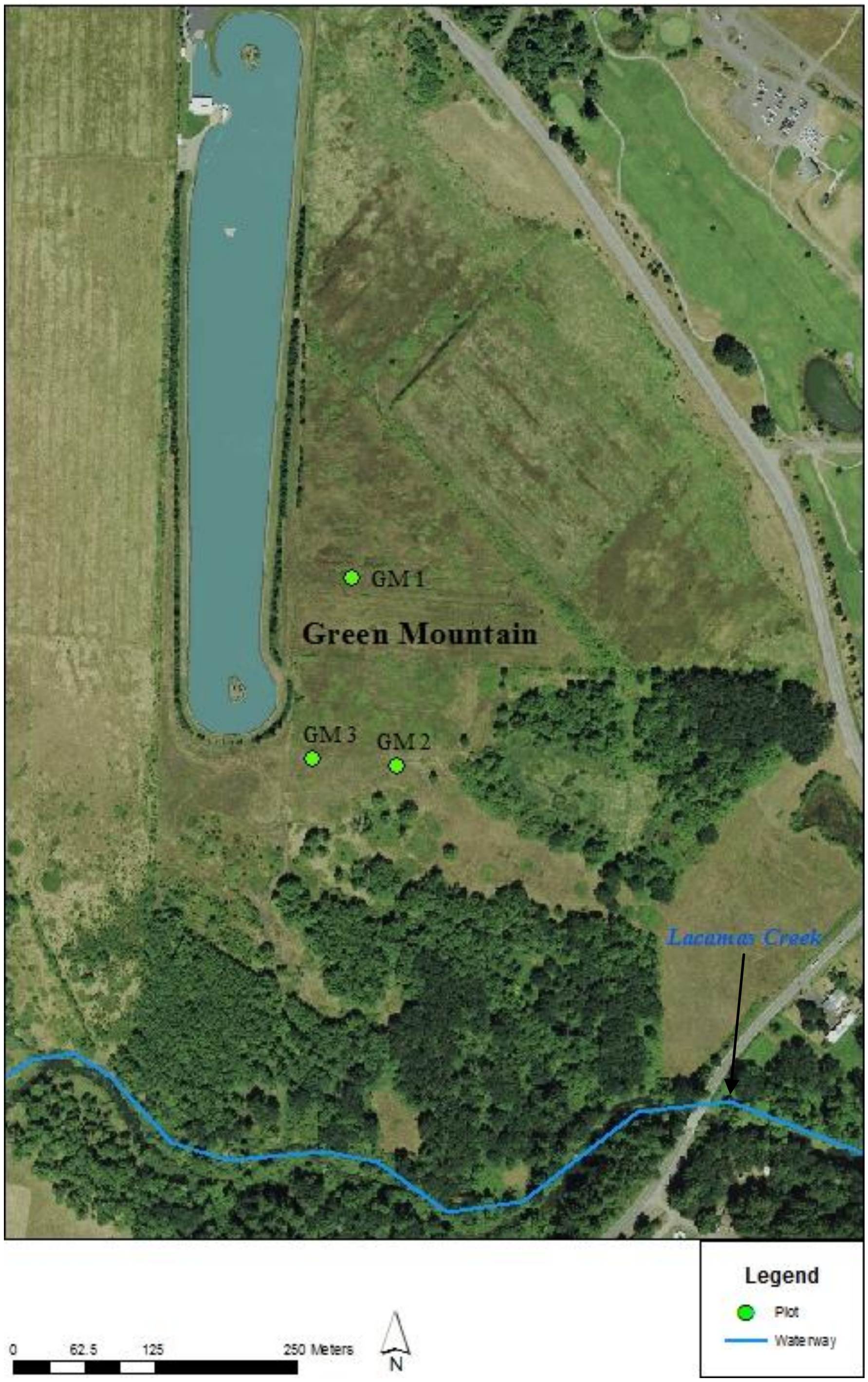
	Restoration management					Seeds	
	fire	yrly-chem	yrly-mow	clean crops	# yrs in restoration/ management	# of native seed types	total lbs of seed/acre
HR1	N	Y	Y	Y	3	25	14
HR2	N	Y	Y	Y	3	25	14
HR3	N	Y	Y	Y	3	25	14
LJ1	N	Y	Y	Y	4	18	21
LJ2	N	Y	Y	Y	4	18	21
LJ3	N	Y	Y	Y	4	18	21
GPN1	Y	Y	Y	N	8	31	22
GPN2	Y	Y	Y	N	8	31	22
GPN3	Y	Y	Y	N	8	31	22
GPS1	Y	Y	Y	N	3	ukn	ukn
GPS2	Y	Y	Y	N	3	ukn	ukn
GPS3	Y	Y	Y	N	3	ukn	ukn
GM1	Y	Y	N	N	13	1	NA
GM2	Y	Y	N	N	13	1	NA
GM3	Y	Y	N	N	13	1	NA
KN1	N	N	N	N	3	7	NA
KN2	N	N	N	N	3	7	NA
KN3	N	N	N	N	3	7	NA
Z1	N	Y	Y	N	NA	NA	NA
Z2	N	Y	Y	N	NA	NA	NA
Z3	N	Y	Y	N	NA	NA	NA
WE1	N	Y	Y	N	NA	NA	NA
WE2	N	Y	Y	N	NA	NA	NA
WE3	N	Y	Y	N	NA	NA	NA
GPA1	N	Y	N	N	NA	NA	NA
GPA2	N	Y	N	N	NA	NA	NA
GPA3	N	Y	N	N	NA	NA	NA

Appendix C. GPS coordinates in decimal degrees for plot locations in remnant, restored and agricultural sites using Garmin eTrex Legend

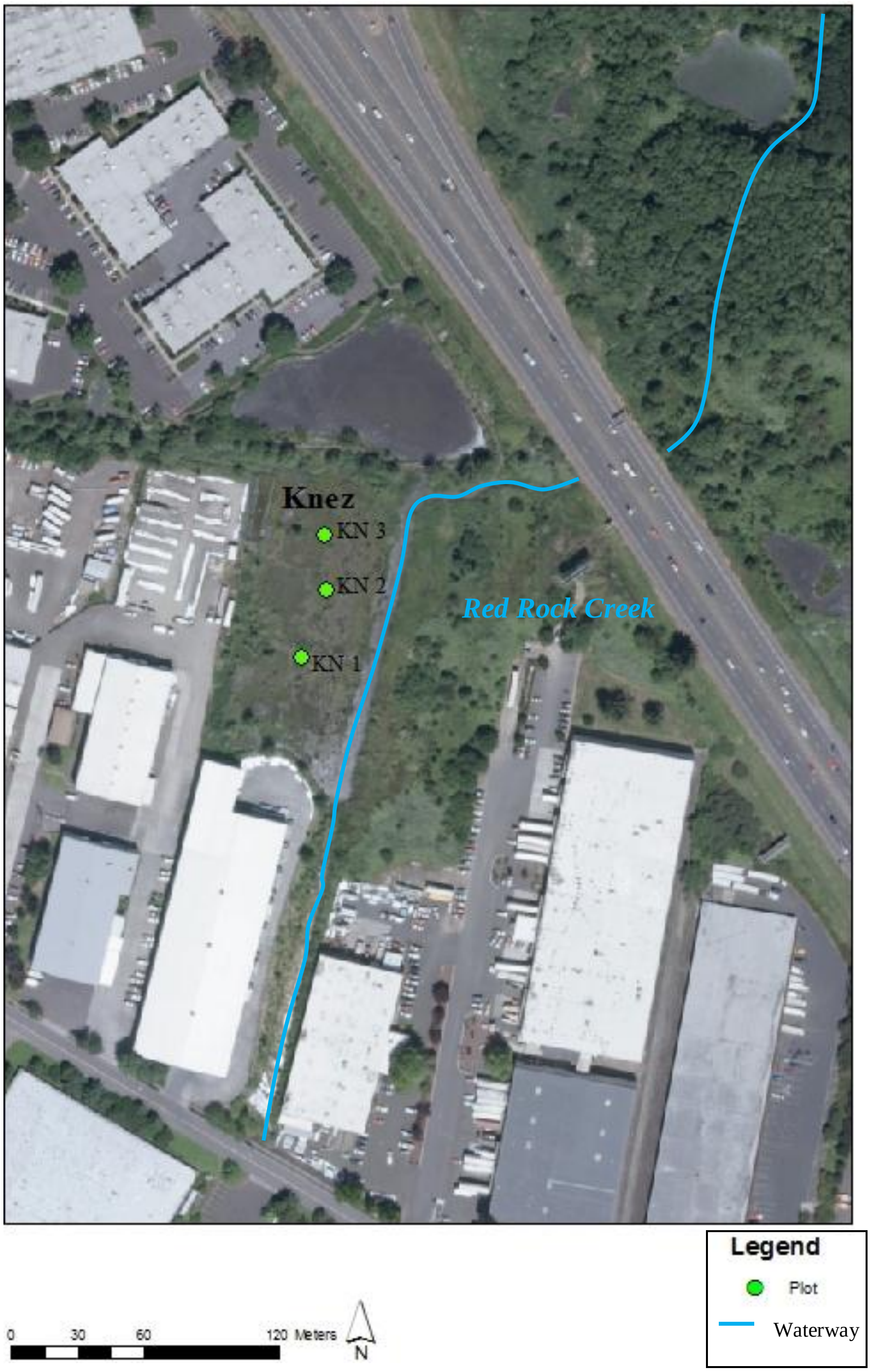
Marker	Latitude ° N	Longitude ° W
GM1	45.64299	122.46092
GM2	45.64151	122.46037
GM3	45.64154	122.46133
GPA1	45.40184	122.93258
GPA2	45.40204	122.93228
GPA3	45.40216	122.93181
GPN1	45.40742	122.93274
GPN2	45.40584	122.93169
GPN3	45.40441	122.92997
GPS1	45.40409	122.93529
GPS2	45.40375	122.93377
GPS3	45.40453	122.93638
HR1	45.47461	123.12891
HR2	45.47428	123.12889
HR3	45.47440	123.12849
KN1	45.43034	122.75963
KN2	45.43062	122.75950
KN3	45.43084	122.75952
LJ1	45.48526	123.11220
LJ2	45.48392	123.11313
LJ3	45.48443	123.11249
WE1	44.96873	123.22648
WE2	44.96871	123.22681
WE3	44.96874	123.22777
Z1A	45.50023	123.10258
Z2A	45.49999	123.10236
Z3A	45.49891	123.10148

Appendix D. Site maps with GPS plot locations and major waterways

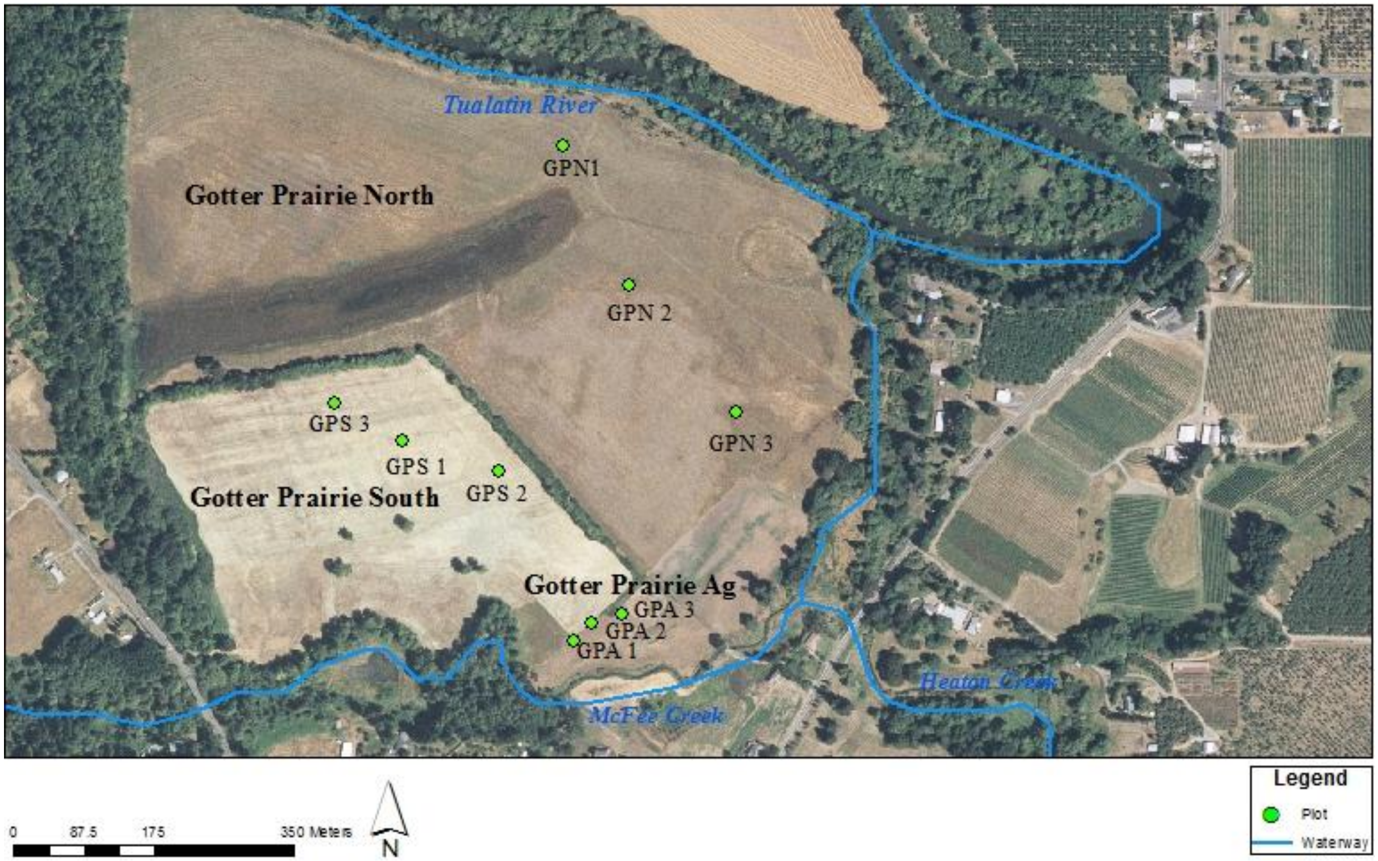
Appendix D1. Map of Green Mountain site with plot locations and major waterways



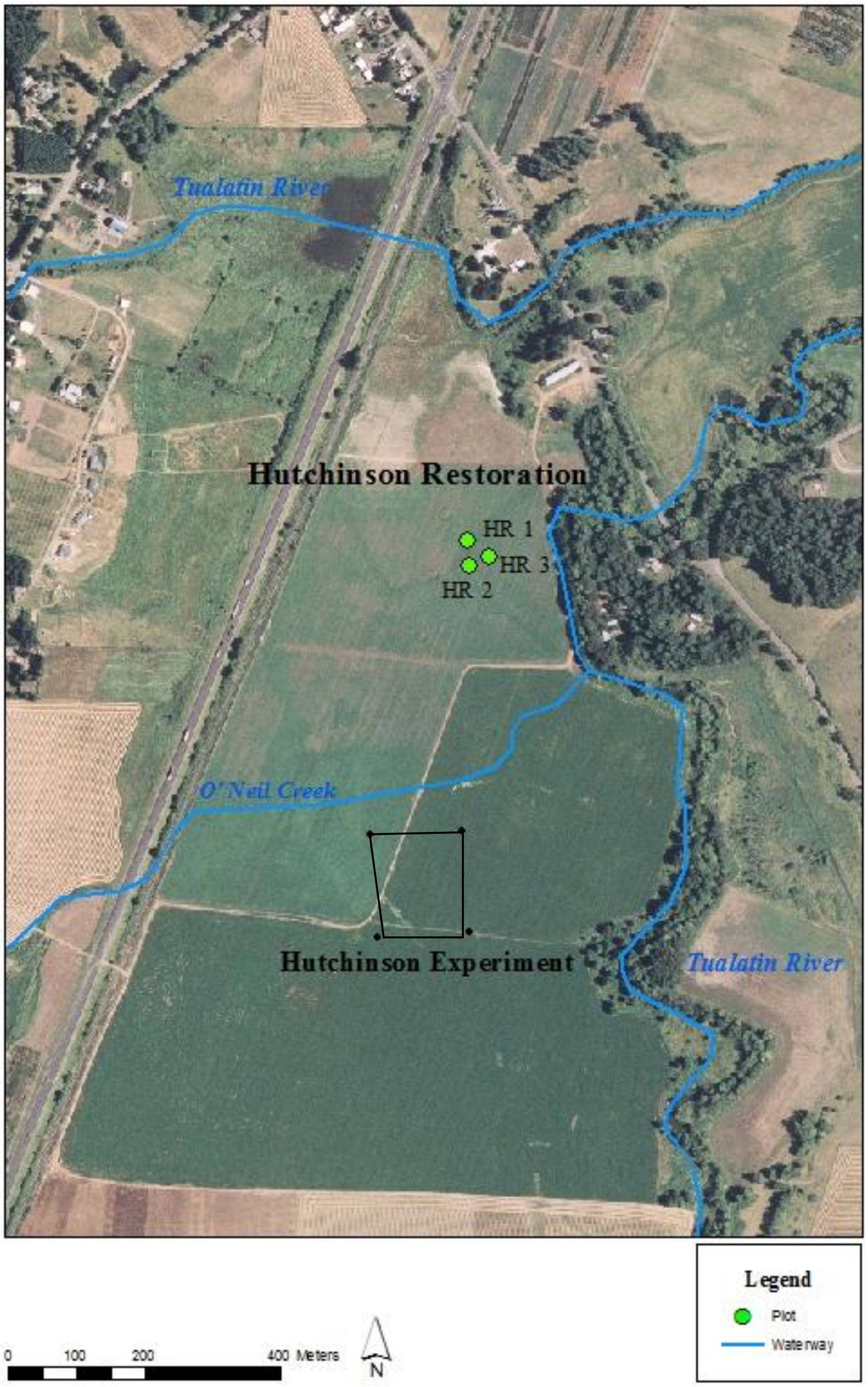
Appendix D2. Map of Knez site with plot locations and major waterways



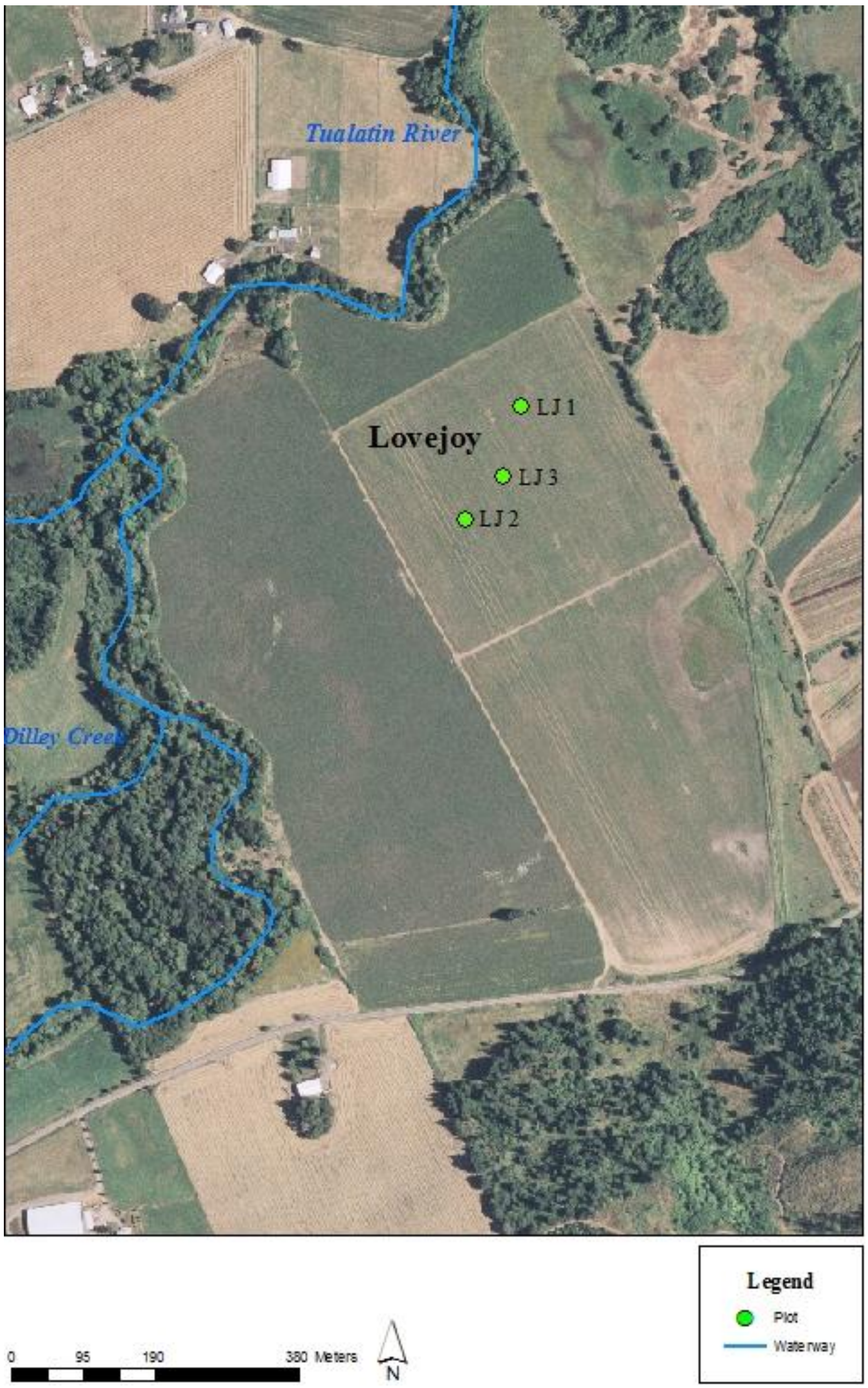
Appendix D3. Map of Gotter Prairie North, Gotter Prairie South and Gotter Prairie Agriculture sites with plot locations and major waterways



Appendix D4. Map of Hutchinson site with plot locations and major waterways



Appendix D5. Map of Lovejoy site with plot locations and major waterways



Appendix D6. Map of Westbrook site with plot locations and major waterways

Appendix D7. Map of Zurcher site with plot locations and major waterways

Appendix E. Species list and status (native or introduced) for Green Mountain

Green Mountain

Genus and Species	**USDA Symbol**	**N/I**
Agrostis capillaris	AGCA5	I
Agrostis stolonifera	AGST2	I
Alopecurus pratensis	ALPR3	I
Amelanchier alnifolia	AMAL2	N
Anthoxanthum odoratum	ANOD	I
Bromus hordeaceus	BRHO2	I
Bromus racemosus	BRRA2	I
Camassia quamash	CAQU2	N
Cardamine breweri	CABR6	N
Carex densa	CADE8	N
Carex ovalis	CAOV8	N
Carex unilateralis	CAUN3	N
Centaurium exaltum	CEEX	N
Cerastium dubium	CEDU2	I
Deschampsia cespitosa	DECE	N
Downingia elegans	DOEL	N
Eleocharis acicularis	ELAC	N
Eleocharis palustris	ELPA3	N
Epilobium densiflorum	EPDE4	N
Epilobium watsonii	EPWA3	N
Eryngium petiolatum	ERPE7	N
Fraxinus latifolia	FRLA	N
Galium trifidum	GATR2	N
Holcus lanatus	HOLA	I
Continued on next page		

<u>Green Mountain (cont.)</u>

Genus and Species	USDA Symbol	N/I
Juncus tenuis	JUTE	N
Leontodon taraxacoides	LETAT	I
Leucanthemum vulgare	LEVU	I
Lomatium bradshawii	LOBR	N
Madia glomerata	MAGL2	N
Madia sativa	MASA	N
Montia linearis	MOLI4	N
Myosotis discolor	MYDI	I
Myosotis laxa	MYLA	N
Parentucellia viscosa	PAVI	I
Perideridia gairdneri	PEGA3	N
Plagiobothrys figuratus	PLFI	N
Plantago lanceolata	PLLA	I
Poa pratensis	POPR	I
Potentilla gracilis	POGR9	N
Prunella vulgaris	PRVU	N
Ranunculus occidentalis	RAOC	N
Rorippa sylvestris	ROSY	I
Rosa eglanteria	ROEG	I
Schedonorus phoenix	SCPH	I
Symphyotrichum spathulatum	SYSPS	N
Veronica serpyllifolia	VESE	N
Vicia tetrasperma	VITE	I

Appendix E (cont.). Species list and status (native or introduced) for Knez

<u>Knez</u>

Genus and Species	USDA Symbol	N/I
Agrostis stolonifera	AGST2	I
Alopecurus geniculatus	ALGE2	I
Carex densa	CADE8	N
Carex obnupta	CAOB3	N
Carex unilateralis	CAUN3	N
Cirsium vulgare	CAUN3	N
Deschampsia cespitosa	DECE	N
Dipsacus fullonum	DIFU2	I
Epilobium sp. (NIF)4	UKN	UKN
Fraxinus latifolia	FRLA	N
Galium aparine	GAAP2	N
Galium trifidum	GATR2	N
Holcus lanatus	HOLA	I
Hordeum brachyantherum	HOBR2	N
Juncus acuminatus	JUAC	N
Juncus effusus	JUEF	N
Juncus tenuis	JUTE	N
Lactuca serriola	LASE	I
Lotus corniculatus	LOCO6	I
Myosotis laxa	MYLA	N
Phalaris arundinacea	PHAR3	I
Rumex sp. (NIF)	UKN	UKN
Typha latifolia	TYLA	N
UNKN grass (NIF)	UKN	UKN
Vicia americana	VIAM	N
Vicia tetrasperma	VITE	I

Appendix E (cont.). Species list and status (native or introduced) for Gotter Prairie South

<u>Gotter Prairie South</u>

Genus and species	USDA Symbol	N/I
Alopecurus geniculatus	ALGE2	I
Cardamine breweri	CABR6	N
Carex ovalis	CAOV8	N
Camassia quamash	CAQU2	N
Deschampsia cespitosa	DECE	N
Eleocharis acicularis	ELAC	N
Eleocharis palustris	ELPA3	N
Eriophyllum lanatum	ERLA6	N
Juncus bufonius	JUBU	N
Juncus tenuis	JUTE	N
Leontodon taraxacoides	LETAT	I
Phalaris arundinacea	PHAR3	I
Spiranthes romanzoffiana	SPRO	N

Appendix E (cont.). Species list and status (native or introduced) for Gotter Prairie North

Gotter Prairie North

Genus and species	USDA symbol	N/I
Agrostis exarata	AGEX	N
Alopecurus geniculatus	ALGE2	I
Anthemis cotula	ANCO2	I
Beckmannia syzigachne	BESY	N
Carex densa	CADE8	N
Camassia quamash	CAQU2	N
Carex unilateralis	CAUN3	N
Centaurium erythraea	CEER5	I
Convolvulus arvensis	COAR4	I
Crepis setosa	CRSE2	I
Danthonia californica	DACA3	N
Deschampsia cespitosa	DECE	N
Eleocharis acicularis	ELAC	N
Epilobium densiflorum	EPDE4	N
Eriophyllum lanatum	ERLA6	N
Eryngium petiolatum	ERPE7	N
Fraxinus latifolia	FRLA	N
Hordeum brachyantherum	HOBR2	N
Continued on next page		

Gotter Prairie North (cont.)

Genus and species	USDA symbol	N/I
Juncus tenuis	JUTE	N
Leontodon taraxacoides	LETAT	I
Lotus unifoliolatus	LOUNU	N
Lupinus polyphyllus	LUPO2	N
Madia sativa	MASA	N
Mentha pulegium	MEPU	I
Parentucellia viscosa	PAVI3	I
Plectritis congesta	PLCO4	N
Plagiobothrys figuratus	PLFI	N
Plagiobothrys scouleri	PLSC2	N
Poa annua	POAN	I
Potentilla gracilis	POGR9	N
Prunella vulgaris	PRVU	N
Psilocarphus elatior	PSEL	N
Rumex crispus	RUCR	I
Spiranthes romanzoffiana	SPRO	N
Veronica perigrina	VEPE2	N

Appendix E (cont.). Species list and status (native or introduced) for Hutchinson

Hutchinson

Genus and species	USDA symbol	N/I
Agrostis exarata	AGEX	N
Anthemis cotula	ANCO2	I
Bromus carinatus	BRCA5	N
Cerastium glomeratum	CEGL2	I
Cirsium arvense	CIAR4	I
Daucus carota	DACA6	I
Deschampsia cespitosa	DECE	N
Deschampsia elongata	DEEL	N
Elymus glaucus	ELGL	N
Epilobium ciliatum	EPCI	N
Leontodon taraxacoides	LETAT	I
Matricaria discoidea	MADI6	I
Plantago major	PLMA2	I
Plagiobothrys scouleri	PLSC2	N
Poa annua	POAN	I
Polygonum lapathifolium	POLA4	N
Polypogon monspeliensis	POMO5	I
Veronica perigrina	VEPE2	N

Appendix E (cont.). Species list and status (native or introduced) for Lovejoy

Lovejoy

Genus and Species	USDA Symbol	N/I
Agrostis exarata	AGEX	N
Anthemis cotula	ANCO2	I
Avena fatua	AVFA	I
Barbarea verna	BAVE	I
Capsella bursa-pastoris	CABU2	I
Circium arvense	CIAR4	I
Dactylis glomerata	DAGL	I
Danthonia californica	DACA3	N
Daucus carota	DACA6	I
Deschampsia cespitosa	DECE	N
Deschampsia elongata	DEEL	N
Epilobium wattsonii	EPWA3	N
Eriophyllum lanatum	ERLA6	N
Hemizonia sp.	UKN	UKN
Hordeum brachyantherum	HOBR2	N
Kickxia elatine	KIEL	I
Lactuca saligna	LASA	I
Lactuca serriola	LASE	I
Leontodon taraxacoides	LETAT	I
Leucanthemum vulgare	LEVU	I
Lolium perenne	LOPE	I
Continued on next page		

Lovejoy (cont.)

Genus and Species	USDA Symbol	N/I
Lotus sp.	UKN	UKN
Lupinus polyphyllus	LUPO2	N
Madia sativa	MASA	N
Matricaria discoidea	MADI6	I
Parentucellia viscosa	PAVI3	I
Plagiobothrys scouleri	PLSC2	N
Plantago lanceolata	PLLA	I
Plantago major	PLMA2	I
Poa annua	POAN	I
Poa sp.	UKN	UKN
Poa trivialis	POTR2	I
Psilocarphus elatior	PSEL	N
Ranunculus orthorhynchus	RAOR3	N
Raphanus sativus	RASA2	I
Rumex crispus	RUCR	I
Sidalcea campestris	SICA2	N
Sisymbrium officinale	SIOF	I
Sonchus asper	SOAS	I
Trifolium hybridum	TRHY	I
Verbascum blattaria	VEBL	I
Veronica perigrina	VEPE2	N

Appendix E (cont.). Species list and status (native or introduced) for Zurcher and Westbrook

Zurcher

Genus and Species	USDA Symbol	N/I
Cirsium sp.	UKN	UKN
Convolvulus arvensis	COAR4	I
Kickxia elatine	KIEL	I
Schedonorus phoenix	SCPH	I

Westbrook

Genus and Species	USDA Symbol	N/I
Convolvulus arvensis	COAR4	I
Hypochaeris radicata	HYRA3	I
Schedonorus phoenix	SCPH	I

Appendix E (cont.). Species list and status (native or introduced) for Gotter Prairie Agriculture

Gotter Prairie Ag

Genus and Species	USDA Symbol	N/I
Anthemis cotula	ANCO2	I
Chenopodium album	CHAL7	I
Convolvulus arvensis	COAR4	I
Cynodon dactylon	CYDA	I
Draba verna	DRVE2	I
Echinochloa crus-galli	ECCR	I
Lactuca serriola	LASE	I
Leontodon taraxacoides	LETAT	I
Misopates orontium	MIOR	I
Plantago major	PLMA2	I
Polygonum aviculare	POAV	I
Portulaca oleracea	POOL	I
Solanum physalifolium	SOPH	I
Sonchus asper	SOAS	I
Spergula arvensis	SPAR	I
Trifiolium sp.	UKN	UKN
Veronica peregrina	VEPE2	N
Zea mays	ZEMA	I

Appendix F: Species traits cover percent per treatment in Hutchinson Experiment

GRASS FIRST 2009					
Species names	**USDA CODE**	**Status**	**Duration**	**Growth Form**	**Av. % cover**
Agrostis exarata	AGEX	N	P	G	35.0
Anthemis cotula	ANCO2	I	A	F	0.8
Arabidopsis thaliana	ARTH	I	A	F	0.5
Cerastium glomeratum	CEGL2	I	A	F	1.3
Convolvulus arvensis	COAR4	I	P	F	0.2
Crepis sp.	CREPI	UKN		F	5.7
Daucus carota	DACA6	I	A	F	2.3
Danthonia californica	DACA3	N	P	G	5.4
Deschampsia cespitosa	DECE	N	P	G	10.2
Deschampsia elongata	DEEL	N	P	G	5.7
Elymus glaucus	ELGL	N	P	G	0.7
Gnaphalium palustre	GNPA	N	A	F	0.1
Hypochaeris sp	HYPOC	UKN		F	0.1
Juncus bufonius	JUBU	N	A	G	1.8
Kickxia elatine	KIEL	I	A	F	0.1
Leontodon taraxacoides	LETAT	I	P	F	2.7
Lotus corniculatus	LOCO6	I	P	F	0.1
Lolium perenne	LOPE	I	P	G	6.7
Matricaria discoidea	MADI6	I	A	F	0.1
Navarretia squarrosa	NASQ	N	A	F	0.1
Phleum pratense	PHPR3	I	P	G	0.1
Plantago major	PLMA2	I	P	F	0.8
Plagiobothrys scouleri	PLSC2	N	A	F	7.4
Poa annua	POAN	I	A	G	7.7
Psilocarphus elatior	PSEL	N	A	F	0.7
Rorippa curvisiliqua	ROCU	N	A	F	0.1
Sonchus asper	SOAS	I	A	F	0.1
Trifolium pratense	TRPR2	I	A	F	0.1
Veronica perigrina	VEPE2	N	A	F	1.4
TOTAL					**97.9**

GRASS FIRST 2010					
Species names	**USDA CODE**	**Status**	**Duration**	**Growth Form**	**Av. % cover**
Agrostis exarata	AGEX	N	P	G	30.8
Bromus hordeaceus	BRHO2	I	A	G	0.1
Cerastium glomeratum	CEGL2	I	A	F	0.1
Daucus carota	DACA6	I	A	F	0.3
Danthonia californica	DACA3	N	P	G	20.4
Deschampsia cespitosa	DECE	N	P	G	33.9
Deschampsia elongata	DEEL	N	P	G	7.8
Juncus bufonius	JUBU	N	A	G	0.7
Kickxia elatine	KIEL	I	A	F	0.4
Leontodon taraxacoides	LETAT	I	P	F	3.0
Lolium perenne	LOPE	I	P	G	1.9
Plantago major	PLMA2	I	P	F	0.2
Plagiobothrys scouleri	PLSC2	N	A	F	0.3
Poa annua	POAN	I	A	G	4.6
Psilocarphus elatior	PSEL	N	A	F	0.1
UNKNOWN DICOT	UK99DI	UKN			0.1
Veronica perigrina	VEPE2	N	A	F	0.5
TOTAL					**105.1**

GRASS AND FORB 2009					
Species names	**USDA CODE**	**Native status**	**Duration**	**Growth Form**	**Av. % cover**
Agrostis capillaris	AGCA5	I	P	G	0.1
Agrostis exarata	AGEX	N	P	G	13.3
Anthemis cotula	ANCO2	I	A	F	0.6
Cerastium glomeratum	CEGL2	I	A	F	0.4
Cirsium arvense	CIAR4	I	P	F	0.1
Convolvulus arvensis	COAR4	I	P	F	0.2
Crepis capillaris	CRCA3	I	A	F	0.1
Crepis sp.	CREPI	UKN		F	3.2
Daucus carota	DACA6	I	A	F	0.8
Danthonia californica	DACA3	N	P	G	1.6
Deschampsia cespitosa	DECE	N	P	G	1.9
Deschampsia elongata	DEEL	N	P	G	5.7
Downingia elegans	DOEL	N	A	F	0.2
Elymus glaucus	ELGL	N	P	G	0.1
Epilobium glaberrimum	EPGL	N	P	F	0.1
Epilobium sp (cf. watsonii)	EPILO	UKN		F	0.1
Eriophyllum lanatum	ERLA6	N	P	F	7.5
Hypochaeris sp	HYPOC	UKN		F	0.1
Juncus bufonius	JUBU	N	A	G	4.9
Juncus tenuis	JUTE	N	P	G	2.2
Kickxia elatine	KIEL	I	A	F	0.1
Lactuca saligna	LASA	I	A	F	0.4
Leontodon taraxacoides	LETAT	I	P	F	28
Lotus corniculatus	LOCO6	I	P	F	0.6
Lolium perenne	LOPE	I	P	G	0.1
Lythrum hyssopifolium	LYHY3	I	A	F	0.1
Matricaria discoidea	MADI6	I	A	F	0.1
Navarretia squarrosa	NASQ	N	A	F	0.3
Plagiobothrys figuratus	PLFI	N	A	F	0.2
Plantago major	PLMA2	I	P	F	16.6

Continued on next page

GRASS AND FORB 2009 (cont.)					
Species names	**USDA CODE**	**Native status**	**Duration**	**Growth Form**	**Av. cover %**
Plagiobothrys scouleri	PLSC2	N	A	F	6.3
Poa palustris	POPA2	N	P	G	0.1
Prunella vulgaris	PRVU	N	P	F	6.6
Psilocarphus elatior	PSEL	N	A	F	4.9
Ranunculus orthorhynchus	RAOR3	N	P	F	0.1
Rorippa curvisiliqua	ROCU	N	A	F	0.9
Sonchus asper	SOAS	I	A	F	0.2
Trifolium hybridum	TRHY	I	P	F	17.8
Trifolium pratense	TRPR2	I	A	F	10.7
UNKNOWN DICOT	UK99DI	UKN			0.2
Verbascum blattaria	VEBL	I	A	F	0.9
Veronica perigrina	VEPE2	N	A	F	2.3
TOTAL					**147.6**

GRASS AND FORB 2010					
Species names	**USDA CODE**	**Status**	**Duration**	**Growth Form**	**Av. % cover**
Agrostis capillaris	AGCA5	I	P	G	0.3
Agrostis exarata	AGEX	N	P	G	18
Cerastium glomeratum	CEGL2	I	A	F	0.2
Cirsium arvense	CIAR4	I	P	F	0.1
Convolvulus arvensis	COAR4	I	P	F	0.4
Daucus carota	DACA6	I	A	F	0.2
Danthonia californica	DACA3	N	P	G	11.3
Deschampsia cespitosa	DECE	N	P	G	16.7
Deschampsia elongata	DEEL	N	P	G	4.9
Downingia elegans	DOEL	N	A	F	0.1
Equisetum arvense	EQAR	N	P	F	0.1
Eriophyllum lanatum	ERLA6	N	P	F	1.3
Fraxinus latifolia	FRLA	N	P	S	0.1
Hypochaeris sp	HYPOC	UKN		F	0.1
Juncus bufonius	JUBU	N	A	G	10.7
Juncus tenuis	JUTE	N	P	G	14.6
Kickxia elatine	KIEL	I	A	F	0.2
Lactuca saligna	LASA	I	A	F	0.1
Leontodon taraxacoides	LETAT	I	P	F	18.9
Lolium perenne	LOPE	I	P	G	0.1
Lythrum hyssopifolium	LYHY3	I	A	F	0.1
Lythrum portula	LYPO4	I	A	F	0.1
Mentha pulegium	MEPU	I	P	F	0.6
Navarretia squarrosa	NASQ	N	A	F	0.1
Phleum pratense	PHPR3	I	P	G	2.8
Plagiobothrys figuratus	PLFI	N	A	F	0.1
Plantago major	PLMA2	I	P	F	2.4
Plagiobothrys scouleri	PLSC2	N	A	F	4.8
Poa annua	POAN	I	A	G	3.5

Continued on next page

GRASS AND FORB 2010 (cont.)					
Species names	**USDA CODE**	**Status**	**Duration**	**Growth Form**	**Av. % cover**
Polygonum douglasii	PODO4	N	A	F	0.1
Potentilla gracilis	POGR9	N	P	F	6.3
Poa palustris	POPA2	N	P	G	0.1
Prunella vulgaris	PRVU	N	P	F	3.9
Psilocarphus elatior	PSEL	N	A	F	3.1
Ranunculus orthorhynchus	RAOR3	N	P	F	0.1
Rorippa curvisiliqua	ROCU	N	A	F	0.1
Sisyrinchium idahoense	SIID	N	P	F	0.1
Sonchus asper	SOAS	I	A	F	0.1
Taraxacum officinale	TAOF	I	P	F	0.1
Trifolium hybridum	TRHY	I	P	F	2.3
Trifolium repens	TRRE3	I	P	F	0.3
Veronica perigrina	VEPE2	N	A	F	0.7
TOTAL					**129.8**

FORB FIRST 2009					
Species names	**USDA CODE**	**Status**	**Duration**	**Growth Form**	**Av. % cover**
Agrostis exarata	AGEX	N	P	G	2.6
Alopecurus geniculatus	ALGE2	I	P	G	0.6
Anthemis cotula	ANCO2	I	A	F	0.9
Arabidopsis thaliana	ARTH	I	A	F	0.1
Aster sp.	ASTER	UKN		F	0.1
Cerastium glomeratum	CEGL2	I	A	F	1.7
Cirsium arvense	CIAR4	I	P	F	1.2
Crepis sp.	CREPI	UKN		F	0.6
Daucus carota	DACA6	I	A	F	3.9
Deschampsia cespitosa	DECE	N	P	G	0.1
Deschampsia elongata	DEEL	N	P	G	3.1
Downingia elegans	DOEL	N	A	F	0.2
Epilobium sp (cf. watsonii)	EPILO	UKN		F	0.3
Erigeron annuus	ERAN	N	A	F	0.2
Eriophyllum lanatum	ERLA6	N	P	F	11.2
Juncus bufonius	JUBU	N	A	G	2.6
Juncus tenuis	JUTE	N	P	G	4.4
Kickxia elatine	KIEL	I	A	F	0.2
Lactuca saligna	LASA	I	A	F	0.3
Leontodon taraxacoides	LETAT	I	P	F	10.3
Lolium perenne	LOPE	I	P	G	1.1
Lythrum hyssopifolium	LYHY3	I	A	F	0.1
Matricaria discoidea	MADI6	I	A	F	0.2
Navarretia squarrosa	NASQ	N	A	F	0.2
Parentucellia viscosa	PAVI3	I	A	F	0.1
Plagiobothrys figuratus	PLFI	N	A	F	0.9
Plantago major	PLMA2	I	P	F	22.3
Plagiobothrys scouleri	PLSC2	N	A	F	18.5
Poa annua	POAN	I	A	G	4.7
Polygonum aviculare	POAV	I	A	F	0.2

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FORB FIRST 2009 (cont.)					
Species names	**USDA CODE**	**Status**	**Duration**	**Growth Form**	**Av. % cover**
Potentilla gracilis	POGR9	N	P	F	5.6
Rorippa curvisiliqua	ROCU	N	A	F	5.5
Sisyrinchium idahoense	SIID	N	P	F	0.1
Sonchus asper	SOAS	I	A	F	1.5
Trifolium hybridum	TRHY	I	P	F	11.1
Trifolium pratense	TRPR2	I	A	F	20.8
UNKNOWN DICOT	UK99DI	UKN			0.1
Verbascum blattaria	VEBL	I	A	F	0.4
Veronica perigrina	VEPE2	N	A	F	8.4
TOTAL					**161.6**

FORB FIRST 2010					
Species names	**USDA CODE**	**Status**	**Duration**	**Growth Form**	**Av. % cover**
Agrostis capillaris	AGCA5	I	P	G	0.6
Agrostis exarata	AGEX	N	P	G	4.1
Alopecurus geniculatus	ALGE2	I	P	G	0.7
Anthemis cotula	ANCO2	I	A	F	0.1
Cerastium glomeratum	CEGL2	I	A	F	0.4
Centaurium sp.	CENTA2	UKN		F	0.1
Cirsium arvense	CIAR4	I	P	F	0.1
Convolvulus arvensis	COAR4	I	P	F	0.1
Daucus carota	DACA6	I	A	F	0.4
Danthonia californica	DACA3	N	P	G	0.1
Deschampsia cespitosa	DECE	N	P	G	0.2
Deschampsia elongata	DEEL	N	P	G	3.6
Downingia elegans	DOEL	N	A	F	0.2
Epilobium glaberrimum	EPGL	N	P	F	0.4
Erigeron annuus	ERAN	N	A	F	0.1
Eriophyllum lanatum	ERLA6	N	P	F	0.6
Juncus bufonius	JUBU	N	A	G	5.4
Juncus ensifolius	JUEN	N	P	G	0.1
Juncus tenuis	JUTE	N	P	G	22.7
Kickxia elatine	KIEL	I	A	F	0.1
Lactuca saligna	LASA	I	A	F	0.1
Leontodon taraxacoides	LETAT	I	P	F	18.2
Lotus corniculatus	LOCO6	I	P	F	1.2
Lolium perenne	LOPE	I	P	G	0.2
Lythrum hyssopifolium	LYHY3	I	A	F	0.1
Lythrum portula	LYPO4	I	A	F	0.2
Navarretia squarrosa	NASQ	N	A	F	0.2
Perideridia oregana	PEOR6	N	P	F	0.1
Plagiobothrys figuratus	PLFI	N	A	F	0.1
Plantago major	PLMA2	I	P	F	1.9

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FORB FIRST 2010 (cont.)					
Species names	**USDA CODE**	**Status**	**Duration**	**Growth Form**	**Av. % cover**
Plagiobothrys scouleri	PLSC2	N	A	F	17
Poa annua	POAN	I	A	G	1.2
Polygonum aviculare	POAV	I	A	F	0.8
Potentilla gracilis	POGR9	N	P	F	6.8
Prunella vulgaris	PRVU	N	P	F	5.3
Psilocarphus elatior	PSEL	N	A	F	6.4
Rorippa curvisiliqua	ROCU	N	A	F	0.1
Rumex conglomeratus	RUCO2	I	P	F	0.2
Sisyrinchium idahoense	SIID	N	P	F	0.1
Trifolium hybridum	TRHY	I	P	F	5.8
Trifolium pratense	TRPR2	I	A	F	0.6
Trifolium repens	TRRE3	I	P	F	5.2
Veronica perigrina	VEPE2	N	A	F	0.4
TOTAL					**111.9**

Appendix G. GPS coordinates in decimal degrees for plot locations in the Hutchinson Experiment using Garmin eTrex Legend

Marker	Latitude ° N	Longitude ° W
HE1A1	45.46940275	123.1299841
HE1A2	45.46939161	123.1300536
HE1A3	45.46936772	123.1305908
HE1B1	45.47048813	123.1284143
HE1B2	45.47050254	123.1288175
HE1B3	45.4704194	123.1290301
HE1C1	45.47052291	123.1307561
HE1C2	45.47062199	123.129723
HE1C3	45.47059944	123.1290674
HE2A1	45.46946285	123.1302994
HE2A2	45.46947182	123.1298536
HE2A3	45.46950024	123.1298351
HE2B1	45.46994741	123.1300524
HE2B2	45.4699138	123.1291533
HE2B3	45.46997834	123.1285207
HE2C1	45.4707214	123.1307324
HE2C2	45.47080287	123.129356
HE2C3	45.47077638	123.1289995
HE3A1	45.46985932	123.1289143
HE3A2	45.46980081	123.1299044
HE3A3	45.46971356	123.1305928
HE3B1	45.46993802	123.1308659
HE3B2	45.47002109	123.1300931
HE3B3	45.47006174	123.1299498
HE3C1	45.47023382	123.1306432
HE3C2	45.4702303	123.1296481
HE3C3	45.47042551	123.1283842

Appendix H. ANOVA tables of Hutchinson Experiment treatments from 2009 to 2010

HEX 2009-2010 Grass First Native Abundance ANOVA:

	Df	Sum Sq	Mean Sq	F value	**P value**
Treatment	1	988.170	988.170	7.991	**0.048**
Residuals	4	494.670	123.670		

HEX 2009-2010 Grass and Forb Native Abundance ANOVA:

	Df	Sum Sq	Mean Sq	F value	**P value**
Treatment	1	6800.700	6800.700	12.876	**0.023**
Residuals	4	2112.700	528.200		

HEX 2009-2010 Forb First Native Abundance ANOVA:

	Df	Sum Sq	Mean Sq	F value	**P value**
Treatment	1	1633.510	633.500	4.854	**0.092**
Residuals	4	1346.000	336.500		

Appendix H (cont.). ANOVA tables of Hutchinson Experiment treatments from 2009 to 2010

HEX 2009-2010 Grass First Native Richness ANOVA:

	Df	Sum Sq	Mean Sq	F value	**P value**
Treatment	1	8.167	8.167	4.900	**0.091**
Residuals	4	6.667	1.667		

HEX 2009-2010 Grass and Forb Native Richness ANOVA:

	Df	Sum Sq	Mean Sq	F value	**P value**
Treatment	1	2.667	2.667	1	**0.374**
Residuals	4	10.667	2.667		

HEX 2009-2010 Forb First Native Richness ANOVA:

	Df	Sum Sq	Mean Sq	F value	**P value**
Treatment	1	2.667	2.667	0.432	**0.547**
Residuals	4	24.667	6.167		

Appendix I. Hutchinson Experiment species with the highest R correlations on Axis 1 and Axis 2 for 2009, 2010 and both years

Genus and species	HEX 2009		HEX 2010		HEX 2009-2010	
	R values					
	Axis 1	Axis2	Axis 1	Axis 2	Axis 1	Axis 2
Agrostis exarata	**0.915**	-0.235	**0.812**	0.178	**0.85**	0.035
Anthemis cotula	0.079	**0.695**	-0.284	**-0.669**	-0.15	**0.773**
Cerastium glomeratum			-0.395	**-0.687**	-0.169	**0.654**
Crepis sp.	0.284	**-0.824**				
Danthonia californica	**0.709**	0.513	**0.866**	0.203	**0.834**	**-0.354**
Deschampsia cespitosa	**0.775**	0.035	**0.924**	0.108	**0.875**	**-0.331**
Downingia elegans	**-0.646**	0.284	**-0.784**	-0.423	**-0.721**	0.003
Equisetum arvense			-0.15	**0.693**		
Eriophyllum lanatum	**-0.754**	0.183			**-0.559**	0.344
Fraxinus latifolia			-0.15	**0.693**		
Hypochaeris sp	0.469	**0.606**	-0.15	**0.693**		
Juncus bufonius	-0.344	**-0.577**	-0.423	**0.636**		
Juncus tenuis	**-0.689**	0.077	**-0.865**	0.345	**-0.615**	**-0.61**
Kickxia elatine			**0.763**	-0.108		
Leontodon taraxacoides			-0.437	**-0.595**		
Lolium perenne	0.415	**-0.723**				
Lythrum hyssopifolium			-0.445	**0.744**		

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Genus and species (cont.)	HEX 2009		HEX 2010		HEX 2009-2010	
	R values					
	Axis 1	Axis2	Axis 1	Axis 2	Axis 1	Axis 2
Mentha pulegium			-0.15	**0.693**		
Navarretia squarrosa			-0.556	**-0.692**		
Plantago major	**-0.809**	-0.075	**-0.707**	0.366	**-0.575**	0.408
Plagiobothrys scouleri	**-0.573**	-0.401	**-0.788**	-0.372	**-0.725**	0.171
Polygonum aviculare			**-0.627**	0.015	-0.473	-0.409
Potentilla gracilis	**-0.819**	0.215			**-0.808**	-0.396
Poa palustris			-0.15	**0.693**		
Prunella vulgaris	**-0.63**	-0.103	**-0.799**	-0.075	**-0.708**	-0.271
Psilocarphus elatior	**-0.743**	-0.163	**-0.679**	-0.39	**-0.7**	0.326
Rorippa curvisiliqua	**-0.732**	0.196			**-0.512**	0.538
Rumex conglomeratus			-0.284	**-0.669**		
Sonchus asper	**-0.541**	0.078	-0.15	**0.693**		
Trifolium pratense	**-0.715**	0.211	-0.284	**-0.669**		
Trifolium repens			-0.474	**-0.618**		
Veronica perigrina	**-0.628**	0.209			-0.396	**0.582**

Appendix J. Hutchinson Experiment treatment seeding rates

Forbs first- Species of forbs seeded into the Forb first treatment in 2007

Year	Treatment	Species Name	lbs of pure live seed/acre
2007	Forbs first	*Symphyotrichum hallii*	0.1
2007	Forbs first	*Plagiobothrys figuratus*	0.3
2007	Forbs first	*Epilobium densiflora*	0.3
2007	Forbs first	*Potentilla gracilis*	0.3
2007	Forbs first	*Solidago canadensis*	0.1
2007	Forbs first	*Downingia elegans*	0.1
2007	Forbs first	*Grindelia integrifolia*	0.3
2007	Forbs first	*Eriophyllum lanatum*	0.2
2007	Forbs first	*Prunella vulgaris var. lanceolata*	0.3
2007	Forbs first	*Wyethia angustifolia*	0.1
2007	Forbs first	*Clarkia amoena*	0.1
2007	Forbs first	*Periderdia oregana*	0.1
2007	Forbs first	*Ranunculus occidentalis*	0.3
2007	Forbs first	*Ranunculus orthoryncus*	0.3
2007	Forbs first	*Sisyrinchium idahoense*	0.2
2007	Forbs first	*Camassia quamash*	0.2
2007	Forbs first	*Juncus tenuis*	0.3

<u>Grass and Forb</u>- Species of grasses and forbs seeded into the Grass and Forb treatment in 2007

Year	Treatment	Species Name	lbs of pure live seed/acre
2007	Grass & Forb	*Deschampsia cespitosa*	0.1
2007	Grass & Forb	*Danthonia californica*	4
2007	Grass & Forb	*Agrostis exarata*	0.2
2007	Grass & Forb	*Deschampsia elongata*	1
2007	Grass & Forb	*Juncus tenuis*	0.3
2007	Grass & Forb	*Bromus carinatus*	1
2007	Grass & Forb	*Elymus glaucus*	1
2007	Grass & Forb	*Symphyotrichum hallii*	0.1
2007	Grass & Forb	*Plagiobothrys figuratus*	0.3
2007	Grass & Forb	*Epilobium densiflora*	0.3
2007	Grass & Forb	*Potentilla gracilis*	0.3
2007	Grass & Forb	*Solidago canadensis*	0.1
2007	Grass & Forb	*Downingia elegans*	0.1
2007	Grass & Forb	*Grindelia integrifolia*	0.3
2007	Grass & Forb	*Eriophyllum lanatum*	0.2
2007	Grass & Forb	*Prunella vulgaris var. lanceolata*	0.3
2007	Grass & Forb	*Wyethia angustifolia*	0.1
2007	Grass & Forb	*Clarkia amoena*	0.1
2007	Grass & Forb	*Periderdia oregana*	0.1
2007	Grass & Forb	*Ranunculus occidentalis*	0.3
2007	Grass & Forb	*Ranunculus orthoryncus*	0.3
2007	Grass & Forb	*Sisyrinchium idahoense*	0.2
2007	Grass & Forb	*Camassia quamash*	0.2

<u>Grass first</u>- Species of grasses seeded in 2007 and forbs seeded in 2008 and 2009 in the Grass first treatment

Year	Treatment	Species Name	lbs of pure live seed/acre
2007	Grass first	*Deschampsia caespitosa*	0.1
2007	Grass first	*Danthonia californica*	4
2007	Grass first	*Agrostis exarata*	0.2
2007	Grass first	*Deschampsia elongata*	1
2007	Grass first	*Bromus carinatus*	1
2007	Grass first	*Elymus glaucus*	1
2008	Grass first	*Sisyrinchium idahoense*	0.2
2008	Grass first	*Camassia quamash*	0.2
2008	Grass first	*Downingia elegans*	0.1
2008	Grass first	*Clarkia amoena*	0.1
2008	Grass first	*Plagiobothrys figuratus*	0.3
2008	Grass first	*Prunella vulgaris var. lanceolata*	0.3
2008	Grass first	*Eriophyllum lanatum*	0.2
2008	Grass first	*Potentilla gracilis*	0.3
2008	Grass first	*Juncus tenuis*	0.3
2009	Grass first	*Ranunculus orthoryncus*	0.3
2009	Grass first	*Carex densa*	0.1
2009	Grass first	*Epilobium densiflora*	0.3
2009	Grass first	*Gridelia integrifolia*	0.3
2009	Grass first	*Periderdia oregana*	0.1
2008	Grass first	*Solidago canadensis*	0.1
2009	Grass first	*Symphyotrichum hallii*	0.1
2009	Grass first	*Wyethia angustifolia*	0.1
2009	Grass first	*Carex unilateralis*	0.3
2009	Grass first	*Ranunculus occidentalis*	0.3