AN ASSESSMENT OF THE NATIVE INVERTEBRATE POLLINATOR COMMUNITY AND FLORAL SOURCES IN GRASSLANDS OF EASTERN NORTH DAKOTA

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ABSTRACT

An Assessment of the Native Invertebrate Pollinator Community and Floral Sources in Grasslands of Eastern North Dakota

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Pollinators are critical for the proper functioning of natural ecosystems and they benefit or are required by many agricultural crops. Despite their importance, there is little information available to enhance restoration efforts or manage habitats to benefit pollinators, especially for native species. My study was conceived to determine the abundance, richness and diet breadth of native invertebrate pollinators using native and restored prairie grasslands in the prairie pothole region (PPR) of eastern North Dakota. I compared native pollinators on native grasslands managed by the U.S. Fish and Wildlife Service (FWS) and on Conservation Reserve Program (CRP) grasslands because they collectively constitute the largest land area of potential pollinator habitat in the United States PPR. Using vane traps and collecting pollinators visiting individual flowers, I evaluated change in species abundance, richness and pollinator/plant interactions biweekly from May to September in 2012 and 2013. I did not detect a significant difference in native pollinator abundance or richness between native and restored prairie grasslands. However, I did detect a decrease in native pollinator and a higher species turnover in CRP grasslands relative to my native grassland sites in 2013. Pollinator richness and abundance changed among seasons and locations, likely due to diverse pollinator taxa responding to temporal and spatial variations in the floral community.

In total, I observed 283 interactions corresponding to 55 plant taxa and 31 native bee taxa resulting in 177 unique links. Interactions and links were significantly higher on native grasslands, likely reflecting the higher diversity of blooming forbs in native prairie grasslands relative to CRP. Native bees were caught mostly on native plants in native grasslands and on introduced plant species on my CRP sites. My study suggests that pollinator abundance and richness in restored grasslands was similar to that in native grasslands. However, the floral composition varied by grassland type and CRP grasslands may not be as effective at providing stable pollinator habitat. My analyses of pollen loads of individual pollinators identified 53 plant species that could be added to seed mixtures to diversify native and restored sites for pollinators. Similarly, identifying management disturbances for native grasslands and mature CRP restorations would increase the diversity of plant species important to native pollinators to enhance the overall value to a diverse pollinator community.

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INTRODUCTION

Pollinators are critical to sustain healthy ecosystems and prosperous human populations (Klein et al. 2007). In fact, nearly a quarter million flowering plant species require pollinators, highlighting their role in the functioning of the planet's ecosystems, maintaining biodiversity and provisioning foods for society (Natural Research Council 2007). Indeed, the relationship between humans and pollinators dates back to ancient times. Europeans brought honey bees, *Apis mellifera*, to the United States at the time of settlement and swarms escaping from managed colonies quickly established an abundant feral population across the nation (Crane 1992). Those honey bees, along with native pollinators, were so abundant that pollination services were taken for granted until nearly the close of the 20th Century. However, over the past few decades, declines in the abundance and diversity of pollinators have been well documented for some species (NRC 2007), and there has been serious discussion among federal, state, university, nonprofit, and private sectors on causal factors and potential solutions.

A recent report on the Status of Pollinators in North America (NRC 2007), in conjunction with intense media coverage of honey bee colony declines beginning in 2006 (Skokstad 2007, Cox-Foster and vanEngelsdorp 2009), sparked a renewed and widespread interest in the role of honey and native bees in the pollination of agricultural crops, maintaining functioning ecosystems and enhancing biodiversity. Nonetheless, the need for agricultural pollination is increasing at the same time that pollinator numbers (Marcelo and Harder 2009) and insect pollinated plants are decreasing (Beismeijer et al.

2006). A main factor contributing to the decline in pollinator populations is the intensification of agricultural practices that disrupt native habitats, both in terms of essential nutrition provided by diverse forage sources and nesting sites (Kearns et al. 1998, Kremen et al. 2002, Steffan-Dewenter et al. 2005, Ricketts et al. 2008). Pesticides are a concomitant problem (Haarmann et al. 2002, Pettis et al. 2004) since they can have detrimental effects on bees that forage on contaminated flowers (Frazier et al. 2008, Mullin et al. 2010, Henry et al. 2012). Other hypotheses being considered to help explain declines in pollinators include habitat loss, pathogens and parasites, transgenic crops, invasive species, loss of ecosystem function, climate change and the synergistic effects (NRC 2007). While some work has been done to address some of these hypotheses, we currently do not have adequate knowledge to inform most management decisions, especially for native pollinators. Although healthy pollinator populations depend on landscapes that provide ample and nutritious sources of non-contaminated pollen and nectar-yielding flowers (Maurizio 1950, Mattila and Otis 2006), few field studies have quantified the availability of specific flowers or cover types across the landscape or the influence these factors have on the health of native pollinators over much of the United States (NRC 2007).

Land-use and inter-annual weather patterns affect the productivity and health of pollinators largely through their influence on flowering plants. Pollen and nectar from floral sources are required by pollinators to meet their nutritional requirements and sustain their populations. Historically, native landscapes provided a diversity of floral resources that sustained equally diverse native pollinator communities (e.g., Muir 1894).

As the human population expanded over the past century, the demand for resources provided by ecosystems has increased five-fold (Karlin 1995). As a consequence, entire landscapes have been modified for human use and what remains is highly altered; there is growing concern over the sustainability of modern ecosystems (Christensen et al. 1996). Landscape modifications to accommodate human needs have altered critical resources for pollinators (e.g., floral sources, ample nesting cavities) as agricultural crops have replaced native landscapes and pesticide use has increased. Not surprisingly, fragmentation of landscapes and pesticide use are two factors thought to contribute to the documented decline of native bees (NRC 2007) and honey bees (Naug 2009).

One area where the fragmentation of habitats has been especially intense is the glaciated prairie pothole region (PPR) of North America. Due to the mineral content of glacial till, prairie soils are highly fertile and the area has been extensively modified for agriculture. The PPR is a major geographic feature of North America comprising approximately 777,000 km^2 that includes portions of North Dakota, South Dakota, Montana, Minnesota, Iowa, Alberta, Saskatchewan, and Manitoba (Smith et *al*. 1964). Originally dominated by grasslands, the PPR also included over 20 million hectares of wetlands prior to European settlement (Tiner 1984, Millar 1989). The PPR is one of the most important areas in North America for breeding waterfowl and it is an important stopover location for many other migratory species. Today, over 50% of the wetland area in PPR of the United States (Tiner 1984) and 71% in Canada (Environment Canada 1986) have been drained for agricultural development. Because of the high value of the PPR to wildlife, the U.S. Fish and Wildlife Service (FWS) and many other conservation agencies

and organizations have land holdings in the PPR that are intensely managed for wildlife. The PPR is also of national significance for pollination services for agricultural crops, as it provides the forage and summer home for about half of the managed honey bee colonies in the United States (Dr. Jeff Pettis, USDA-ARS Bee Research Laboratory, personal communication). The loss of upland and wetland habitat in the PPR to accommodate agricultural production has stimulated considerable interest in restoring prairie grassland and wetlands for a wide variety of conservation purposes (Knutson and Euliss 2001, FSA 2006, FSA 2008, USFWS 2010) that provide and support an even greater diversity of ecosystem services (Euliss et al. 2006, Gleason et al. 2008). While we have learned a great deal about the ability of restoration of degraded lands to mitigate ecosystem services lost from agricultural development, there is a paucity of knowledge to guide restorations that benefit pollinators, especially native species.

Conservation lands in the PPR that potentially provide habitat for pollinators are under federal, state and private ownership. The FWS manages over 180,000 hectares in North Dakota alone. USDA has a number of conservation programs (e.g., Conservation Reserve Program (CRP), Grassland Reserve Program, Wildlife Habitat Incentive Program, and Wetlands Reserve Program) that restore lost habitat on private lands that varies considerably in area (e.g., from roughly 15,000 hectares in 1986 to more than 1 million during 1998 to 2007) in relation to shifting Farm Bill policy and global commodity markets. However, the CRP is the largest USDA restoration program. CRP is a voluntary program that helps agricultural producers and landowners to protect the integrity and productivity of specific sensitive lands for the benefit of conservation (e.g.,

controlling soil erosion, improving water and air quality, and restoring wildlife habitat). While much research has focused on the value of CRP lands to vertebrate wildlife (Reynolds et al. 1994, Haufler 2005), we generally do not know the benefits of these lands to native pollinator communities. New knowledge gained on the native pollinators and the plants they utilize will allow federal, state and private landowners to enhance restorations and manage lands to enhance their value to native pollinators.

To address this information need, I characterized native pollinator communities on native and restored grasslands and identified the flowering plants they used to obtain pollen in eastern North Dakota. Specifically, evaluating native prairie grasslands managed by the FWS and restored prairie grasslands enrolled in the USDA Conservation Reserve Program from September to May of 2012 and 2013. My objectives were to: 1) characterize and compare the pollinator community in the grassland types, and 2) identify major pollen floral sources for native bees in each grassland type that could be incorporated into future restoration efforts.

METHODS

Study Area

This study was conducted within the PPR of eastern North Dakota. The PPR is an immense and vital region of North America that supplies a variety of goods and services to humans. The region stretches from central Alberta through the eastern parts of the Dakota's and into Minnesota and Iowa (Figure 1). This landscape was forged from Pleistocene glaciation, which ended approximately 12,000 years ago. Glacial actions, especially scouring and melting, sculpted the present-day landscape that contains many thousands of depressional wetlands, a variety of grasslands and highly productive soils.

The study areas were in four separate locations in Eastern North Dakota (Figure 2). Each location consisted of a native prairie grassland located on FWS lands managed under the Native Prairie Adaptive Management (NPAM) system and on restored prairie grassland enrolled in CRP but under private ownership. Each locations grasslands (NPAM and CRP) were approximately a quarter section (~64 hectares) in area, and were separated by no more than 32 kilometers to increase the chance that each would experience similar weather conditions and no closer than 5 kilometers to ensure that each location would support an independent pollinator population (the flight range of honey bees is about 4 kilometers and that of native bees is usually less, but is dependent on body size; Araujo et al. 2004, Greenleaf et al. 2007). Management practices on FWS and CRP lands included burning, grazing, spraying and/or haying. These practices were beyond

my control, but any management disturbance was recorded to help interpret our findings.

The four locations used for the study were centered around and sampled on the following FWS lands:

1. **Arrowwood National Wildlife Refuge** - G14 Pastures (Stutsman County)—72 hectares of grasslands and wooded coulees located along the James River in the drift prairie.
2. **Tewaukon Wetland Management District** - Hartleben Unit (Richland County)—25 hectares composed of wetlands, tall grass prairie remnants, and riparian habitats located near the Wild Rice River in the Red River Valley.
3. **Sully's Hill National Game Reserve** - Sully's Hill Native Prairie Unit (Benson County) —62 hectares consisting of prairie habitats to forested hills along the southern shore of Devils Lake within the drift prairie (Figure 3).
4. **Kulm Wetland Management District** - Geiszler Unit 1 (McIntosh County)—roughly 65 hectares of mixed-grass prairie and wetlands, located in the Missouri Coteau.

These sites were selected based on meetings with and recommendations from FWS Biologists. Each CRP study site was chosen based on its proximity to the NPAM grassland and landowner willingness to participate in the study. The four sites were:

1. **Arrowwood CRP** – roughly 52 hectares enrolled in Conservation Practice (CP)-1 (i.e., Establishment of Permanent Introduced Grasses and Legumes).
2. **Tewaukon CRP** – roughly 73 hectares enrolled in CP-4D (i.e., Permanent Wildlife Habitat).
3. **Sully's Hill CRP 2012** – roughly 55 hectares enrolled in CP-1.
4. **Sully's Hill CRP 2013 –** roughly 71 hectares enrolled in CP-4D (i.e., Permanent Wildlife Habitat) (Figure 4).
5. **Kulm CRP** – roughly 59 hectares enrolled in CP-2 (Establishment of Permanent Native Grasses).

In the fall of 2012, the landowner of the Sully's Hill CRP terminated his CRP site, so a new CRP field was located for the 2013 season. The 2013 CRP site was located 2.7 kilometers south of the previous CRP sampled in 2012.

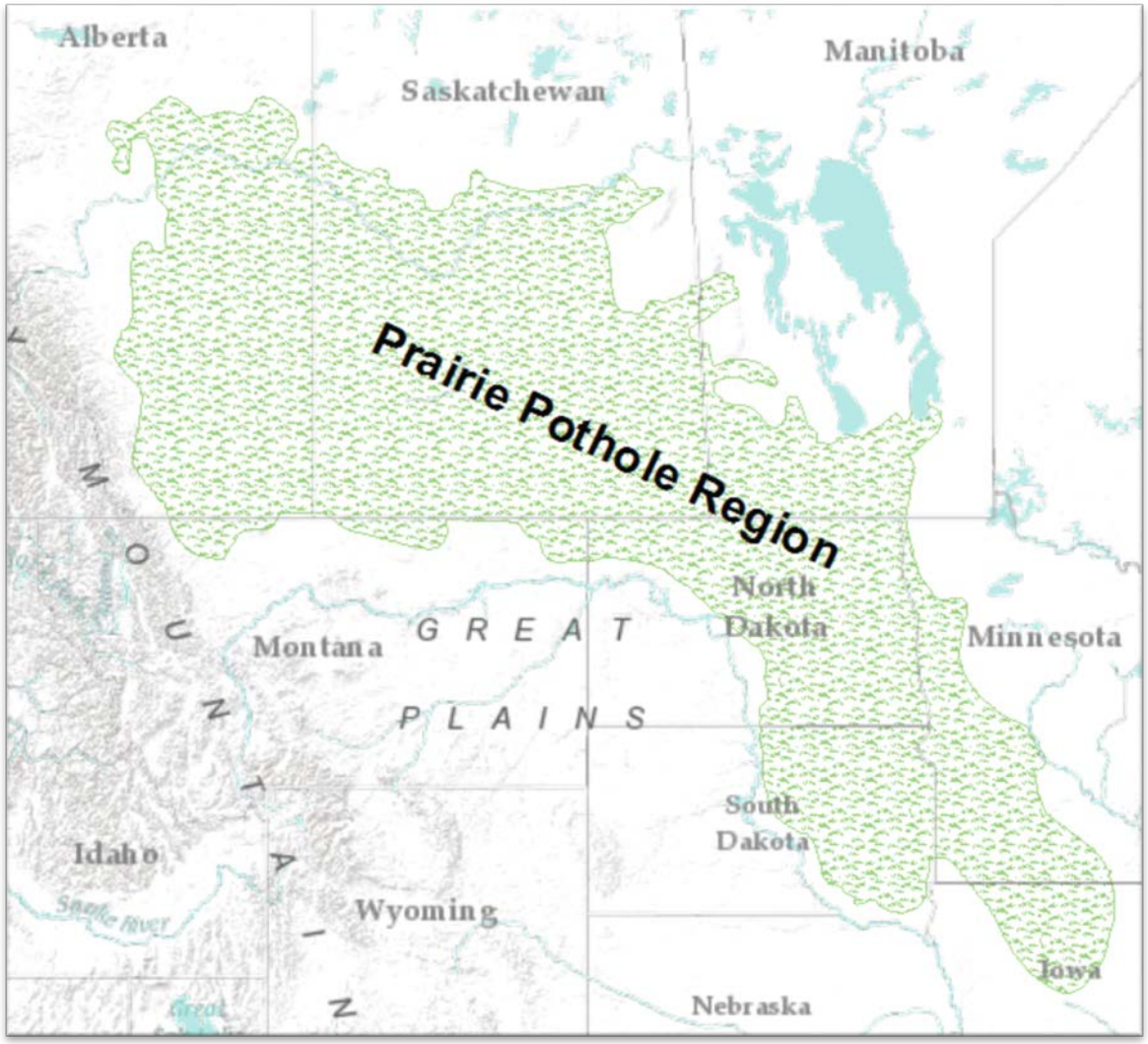

Figure 1. The prairie pothole region (PPR) of North America (shaded in).

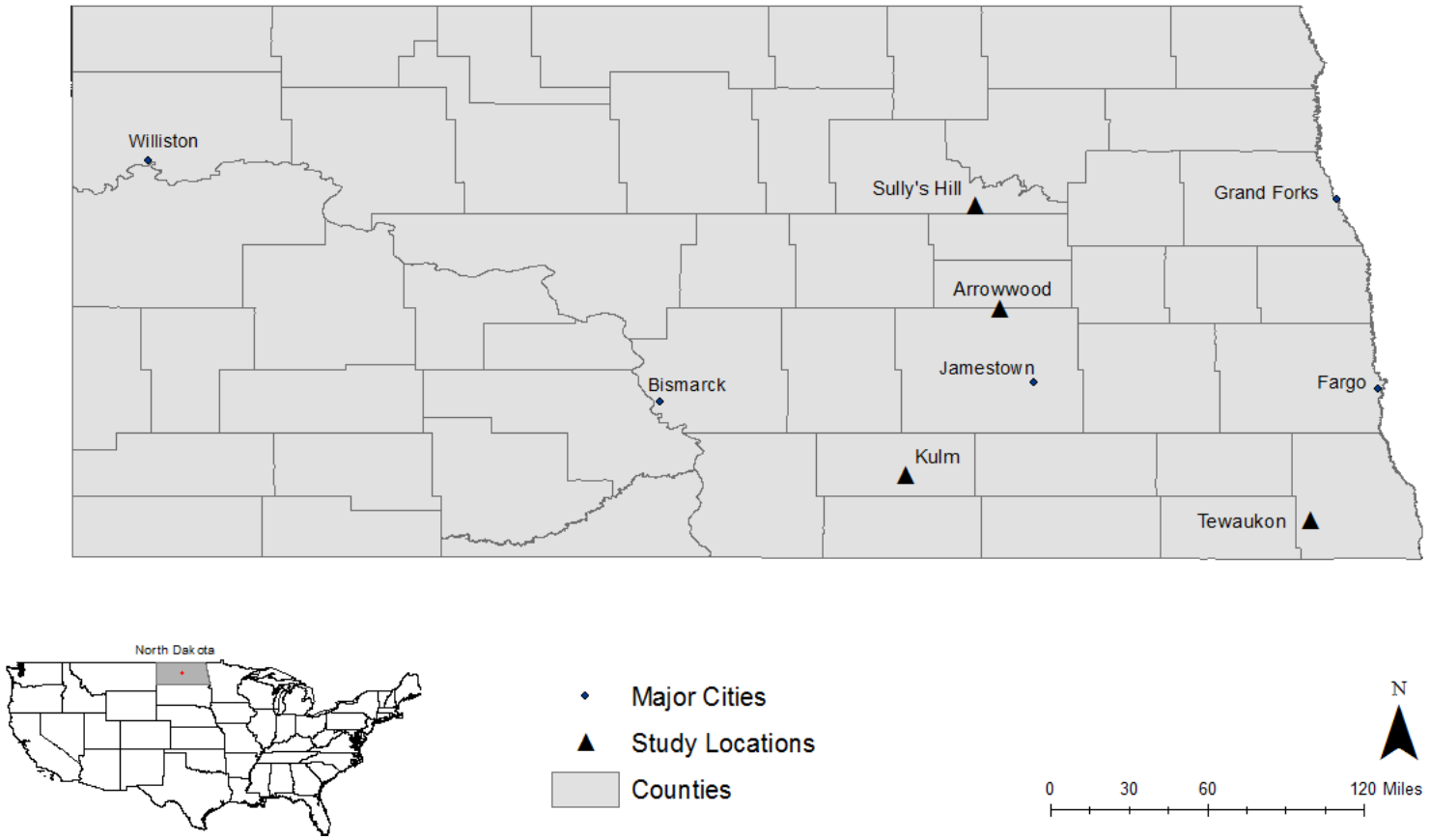

Figure 2. Study locations in eastern North Dakota. At each location two study sites were chosen, a native prairie grassland located on United States Fish and Wildlife Service managed lands and an adjacent restored prairie grassland enrolled in the United States Department of Agriculture's Conservation Reserve Program.

Figure 3. Sully's Hill native prairie unit (NPAM) on 22 August 2013 highlighting the late-summer forage including sunflowers and blazing stars.

Figure 4. Sully's Hill restored prairie unit (CRP) on 16 July 2013 with alfalfa in bloom.

Experimental Design

The NPAM transect design (Gannon et al. 2011) was used for sampling pollinators and vegetation from May to September in 2012 and 2013. The NPAM transects are 25 meters long by 0.1-meter-wide and are surveyed annually on FWS lands to document changes in the vegetation community in response to specific management disturbances; major management goals are to increase native flora and decrease invasive species, especially smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*) (Gannon et al. 2011). FWS personnel generated transects on my CRP sites using the same GIS methodology used to generate NPAM transects on FWS lands. Transects were separated by at least 65 meters to each other and were buffered 5 meters around native sod boundaries to reduce the risk of transects falling on fences, wetlands, and shelterbelts. The Tewaukon NPAM site was small (25 hectares) and only 9 transects could be generated and sampled; all other NPAM and CRP sites had 20 transects. At each site, I buffered 2 meters away from the actual NPAM generated transect to avoid disturbing vegetation on FWS transects and compromising FWS surveys. Transects were fixed, so the same transects were sampled throughout the study both years excluding the Sully's Hill CRP sites. The Sully's Hill CRP site was taken out of the CRP by the landowner and converted to cropland; thus, I had to select an alternate CRP site for 2013.

All locations were sampled bi-weekly (i.e., every other week), to increase the chance of collecting pollinators during ephemeral blooming periods. Study sites were sampled over two consecutive days when the time and weather was favorable for

pollinator activity (0800. to 1800; temperatures greater than 15^{o} C, and no precipitation). The following abiotic factors were measured using a Kestrel weather meter at each site during each visit: air temperature (°C), wind speed (average and maximum gusts), and relative humidity. I also obtained daily precipitation amounts (inches) and the daily high and low temperatures for each study site from the National Oceanic and Atmospheric Administration's National Climatic Data Center (National Climate Data Center 2014).

Sampling Pollinator Abundance and Richness

I used blue vane traps to collect potential pollinators at each grassland site. At the beginning of each site visit in both years a single unscented Springstar™ blue vane trap (Stephen and Rao 2005) was placed at one fixed end of each transect (one trap per transect). Traps were set in the morning (0900-1200) on the first day's visit and were collected the following day (0900-1200) to provide 24 hour samples. Each trap was attached to a 5-foot rebar-post and hung by a 6-inch long tie wire, so each vane trap was at the approximate height of the nearby flora (Figure 5). Each trap sample was placed in a jar with a labeled lid (containing date, site, and transect number) and frozen at NPWRC after field work was completed each day. Any queen bumblebees, or threatened or endangered species (e.g. Dakota Skipper, *Hesperia dacotae*, is a candidate species so therefore was not collected) observed in a trap were counted and released.

Pollinators were identified to the lowest possible taxonomic level at the Northern Prairie Wildlife Research Center (NPWRC) invertebrate lab in Jamestown, North Dakota. Numerous taxonomic keys were used to identify specimens and a subset of specimens

was verified by outside experts by the lab manager. After the identity of specimens was verified, they were archived at NPWRC and some are served on a pollinator library developed by NPWRC (http://www.npwrc.usgs.gov/pollinator/).

Figure 5. A Springstar™ blue vane trap attached to rebar I used to capture invertebrate pollinators.

Vegetation Surveys

In 2013, I conducted vegetation surveys along each transect to characterize the plant species and phenology among study sites at each sample event. Surveys were conducted by myself and a field technician after each vane trap was installed. Plants were keyed out in the field using various field guides and if plants could not be identified, they were brought back to the NPWRC Herbarium. The blooming plants I observed were collected off transect for pollen extraction and reference to avoid disturbing the vegetation on my transects. Whenever I collected a plant for pollen extraction, I took note of it in a field checklist to avoid duplicate samples.

Sampling Plant-Pollinator Interactions

I selectively caught native bees after observing them visiting blooming plants along my transects using a net or by placing them gently directly into vials. I placed each bee I collected into individual vials to ensure that any pollen in the vial came from the specimen I collected. Transects were paced for roughly 10 minutes, with time being equally delegated to each blooming plant species.

Native bees caught selectively were washed and analyzed for pollen (see below), to determine how many other plant species they had visited prior to capture and to determine the most abundant pollen on their bodies. To identify non-target pollens that may have contaminated samples from prior sampling events, we sprayed each sweep net with a 1% aniline-blue aqueous solution (Kearns and Inouye 1993). This method stains

pollen grains already present on the sweep net blue, therefore any pollen grains observed from each washed bee that were blue were excluded from the analysis. We used a total of four sweep nets that were rotated throughout each week. Each sweep net was sprayed after sampling five transects and left to dry before using it again. Each net was washed thoroughly with hot soapy water, rinsed with clean water, and dried at the end of each day.

Collecting Pollen

Pollen Collected from Plants

I used a standard step-by-step chemical preparation following the procedures of Kearns and Inouye (1993), and Jones and Bryant (2007) to preserve the morphology of plant pollen specimens. Anthers were extracted from blooming plants species off transect and placed into labeled vials in the field for reference and use to identify plant species by pollen on captured pollinators. Once in the lab, anthers were placed in a 15 mL centrifuge tube and filled with roughly 2 mL of glacial acetic acid. After a few days the acid was decanted and a few mL of an acetolysis solution (9 parts acetic anhydride $C_4H_6O_3$ and 1 part sulfuric acid H_2SO_4) was added. A glass rod was used to crush the anthers and release pollen grains. After anthers were thoroughly crushed, 5-10 mL of the acetolysis solution was added and the centrifuge tube was placed in a hot water bath for roughly 5 minutes before being removed to let cool to room temperature. Once cooled, the solution was centrifuged for 3 minutes at 2,400 rpm and then decanted into an acid storage container. I washed each tube three times with DI water to remove any remaining

acetolysis solution, centrifuged the solution, and decanted. Once the pollen was acetolysized and washed, the pollen was swabbed with a small (~0.25 mm^2) stained (0.2% Saffranin O) square piece of glycerin jelly. The glycerin jelly swab was then transferred onto a clean microscope slide and placed onto a hot plate set at 80°C. Once the glycerin jelly started to melt, a coverslip was placed on top at an angle to avoid bubbles. Once the glycerin jelly had sufficiently melted and created a smooth layer under the cover slip, it was removed from the hotplate. To avoid cross contamination of pollen samples, utensils and associated lab equipment were thoroughly cleaned between every sample.

Pollen Collected from Bees

Bees caught selectively were placed in a 400 mL glass beaker filled with 15 mL of a 1:1 solution of deionized (DI) water and 95% ethanol, then stirred with a magnetic stirrer and brushed by-hand to wash pollen off the bee. The bee was removed from the beaker after 3-5 minutes of washing. The 15 mL ethanol-pollen mixture was then pipetted into a 15 mL centrifuge tube. The mixture was centrifuged for five minutes at 2,400 rpm and then decanted back into the original beaker after resting for two minutes. I washed each beaker three times and all equipment was sterilized to eliminate pollen grains from previous samples contaminating subsequent samples. The pollen at the bottom of the centrifuge tube was then swabbed with a small (~0.25 mm^2) stained (0.2% Saffranin O) square piece of glycerin jelly. The glycerin jelly swab was then transferred onto a clean microscope slide and placed onto a hot plate set at 80°C. Once the glycerin jelly started to melt, a coverslip was placed on top at an angle to avoid bubbles. Once the

glycerin jelly had sufficiently melted and created a smooth layer under the cover slip, it was removed. After bees were washed, they were air-dried on paper towels under a fume hood and placed back into their original vials when dried for identification.

Microscopy

Pollen was observed at 200x to 1000x on an Olympus BX46 clinical microscope and a DP72 digital camera was used to obtain digital images of each plant pollen species for reference and cataloging. Plant pollen was identified based on the majority of pollen seen on the slide for that identified plant species and placed into a pollen grain class based off of the morphology of the pollen grain. The polar length, equatorial length and exine thickness, when available, were measured for a minimum of 10 pollen grains from each plant species. Literature (Crompton and Wojtas 1993) was also used to aid in identifying pollen grains observed.

Bee pollen loads were observed and pollen grains were identified based on the established plant pollen reference. Pollen collected from each bee was examined and identified to species to quantify how many different species of plants each specimen had visited prior to capture. Each slide was observed at 200x to 1000x and scanned around the entire borders of the cover slip (as the majority of pollen grains were forced to the edges), as well as in the center for pollen grains. I counted pollen grains on each slide and placed them in one of four frequency classes: predominant pollen (> 45% of all grains counted), secondary pollen (16-45%), important minor pollen (3-15%), and minor pollen (< 3%) (Louveaux et al. 1978).

Analysis of Pollinator Abundance and Richness

I used repeated measures of Analysis of Variance (ANOVA) to assess differences in pollinator abundance and richness. Species richness was measured as the number of taxa during each sample event. Species abundance was measured as the total number of invertebrate pollinator specimens collected. Individual vane trap samples were units of replication resulting in 981 samples for 2012 and 908 samples for 2013. I analyzed models with sample event (date, within-subject factor), year, location, and grassland type as fixed factors, and all possible interactions among variables were evaluated. When significant, Tukey-Kramer multiple comparisons test were used to check for pairwise differences between means. I also, analyzed if individual transects (n = 170) had any significant variation in abundance and richness, given that transects had varying locations (i.e., elevation, distance to study site borders). Biodiversity indices were calculated utilizing the Shannon and Simpson Index for each year and each study site. To measure differences in species composition among sites, I calculated a Bray-Curtis dissimilarity measure using presence/absence data of pollinator and plant species among study sites. The Bray-Curtis dissimilarity is a statistic to quantify the compositional dissimilarity between different sites, and is bound between 0 (identical composition; share every species) and 1 (opposite composition; share no species) (Bray and Curtis 1957). All analysis was carried out in R 3.2 using the libraries “bipartite” (Dormann et al. 2008) and “*BiodiversityR”* (Kindt and Coe 2005, R Core Team 2015).

For statistical analysis, insect Families that were not “true” potential pollinators (trap by-catch) were excluded from the analysis, as were honey bees (*Apis mellifera*) (Appendix A). Also, six sampling events from 2012 were removed from the analysis. Three of these were conducted in unfavorable weather conditions. The other three were removed in order to correspond with similar dates sampled in 2013 and to have the same sample size as in 2013.

Analysis of Plant-Pollinator Interactions

To quantify and compare how plant-centered surveys with supplemented pollen data, I built three plant-pollinator matrices. Matrices were constructed from field surveys of selectively caught native bees (matrix F), pollen analysis of those bees (matrix P) and both datasets (matrix FP) within each grassland type (NPAM and CRP). The FP matrix was then constructed into a checkerboard bipartite graph detailing interactions (or no interactions) between a plant or pollen source and a native bee on each grassland type.

I pooled 2013 transect vegetation surveys per sample event and obtained an average of blooming floral diversity for each locations grassland type. This resulted in 56 sample events that were analyzed using One-way Analysis of Variance (ANOVA). I developed models using individual months, sample dates, grassland type (CRP and NPAM) and locations to assess floral diversity.

I also characterized the following measures at the network level for each grassland type: plant and pollinator species richness, interactions, unique links, connectance, links per species, nestedeness. Plant and pollinator species richness were

recorded as the unique number of species observed from each of three data sets (F, P and FP). Interactions were characterized as the sum of each plant-pollinator contact observed within each data set. Unique links were calculated as the number of unique plant-pollinator relations observed within each data set. Connectance is the proportion of observed links divided by the total number of possible links (Dunne et al. 2002). Links per species is the mean number of links per species: sum of links divided by number of species. Nestedness (measure of organization in an ecosystem) was calculated between 0, fixed system, and 100, absolutely random system, for each matrix (Bascompte et al. 2003).

RESULTS

Weather

The 2011-2012 winter and 2012-2013 winter were warmer and drier than historical averages (Mullins et al. 2012 and Mullins et al. 2013). In 2012, much of eastern North Dakota was under moderate drought conditions despite drier than normal conditions statewide during the 2012-2013 winter, and slightly wetter conditions that persisted in eastern North Dakota in 2013 (Figure 6). However, weather conditions (i.e., temperature and precipitation) during each field season were similar among study sites.

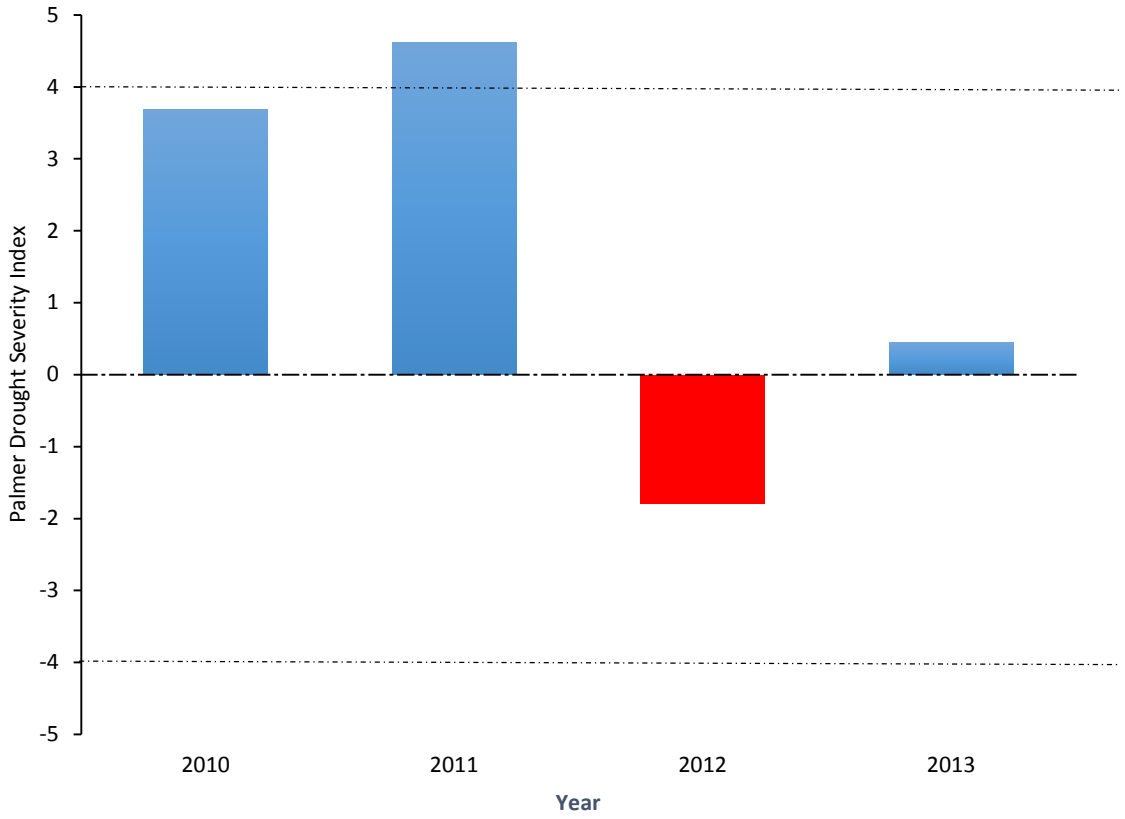

Figure 6. Palmer Drought Severity Index for eastern North Dakota. 0 is normal and thresholds are set at 4 (extremely wet) and -4 (extreme drought).

Pollinator Abundance and Richness

I collected 25,389 potential pollinators from four orders, 47 families, 138 genera and representing 270 taxa from blue vane traps (1,889 vane trap samples) during 2012 and 2013 (Appendix B). Pollinator abundance and richness were greater in 2012 than in 2013, with 13,325 individuals collected from 214 unique taxa in 2012 and 12,064 individuals from 165 taxa in 2013. Blue vane traps were highly successful at capturing Hymenoptera, which accounted for 84.8% of the total vane trap catch, Diptera (11.6%), Coleoptera (2.4%), and Lepidoptera (1.3%) were also collected.

I continued to collect new species throughout my study (Figure 7). Species accumulation curves for each grassland type rose exponentially early on, but then gradually increased as sample events (n = 56) increased. Each curve begins to reach an asymptote around 40 sample events for each grassland type, but do not reach a complete baseline. Both grassland types' species accumulation curves have similar rises, potentially based on emergence of the same pollinator taxa. It is likely that more than 200 taxa use NPAM and CRP grasslands in eastern North Dakota.

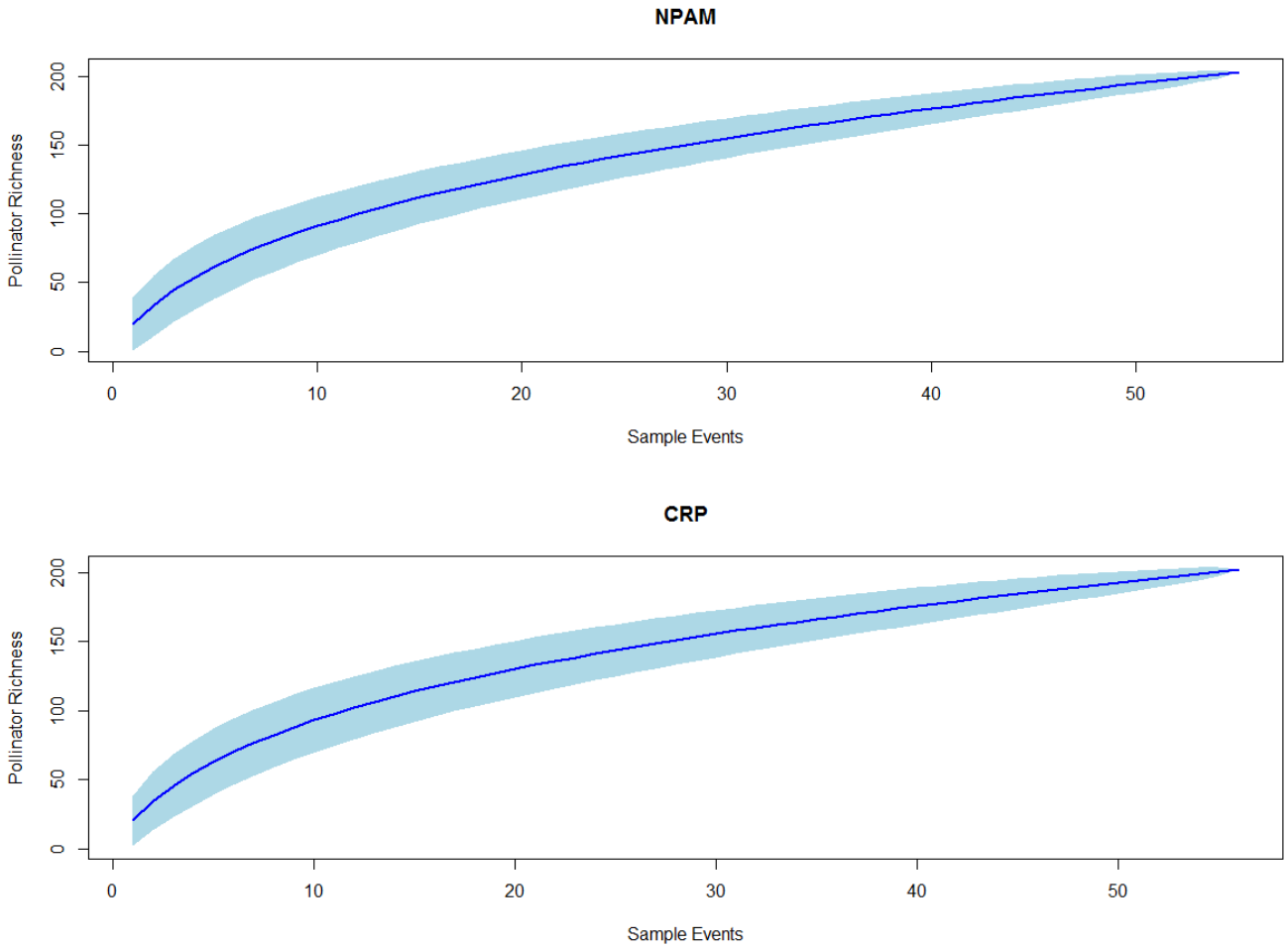

Figure 7. Species accumulation curves for each grassland type (NPAM = native, CRP = restored) based off each sample event (*n* = 56). Curves are generated as the mean number of newly discovered species for each sample event. Light blue shaded areas represent 95% confidence intervals from standard deviation.

I detected significant differences in species abundance and richness per trap among dates sampled (df = 55,1883, F = 18.90, $P < 0.001$ and df = 55,1883, F = 23.92, $P < 0.001$) for abundance and richness respectively (Figure 8). I also detected a significant difference in pollinator abundance and richness per trap among locations (df = 3,1885, F = 15.59, $P < 0.001$ and df = 3,1885, F = 44.68, $P < 0.001$; for abundance and richness respectively) (Table 1).

Mean richness per trap was significantly different between years and individual transects (df = 1,1887, F = 6.66, $P = 0.009$ and df = 169,1719, F = 1.56, $P < 0.001$ for years and transect richness, respectively). Mean richness per trap was 3.8±2.6 in 2012 and rose to 4.2±3.3 in 2013. However, I did not detect significant differences in pollinator abundance per trap ($\overline{x}$ = 13.4±15.3) between years, or among individual transects ($P > 0.05$) (Table 1).

The interaction between years and among location was a significant influence on pollinator abundance and richness ($P > 0.01$, Table 1). Mean trap abundance and richness increased in 2013 at Arrowwood and Sully's Hill, and decreased at Kulm and Tewaukon. The interaction of location and grassland type had a significant influence on abundance and richness ($P > 0.01$, Table 1). Locations were relatively similar to each other, but Tewaukon had lower averages in pollinator abundance and diversity (Figure 9 and 10). The interaction between year and grassland type was also a significant influence on abundance (Figure 11). A decrease in mean abundance per vane trap was observed on restored grasslands, while an increase was evident on native grasslands in 2013.

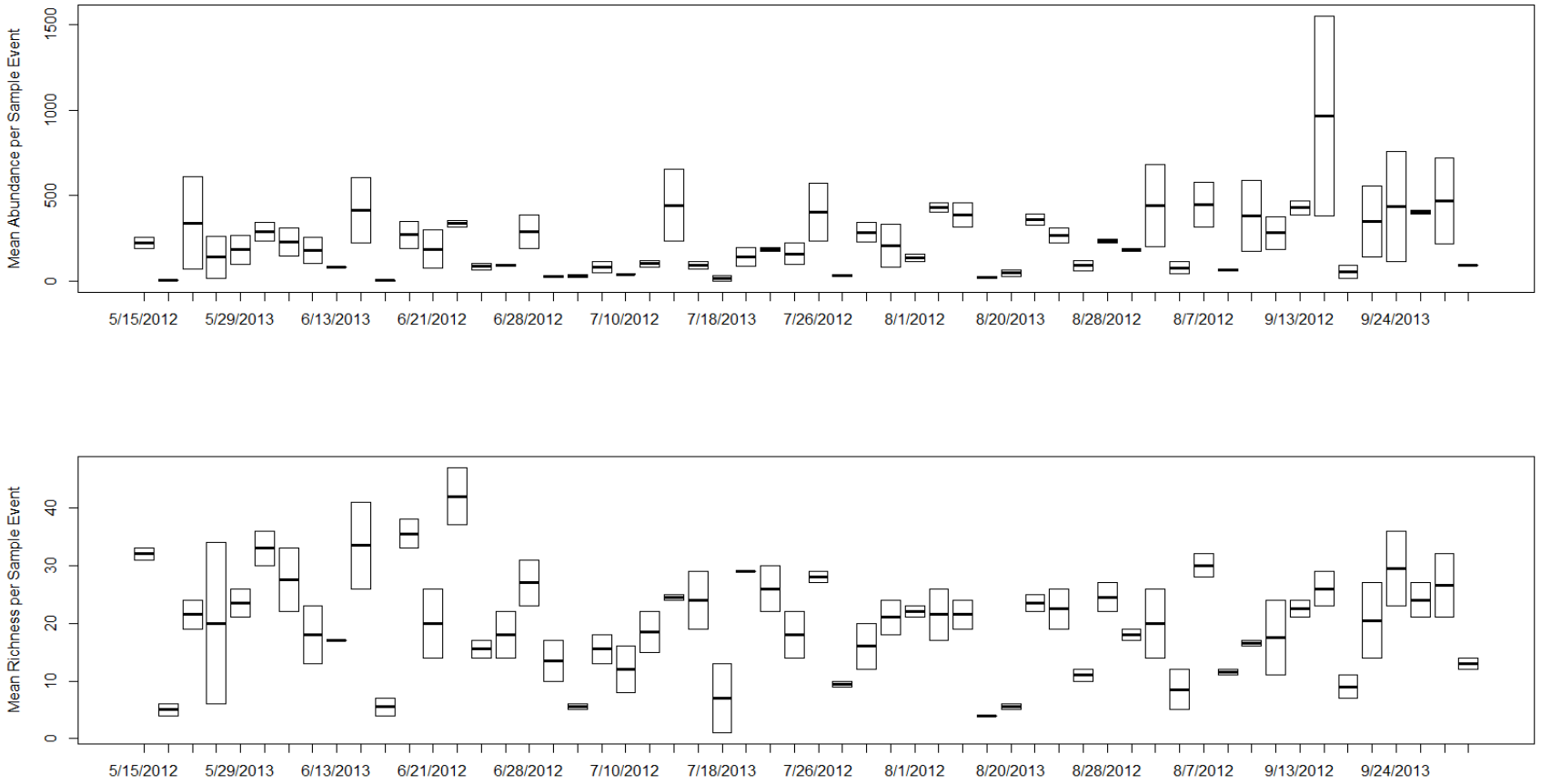

Figure 8. Boxplots showing variation in mean abundance (top graph) and richness (bottom graph) per sample event for both years. Each box represents 2 samples for that date; the Native Prairie Adaptive Management grassland (NPAM) sample and the Conservation Reserve Program grassland (CRP) sample.

Table 1. Analysis of Variance (ANOVA) results evaluating differences in mean native invertebrate pollinator abundance and richness within sample events (DATE), years (2012 & 2013), transect, location, grassland type (native and restored), and the interaction between predictors. Cells shaded in gray indicate significant differences ($P < 0.05$)**.** All interactions were analyzed, but only ones where $P < 0.05$ were reported.

Predictor	Response Variable	F	*df*	P
DATE	POLLINATOR ABUNDANCE	18.90	55,1833	<0.001
	POLLINATOR RICHNESS	23.92	55,1883	<0.001
YEAR	POLLINATOR ABUNDANCE	0.18	1,1887	0.675
	POLLINATOR RICHNESS	6.66	1,1887	0.009
TRANSECT	POLLINATOR ABUNDANCE	0.98	169,1719	0.549
	POLLINATOR RICHNESS	1.56	169,1719	<0.001
LOCATION	POLLINATOR ABUNDANCE	15.59	3,1885	<0.001
	POLLINATOR RICHNESS	44.68	3,1885	<0.001
GRASSLAND TYPE	POLLINATOR ABUNDANCE	0.13	1,1887	0.719
	POLLINATOR RICHNESS	2.08	1,1887	0.150
LOCATION*YEAR	POLLINATOR ABUNDANCE	5.14	3,1881	<0.01
	POLLINATOR RICHNESS	7.19	3,1881	<0.001
LOCATION*GRASSLAND TYPE	POLLINATOR ABUNDANCE	5.235	3,1881	<0.01
	POLLINATOR RICHNESS	5.066	3,1881	<0.01
YEAR*GRASSLAND TYPE	POLLINATOR ABUNDANCE	23.64	1,1885	<0.001
	POLLINATOR RICHNESS	1.75	1,1885	0.186

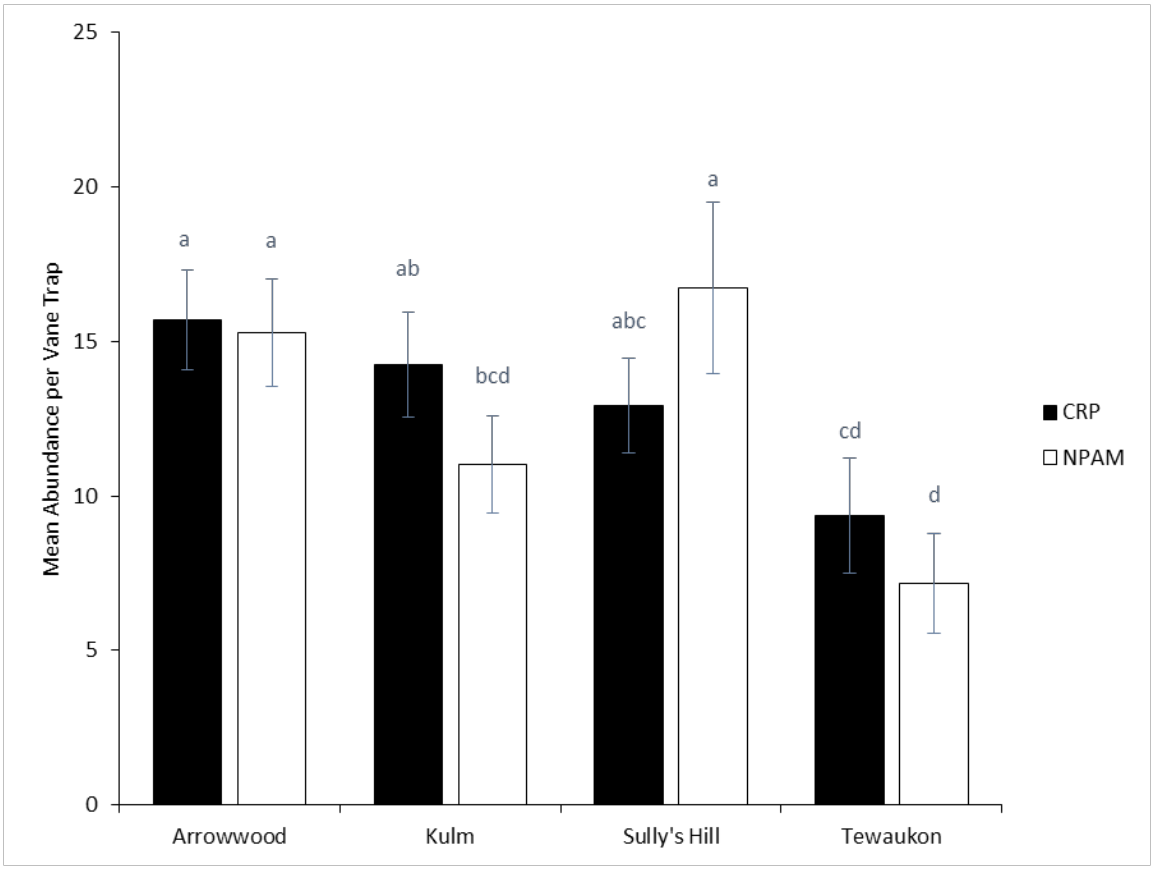

Figure 9. Mean capture (abundance) of native invertebrate pollinators per trap (n=1,889) for each locations grassland type within Eastern North Dakota during 2012 and 2013. Letters above each column indicate if there were significant differences among the sites based on Analysis of Variance and Tukey-Kramer Multiple Comparisons test. Columns with the same letter indicate no significant difference between sites ($P > 0.05$).

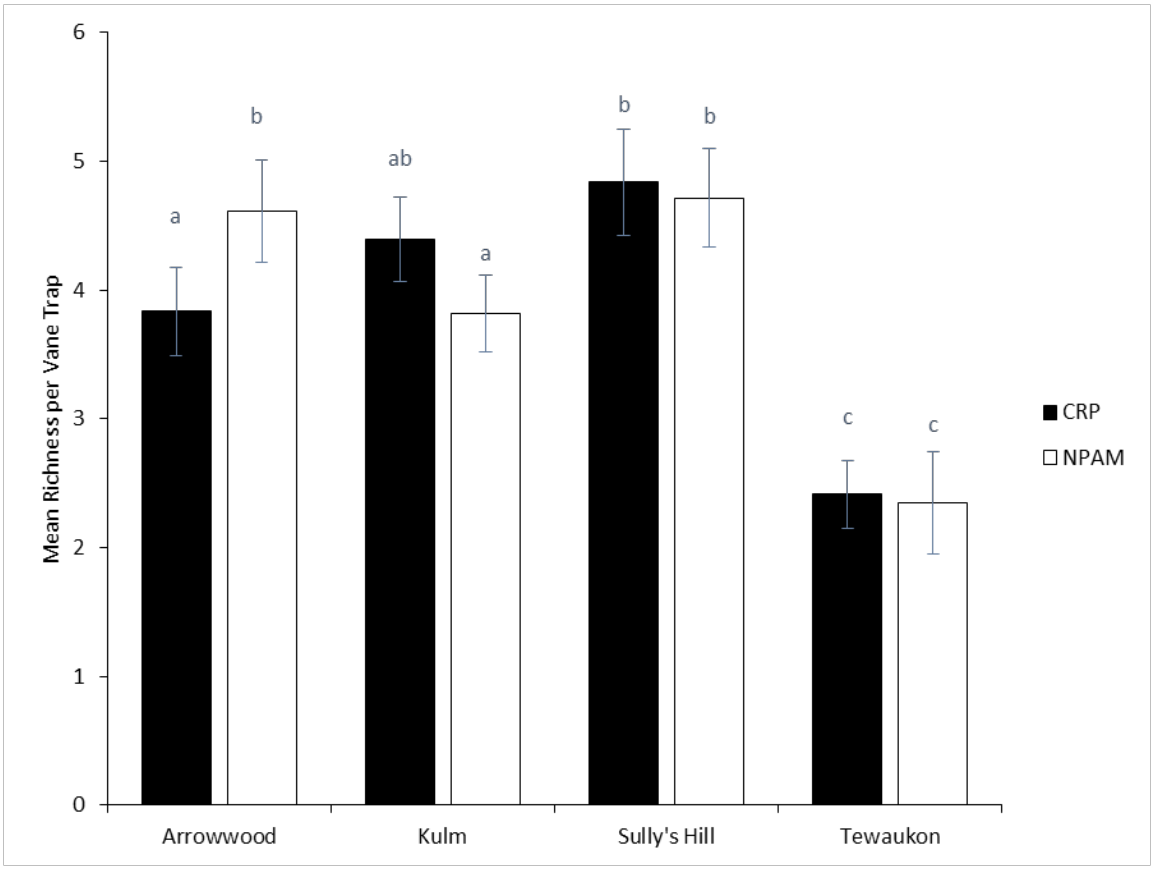

Figure 10. Mean species richness of invertebrate native pollinators per trap (n=1,889) for each locations grassland type within Eastern North Dakota during 2012 and 2013. Letters above each column indicate if there were significant differences among the sites based on Analysis of Variance and Tukey-Kramer Multiple Comparisons test. Columns with the same letter indicate no significant difference between sites ($P > 0.05$).

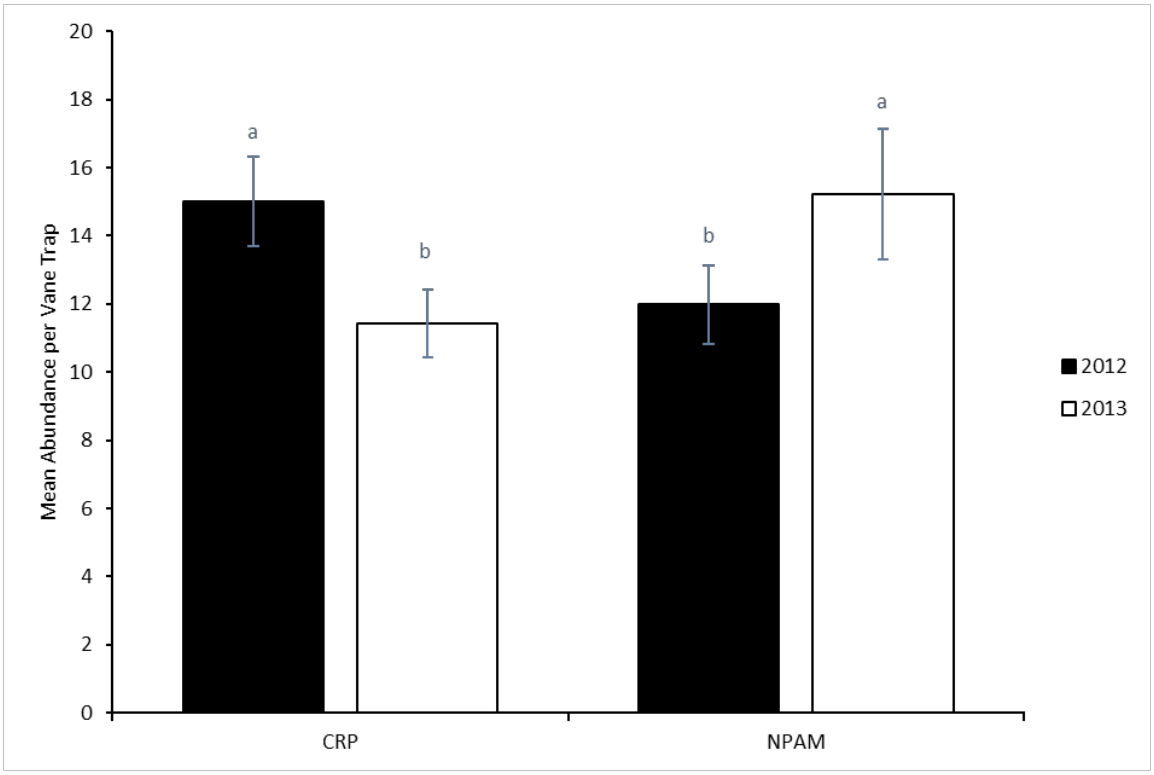

Figure 11. Mean abundance per vane trap for Conservation Reserve Program grasslands (CRP) and Native Prairie Adaptive Management grasslands (NPAM) and years (2012 and 2013). Letters above each column indicate if there were significant differences among the sites based on Analysis of Variance and Tukey-Kramer Multiple Comparisons test. Columns with the same letter indicate no significant difference between grassland types ($P > 0.05$).

Bray-Curtis dissimilarity measures suggested that pollinator species composition differed among my sample locations but my paired grasslands for each location (NPAM versus CRP) were similar (Figure 12). Mean similarity of pollinator community composition among my study sites was 55% considering species presence-absence at each study site. Paired grasslands (NPAM and associated CRP) located less than 32 kilometers from each other shared 61.5±4.5% of pollinator species composition. However, as distance between locations increased, pollinator community composition became less similar. Kulm and Arrowwood locations (roughly 109 kilometers apart) shared 57±1.5% of species, while Tewaukon and Arrowwood locations (roughly 185 kilometers apart) shared 46.5±5% of species.

Plant species composition at my study sites mostly differed by grassland type (NPAM and CRP) rather than spatial location among sites (Figure 13). NPAM and CRP sites were 66±13% and 55±12% similar in plant species composition, respectfully. Decreased similarity among the CRP sites was likely due to variations in the conservation practice (CP) unique to each CRP field I evaluated. For example, Kulm CRP was the only restored grassland enrolled in CP-2 (Establishment of Permanent Native Grasses), and it was more dissimilar to the restored grasslands enrolled in CP-1 (Establishment of Permanent Introduced Grasses and Legumes; Arrowwood CRP) and CP-4D (Permanent Wildlife Habitat; Tewaukon and Sully's Hill CRP).

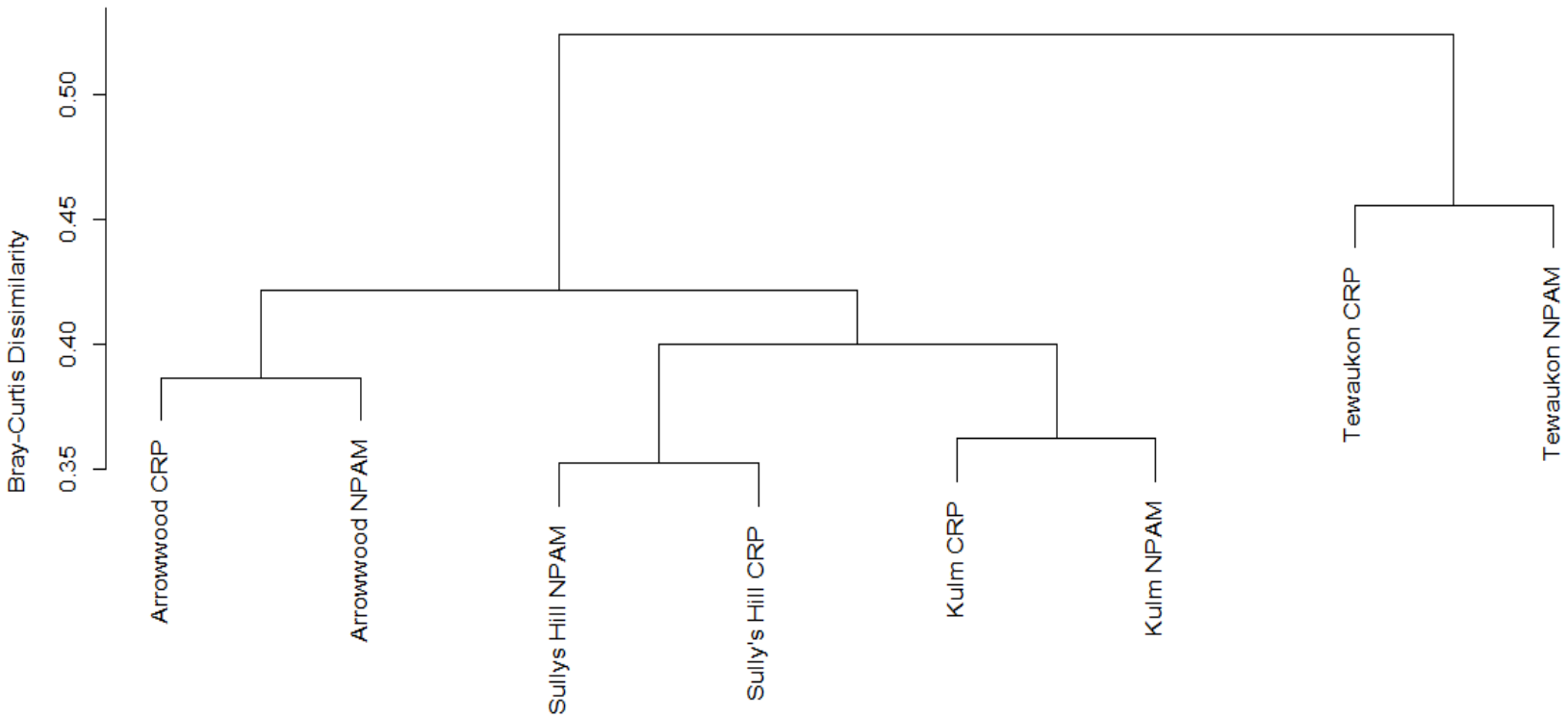

Figure 12. A dendrogram showing the dissimilarity among the invertebrate pollinator community among study sites using presence/absence data from 2012 and 2013. The cluster analysis was quantified using the Bray-Curtis dissimilarity measure. Sites that are paired with each other and closer to 0 are relatively similar in species abundance and composition, while sites further up the model and closer to 1 are gradually more dissimilar in community abundance and composition.

Figure 13. A dendrogram showing the dissimilarity among the plant community among study sites using only presence/absence data from 2013 vegetation surveys. The cluster analysis was quantified using the Bray-Curtis dissimilarity measure. Sites that are paired with each other and closer to 0 are relatively similar in species composition, while sites further up the model and closer to 1 are gradually more dissimilar in community composition.

Of the 25,389 potential pollinators collected, 21,339 were native bees that represented 118 taxa, including 95 that were identified to species from 38 genera. Of those 25,389 bees, 10,514 from 96 of the taxa were collected from NPAM and 10,825 from 87 of the taxa from CRP. Native bee abundance followed a right-skewed distribution, with a few abundant species and a high proportion of rare species (Figure 14). *Melissodes spp*. was the most abundant native pollinator I collected both years at NPAM and CRP grassland types (32% of total catch). *Agapostemon spp.* was the 2nd most abundant (19%) followed by *Lasioglossum spp*. (16%) and *Bombus spp*. (6%). However, these genera underwent significant variations in abundance between 2012 and 2013 (Figure 15). *Bombus* had dramatic declines in abundance on both grassland types in 2013. Individual *Bombus* species suffered dramatic decreases in 2013 catch, except *B. pensylvanicus* (only one individual was collected in 2013 at my Kulm NPAM location) (Figure 16). My catch of *Agapostemon* in CRP decreased 51% between 2012 and 2013, whereas they increased 103% from 2012 to 2013 in my NPAM locations. My catch of *Melissodes* declined 11% at my NPAM sites and 62% at my CRP sites. However, *Lasioglossum* increased in 2013 in both grassland types. The other 34 genera of native bees, each accounted for 3% or less of the total native bee abundance, with 91 bee taxa being collected 10 times or less.

Arrowwood NPAM had the highest overall pollinator richness of all NPAM sites in 2012 and 2013. Kulm CRP had the highest overall pollinator abundance in 2012, while Arrowwood NPAM had the highest in 2013. Sully's Hill had the overall highest

Shannon Index and Simpson Index for both NPAM and CRP grasslands in 2012 and 2013 (Table 2).

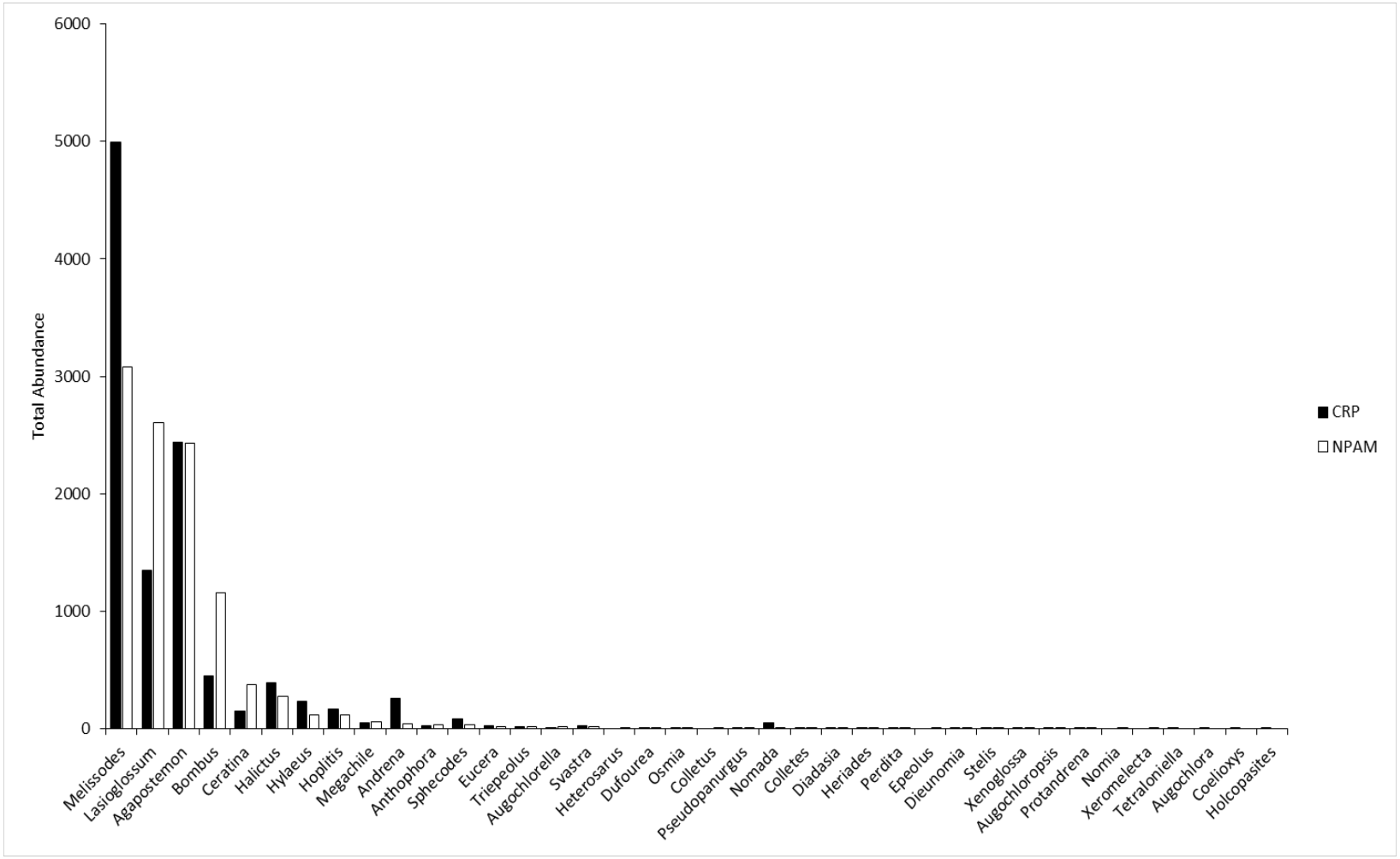

Figure 14. Total number of bee per genus caught in vane traps among Native Prairie Adaptive Management grasslands (NPAM, white bars) and Conservation Reserve Program grasslands (CRP, black bars) in 2012-2013. *Melissodes spp., Lasioglossum, spp, Agapostemon spp. and Bombus spp.* together accounted for 73% of the total pollinator community composition and 86.8% of the native bee community.

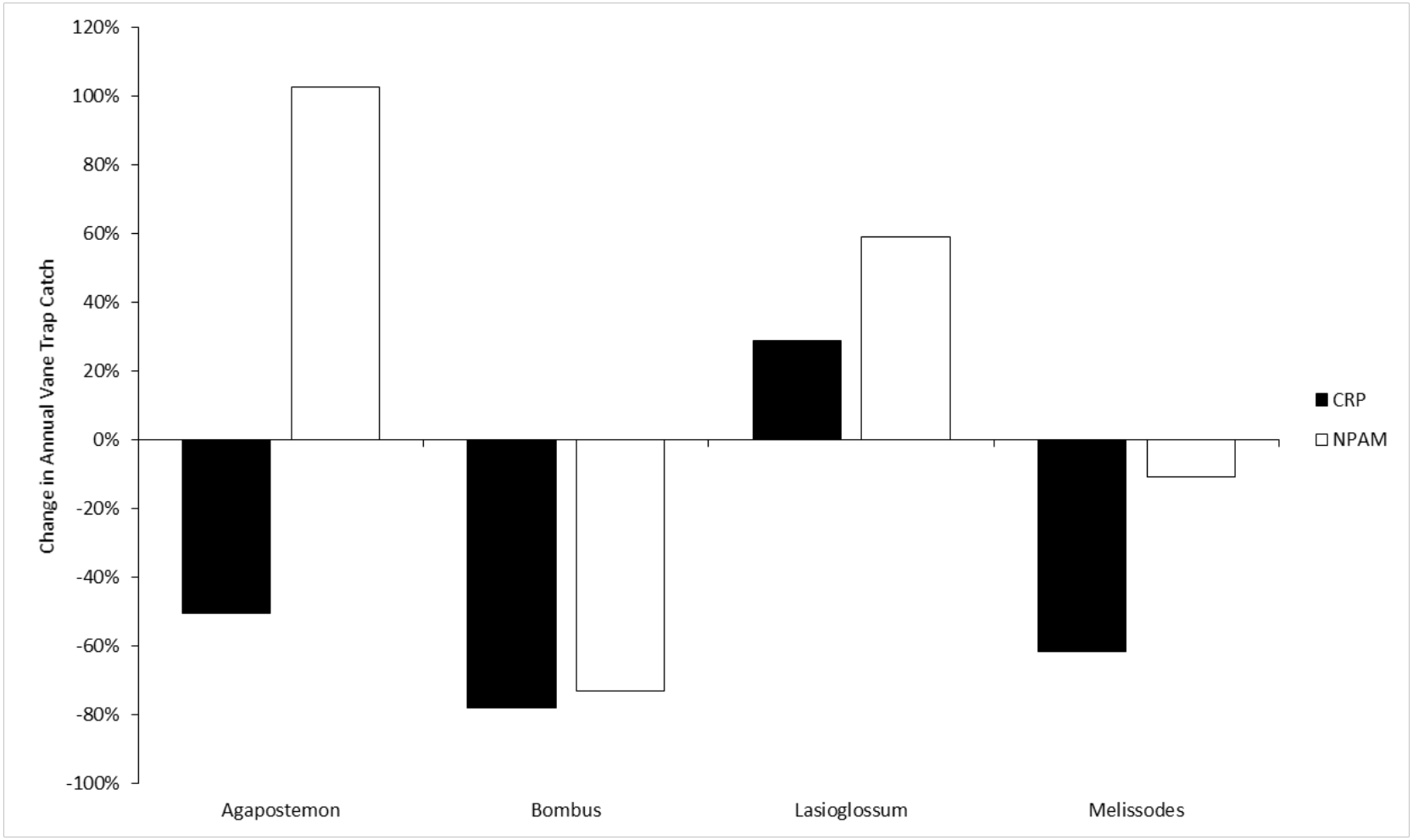

Figure 15. Change in 2013 relative to 2012 vane trap catch for the four of the most predominant native bee genera in Eastern North Dakota. Significant variations in annual catch was apparent across both grassland types.

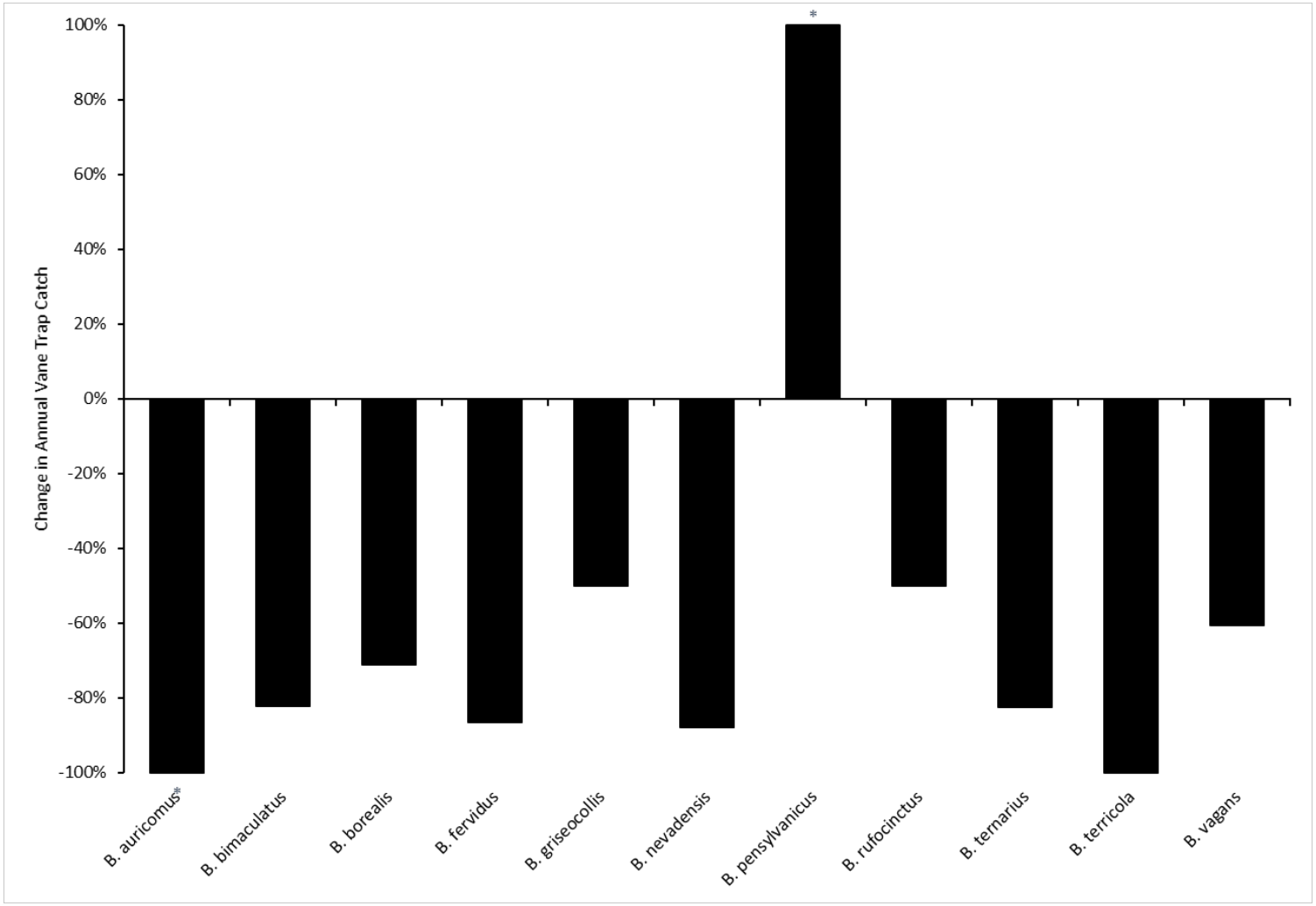

Figure 16. Change in 2013 relative to 2012 vane trap catch for all *Bombus spp.* collected in Eastern North Dakota. Significant decreases in annual catch was apparent in each *Bombus* species collected. * Only one *B. pensylvanicus* discovered in 2013, compared to zero in 2012 representing the 100% increase.

Table 2. Diversity indices (richness, abundance, Shannon Index and Simpson Index) for each study site per year.

Site	Richness		Abundance		Shannon Index		Simpson Index	
	2012	2013	2012	2013	2012	2013	2012	2013
Arrowwood CRP	79	75	2,432	1,852	1.49	2.17	0.497	0.708
Arrowwood NPAM	83	89	1,562	2,611	2.21	2.55	0.763	0.829
Kulm CRP	74	69	2,506	1,073	2.09	2.90	0.732	0.906
Kulm NPAM	63	69	1,391	1,478	2.53	2.47	0.870	0.842
Sullys Hill CRP	80	75	1,388	1,958	2.78	2.98	0.845	0.921
Sullys Hill NPAM	71	73	2,101	2,436	2.65	2.53	0.878	0.840
Tewaukon CRP	57	39	1,438	418	1.70	2.39	0.578	0.829
Tewaukon NPAM	37	39	507	238	1.63	2.27	0.540	0.783
Mean	**68**	**66**	**1,665**	**1,508**	**2.14**	**2.53**	**0.713**	**0.832**

Plant-Pollinator Interactions

A total of 92 potential floral sources for native bees from 26 families were identified on NPAM and CRP grasslands in 2012 and 2013. Of those 92, I observed native bees visiting 47 of those plant species on NPAM grasslands and 11 on CRP grasslands (Appendix C).

Floral diversity was significantly different among sample dates, months, and grassland type ($P < 0.05$, Table 4). However, location did not influence floral diversity. The diversity of monthly blooming forbs displayed a normal distribution, and was significantly greater on NPAM grasslands than CRP grasslands ($P < 0.05$, Figure 17). Flowering plant availability was low in late spring, and in early fall for both grassland types. However, floral diversity increased significantly during the summer months, peaking in July for NPAM and CRP grasslands. I found no significant correlation between floral diversity and pollinator abundance or richness ($P > 0.05$).

I collected significantly more native bees via selective sweeping from NPAM grasslands than on CRP grasslands per sample event (df = 1,92, F = 15.67, $P < 0.001$, Figure 18). More native bees were collected from native plant species (versus introduced plant species) on NPAM grasslands (df = 1,92, F = 19.04, $P < 0.001$, Figure 18). However, I collected more native bees from introduced plant species (versus native plant species) on CRP grasslands (df = 1,92, F = 3.88, $P = 0.05$, Figure 18).

Table 3. Analysis of Variance (ANOVA) results evaluating differences in floral diversity within individual months (Month), sample events (DATE), grassland type (CRP and NPAM), and each location. Cells shaded in gray indicate significant differences found**.**

Predictor	**Dependent Variable**	**F**	***df***	**P**
MONTH	FLORAL DIVERSITY	7.348	4,51	<0.001
DATE	FLORAL DIVERSITY	2.059	27,28	0.03
GRASSLAND TYPE	FLORAL DIVERSITY	9.482	1,54	<0.01
LOCATION	FLORAL DIVERSITY	2.094	3,52	0.11

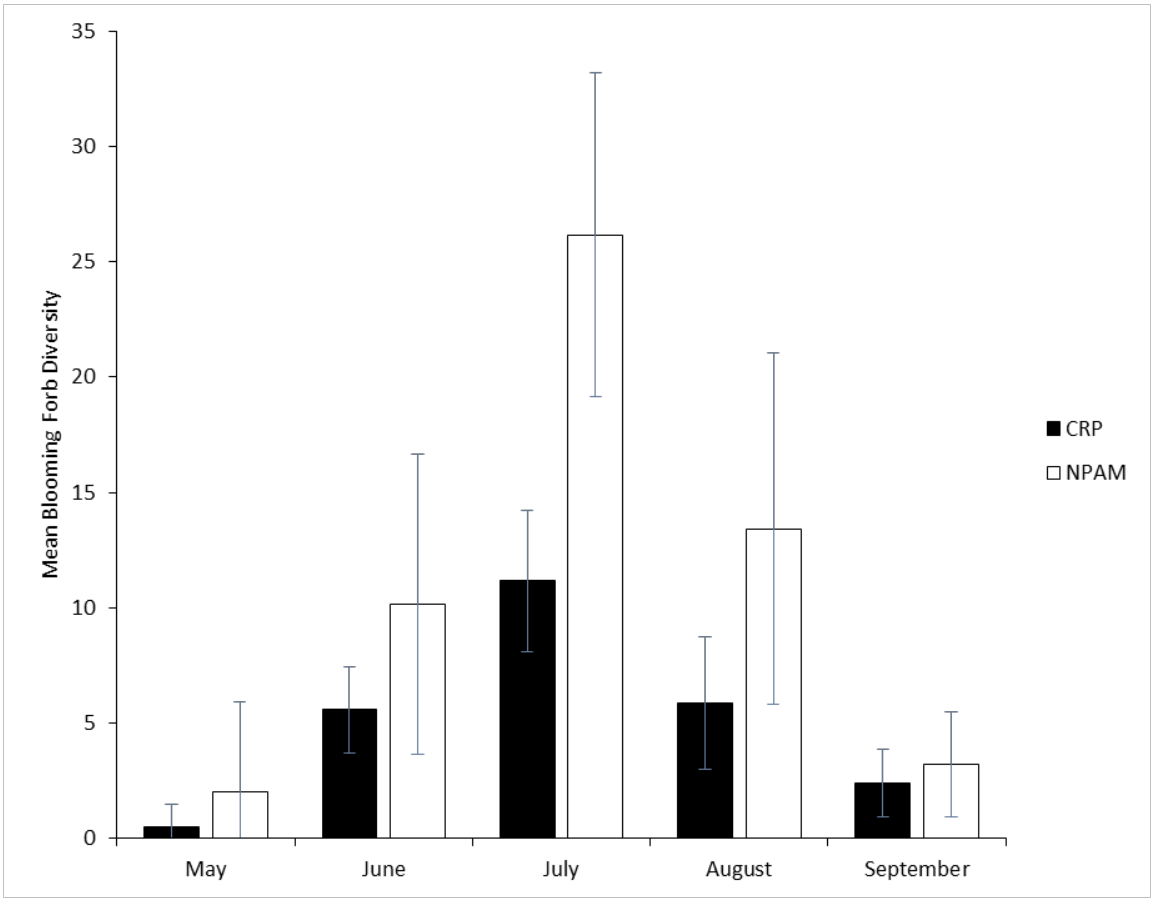

Figure 17. Mean blooming forb diversity observed in 2013 on the Conservation Reserve Program grasslands (CRP, black bars) and Native Prairie Adaptive Management grasslands (NPAM, white bars).

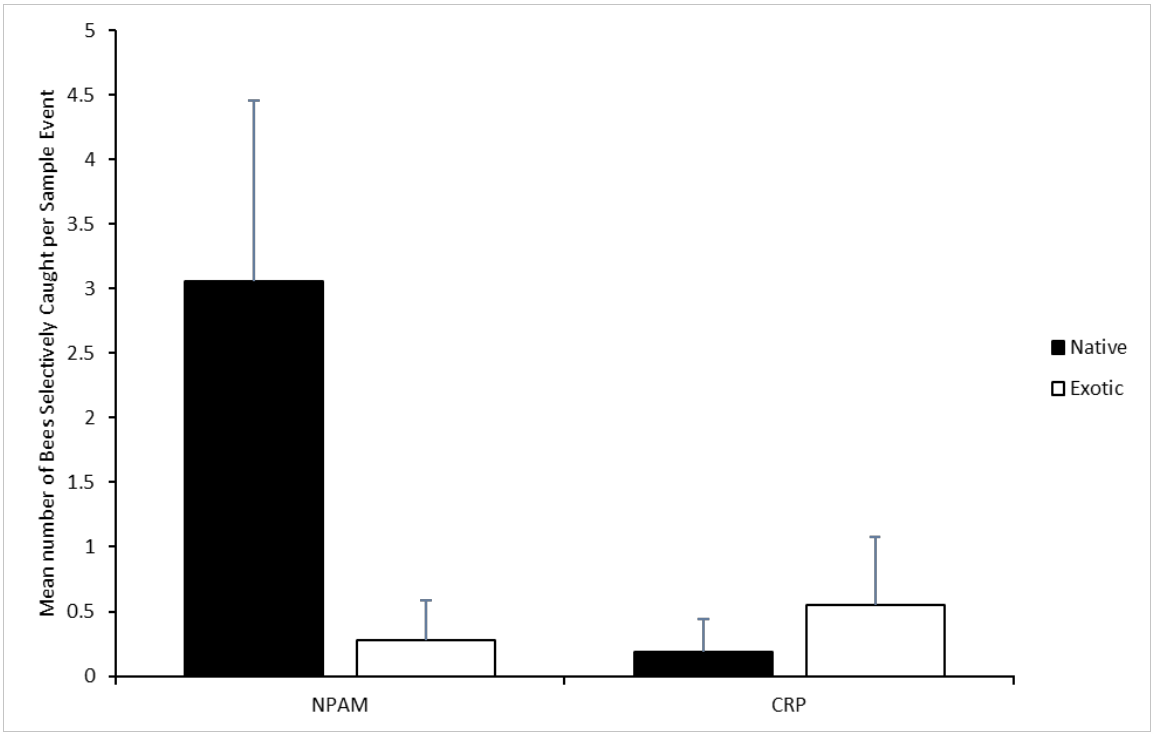

Figure 18. Mean number of native bees selectively caught per sample event on native (black bars) and exotic (white bars) plant species for Conservation Reserve Program grasslands (CRP) and Native Prairie Adaptive Management grasslands (NPAM).

I collected and washed 215 native bees from 32 taxa from my selective sweep net samples in 2012 and 2013. Of these, 176 bees were collected from NPAM sites and 39 were collected from CRP sites. I collected pollen grains from 181 (84%) of the 215 bees. Of those individuals having pollen, 121 (67%) had multiple (> 1) species of pollen grains on their bodies ($\overline{x}$ = 2.4, Figure 19). I was able to identify all but eight pollen types using the reference collection from the 92 plant species (Appendix D).

My analysis of pollen combined with initial plant-bee contacts from the 215 bee specimens captured documented 234 interactions on 153 links on NPAM grasslands and 52 interactions on 29 links on CRP prairie grasslands (Table 4). Of these, interactions were significantly greater on NPAM grasslands (df = 1, F = 5.34, P = 0.05) as were unique links (df = 1, F = 7.73, P = 0.03, Figure 20). Connectance was 0.09 in F network (only field observations), 0.11 in P network (only pollen observations) and FP network (field observations + pollen observations) within NPAM grasslands and 0.15 in F network, 0.32 in P network and 0.19 in FP network within CRP grasslands (Table 4). Links per species increased with the addition of pollen data and a combination of both matrices (Table 4). Similarly, nestedness increased with the addition of pollen data. All three matrices were well nested, but CRP grasslands were significantly more random than NPAM grasslands (P < 0.001, Table 4).

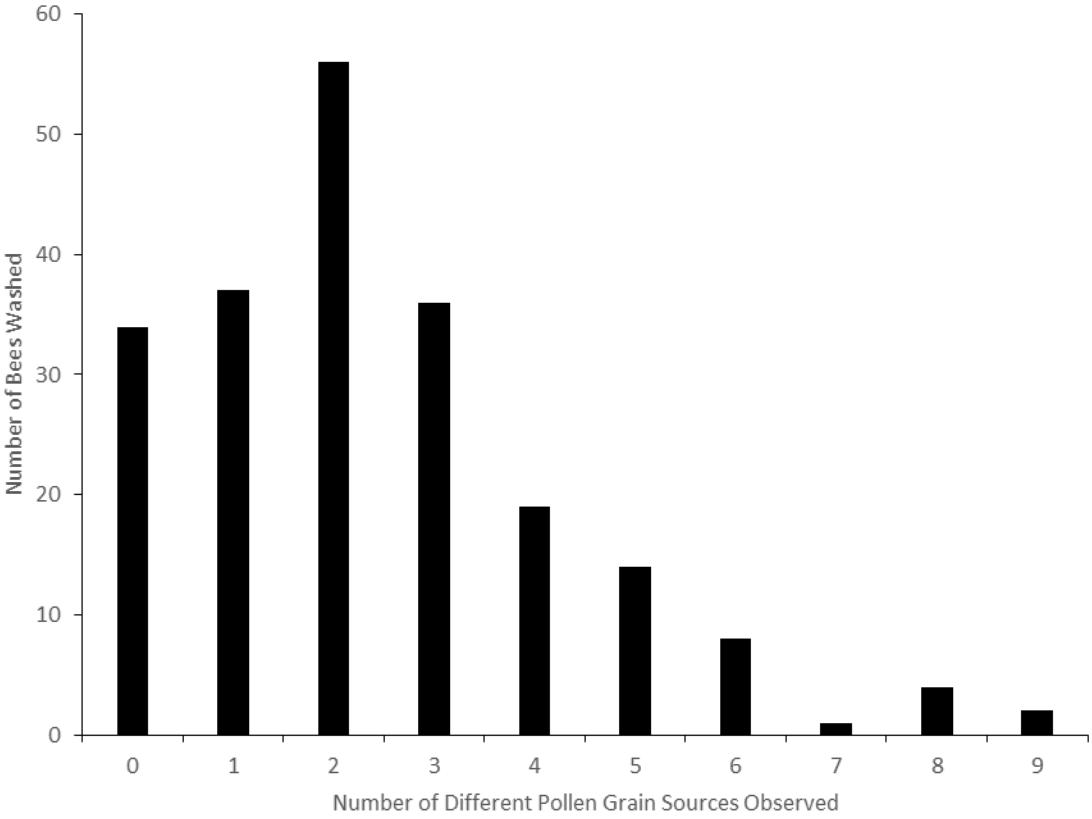

Figure 19. Distribution of total count of different pollen grain sources (plant species) observed on each native bee washed.

Table 4. Parameters describing the structure of the pollination network in Native Prairie Adaptive Management grasslands (NPAM) and Conservation Reserve Program grasslands (CRP) based on field surveys (F), pollen analysis (P), and field surveys + pollen analysis (FP).

	F Network		P Network		FP Network	
	NPAM	CRP	NPAM	CRP	NPAM	CRP
Plant species	47	12	38	7	53	13
Bee species	27	12	24	9	27	12
Interactions recorded	176	39	159	37	234	52
Connectance (%)	0.09	0.15	0.11	0.32	0.11	0.19
Links per species	1.59	0.92	1.68	1.25	1.91	1.16
Nestedness	8.78	27.48	11.5	32.85	9.40	28.33

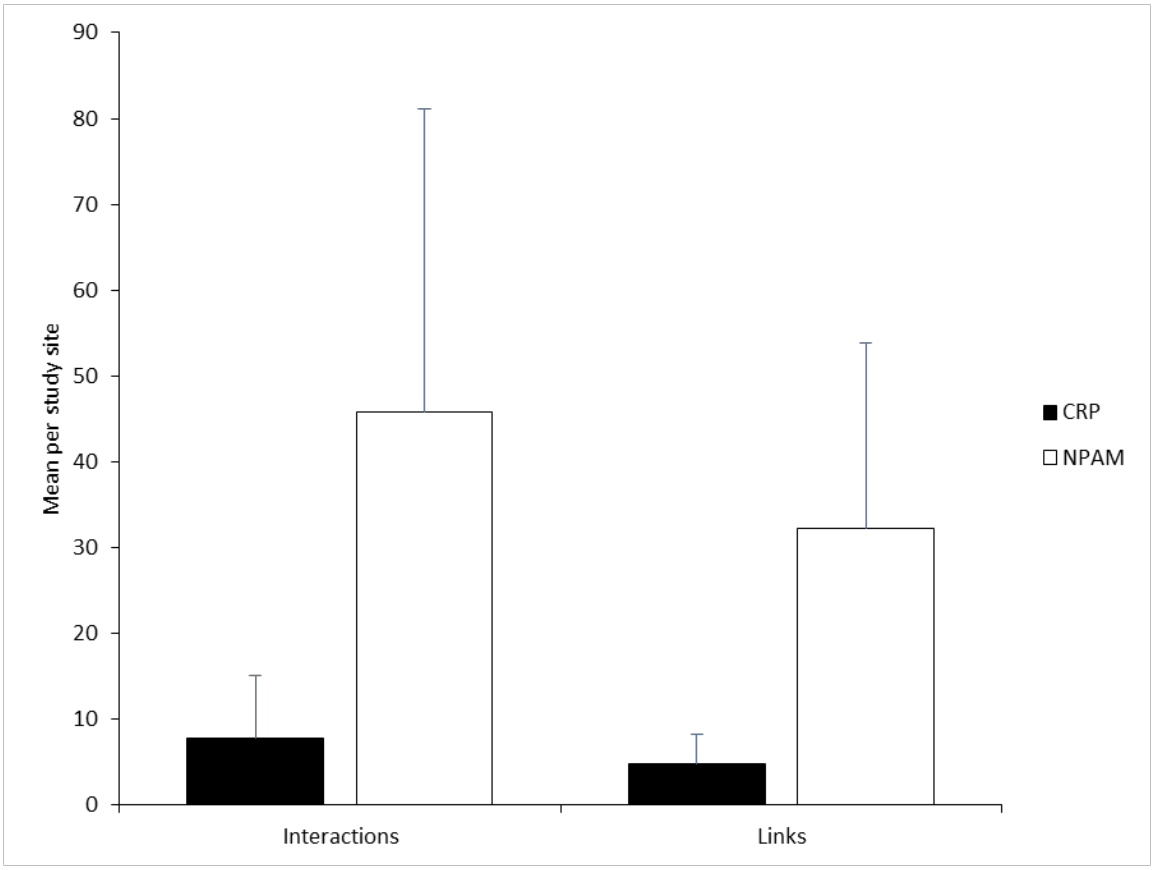

Figure 20. Mean interactions and unique links on restored prairie grasslands (black bars) and native prairie grasslands (white bars).

The introduced perennial sowthistle (*Sonchus arvensis*) was the predominant floral source native bees used on CRP grasslands (Figure 21). I found sowthistle pollen grains on 58% of the native bees I analyzed from CRP grasslands but I did not detect it on bees I captured from NPAM grasslands. Other predominant pollen grains I found on bees from CRP sites were: Canada thistle (*Cirsium arvense*), prarie rose (*Rosa arkansana*), yellow sweetclover (*Melilotus officanlis*), and alfalfa (*Medicago sativa*).

NPAM grasslands had a greater diversity of floral sources for native bees that included more native plant species (Figure 22). Leadplant (*Amorpha canescens*) was the predominant pollen source for seven of the native bee species collected from NPAM grasslands, especially for *Bombus spp*. Other predominant pollen sources on NPAM grasslands included: prairie rose (*Rosa arkansana*), narrow-leaved meadowsweet (*Spirea alba*), stiff sunflower (*Helianthus pauciflorus*), and American silverberry (*Elaeagnus commutata*).

My analysis indicated that *Lasioglossum spp*., *Melissodes spp*., and *Bombus spp*. usually had pollen from multiple plant species on their bodies (Figure 23). These bee genera were also prevalent throughout the entire field season (May-September), except *Melissodes spp*. which emerged in Late-June (Figure 24).

Also, not observed on transects, but present on study sites were blooming tree species including: Russian olive (*Elaeagnus angustifolia*) and American basswood (*Tilia americana*). As American basswood was also a pollen source identified on multiple native bees washed, these tree species when in bloom, were highly attractive to native bees.

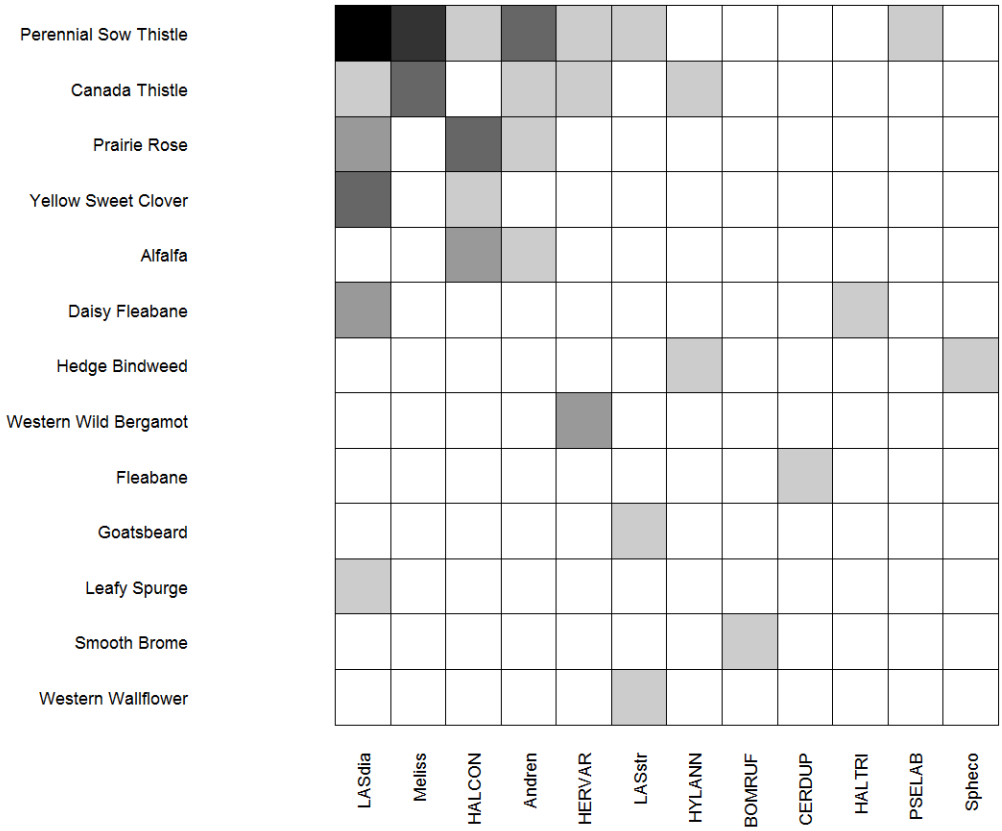

Figure 21. Conservation Reserve Program grasslands (CRP) interaction web detailing bee taxa (x-axis) and plant taxa (y-axis). The darker the cell shade, the greater number of interactions observed (bees collected off a plant species + pollen analysis); a white cell indicates no observed interaction during field surveys and pollen analysis.

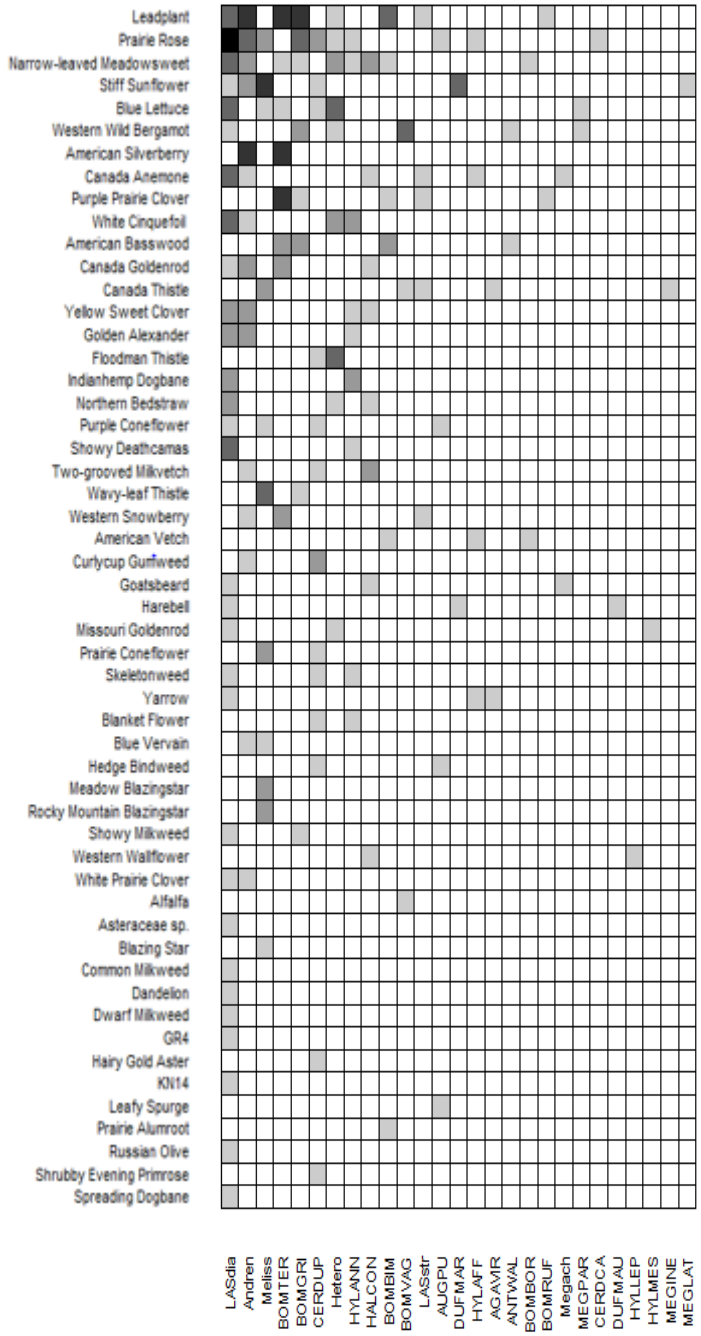

Figure 22. Native Prairie Adaptive Management grasslands (NPAM) interaction web detailing bee taxa (x-axis) and plant taxa (y-axis). The darker the cell shade, the greater number of interactions observed (bees collected off a plant species + pollen analysis); a white cell indicates no observed interaction during field surveys and pollen analysis.

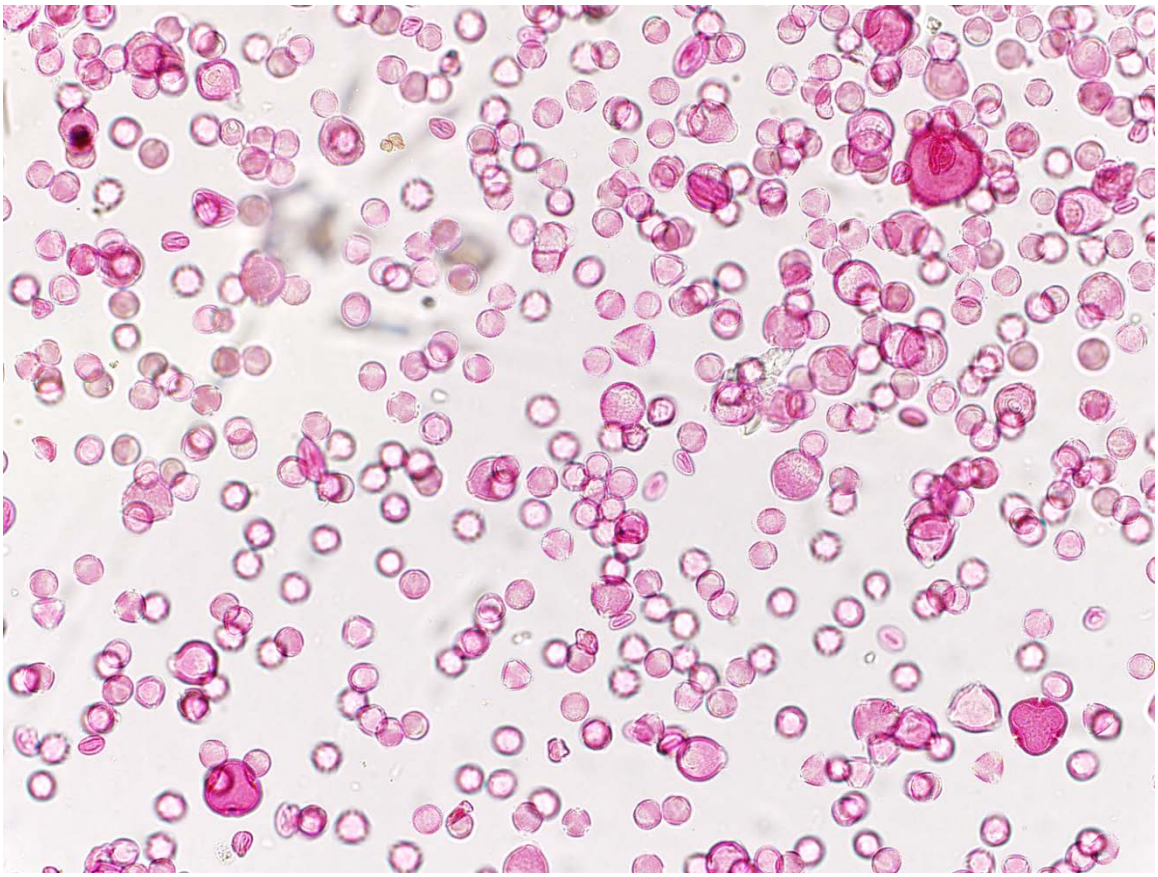

Figure 23. Image of the pollen load of a *Bombus griseocollis* (Brown-belted bumble bee) showcasing the diverse diet which included 7 different pollen sources. The predominant pollen source here is *Amorpha canescens* (Leadplant) followed by *Rosa arkansana* (Prairie Rose) and *Tilia americana* (American Basswood).

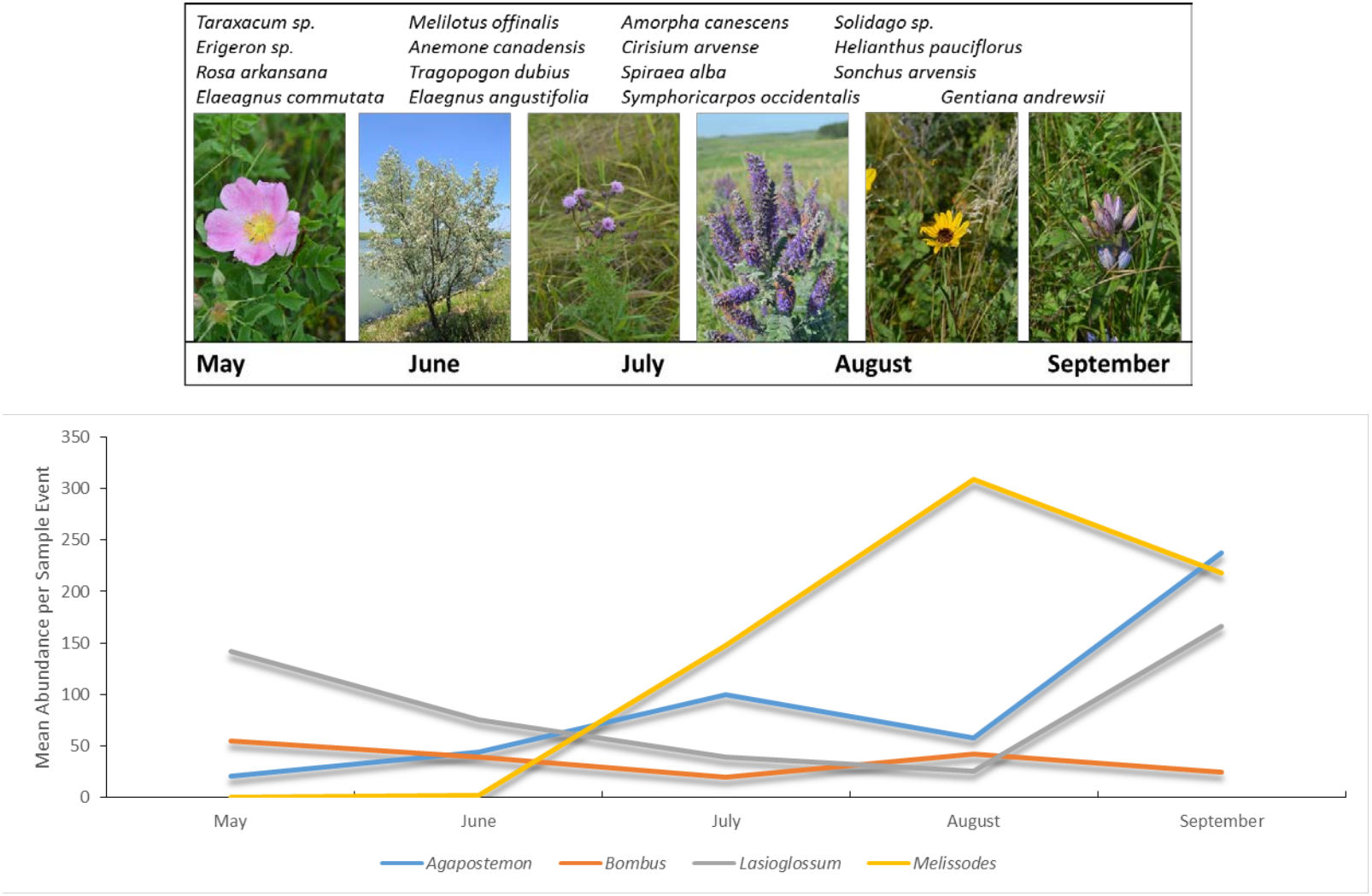

Figure 24. Phenology graphic detailing bloom months of various plant taxa that were observed to be pollen sources and the mean abundance per sample event of the four major bee taxa found in grasslands of eastern North Dakota

DISCUSSION

Pollinator Abundance and Richness

In my study, the 270 potential invertebrate pollinator taxa, which included 118 native bee taxa, represents the highest diversity of species previously found in the Prairie Pothole Region (Dr. John Ascher, American Museum of Natural History, personal communication). I observed significant variation in species abundance across sample dates, location, interactions of year and location, year and grassland type, and among location and grassland type. I also observed significant variation in species richness across sample dates, years, transects, study sites, interactions of year and location, and among location and grassland type. However, species abundance was not significantly different among years, grassland types, and transects (Table 2). Pollinator community composition based on species presence-absence data was more similar among paired grasslands (i.e., Tewaukon, Arrowwood, Kulm, and Sully's Hill), but gradually became dissimilar as distance between locations increased. Hence, spatial location, surrounding land use are likely important factors influencing native invertebrate pollinator abundance and richness within grasslands of eastern North Dakota.

The results of my study suggest that native invertebrate pollinator abundance and richness between native and restored grasslands of eastern North Dakota are relatively similar. However, my vane trap catch in CRP grasslands was lower in 2013 (Figure 11) and had fewer native bee taxa (Figure 15), suggesting that CRP grasslands may not be as

effective as NPAM grasslands at supporting native pollinator populations. Fewer species of flowering plants are planted in CRP fields than occurs naturally in NPAM and other native prairie grasslands. Native pollinators require a continuous food supply when they are active and increasing the number of plant species to ensure there are no dearth's in food supply would improve the quality of restored grasslands to pollinators.

Although the abundance and richness of pollinators mostly differed among locations, the difference was especially pronounced at the Tewaukon grasslands (Figure 9 and 10). I sampled 20 transects at Arrowwood, Kulm and Sully's Hill grasslands but it was only possible for FWS to establish nine transects at the Tewaukon grasslands due to their smaller area. While my sample at Tewaukon was likely not adequate to facilitate comparison with the other three-paired locations, my finding that richness and abundance sample were similar at Tewaukon is largely consistent with my findings at the other paired locations. Consequently, we do know that habitat area is a critical factor influencing native invertebrate pollinator richness (Steffan-Dewenter 2002), but whether reduced habitat availability or the reduced number of transects influenced the reduced richness and abundance at Tewaukon is unclear. However, my finding that abundance and richness were similar at the Tewaukon sites is consistent with my findings at the other three locations.

Although I did not find statistical differences in overall pollinator abundance between years, I suspect that annual variation would be more apparent at the species level. Variations in many of the more populous native bee genera (i.e., *Agapostemon*, *Bombus*, *Lasioglossum*, and *Melissodes*) collected in 2012 were significantly different (*P*

< 0.05) in 2013 among grassland types (Figure 15). This could be due to a number of factors (i.e. oversampling in 2012, natural population dynamics, decreased surrounding habitat, and/or pathogens), but is startling and consistent with ongoing declines in a number of native bee taxa, especially bumble bees (*Bombus*, Figure 16) in North America (NRC 2007, Grixti et al. 2009, Cameron et al. 2011).

In Illinois for example, bumble bee richness declined during the 1940s-1960s, when major agricultural intensification in the Midwest was severe (Grixti et al. 2009). Farms that previously grew a diversity of crops, switched to growing corn and soybeans (Iverson 1988). This exchange resulted in the loss of beneficial wildlife habitats and a landscape dominated by fewer floral sources. Therefore, agricultural intensification may be contributing to the decline in *Bombus* species and other pollinators in North Dakota, where similar land-use changes have taken place over the past decade.

It is likely that factors not measured in my study influence pollinator populations in North Dakota. Reductions in the abundance and richness of native bees within landscapes associated with declining floral sources due to intensive agricultural development (Rundlof et al. 2008), reduced nesting sites (Williams et al. 2010), and increased pesticide use (Mullin et al. 2010) are examples. While outside the scope of my study, extensive local and landscape level analysis may provide insight into these and other potential effects driving variations in the abundance and richness of native pollinators.

Kennedy et al. (2013), modeled the relative effects of landscape composition (nesting and floral resources within an area), landscape configuration, and farm

management and their interactions, on native bee abundance and richness. Their findings indicated that native bee abundance and richness was higher in organic-diversified lands, where surrounding land cover was of high quality. They also noted that just a 10% increase in the amount of high quality habitat in the landscape could potentially increase pollinator abundance and richness by 37%. Landscape scale studies that analyze the surrounding land cover may reveal effects that were undetected at the local scale of my study. Land practices that increase habitat heterogeneity has been suggested as a tool to mitigate pollinator declines (NRC 2007).

Plant-Pollinator Interactions

My study identified a number of interactions and links that have important implications for native pollinator management. NPAM grasslands had significantly more plant species that provided more floral resources to pollinators each month (Figure 17) that increased the interactions and unique links I was able to detect (Figure 20). Lower floral diversity on CRP grasslands likely reduced potential interactions and unique links available to native pollinators. Diversifying seed mixtures to include more plants important to native pollinators, to provide continuous forage over the period when pollinators are active should enhance the overall quality of restored grasslands.

My estimates for connectance (NPAM = 0.09, CRP = 0.15) were similar to those reported by Jordano et al. (2006). While my sampling frequency was comparable to past studies, I believe intensifying surveys would improve connectance estimates because it is only possible to observe a small fraction of all possible interactions during field surveys;

increasing field time would enhance the likelihood of detecting more plant-pollinator interactions, I selectively swept for native bees on blooming plant species for roughly 10 minutes per transect. Transects were fixed and randomly placed before the field season in each study site; however, we would regularly observe plant-pollinator interactions off transect that were otherwise undetected (i.e. Russian olive, *Elaeagnus angustifolia*, and American basswood, *Tilia americana*) were very attractive to native bees when in bloom). I believe that emplacing a more rigorous sampling effort and a different sampling approach (e.g., larger transects) would increase the chance of observing interactions and improve the overall connectance estimates for plant-pollinator networks.

My study revealed that native pollinators in North Dakota visit flowers from a diversity of plant species, suggesting they have diverse pollen diets. Most of the bees I washed had multiple species of pollen on them and those that had only one pollen source, may not mean they are specialist. In a study in Greece, Petanidou et al. (2008) stated that "no species recorded in all four years was truly a specialist. This allows us to speculate that reported levels of specialization in the literature are overestimates of real specialization." In my observed plant-pollinator networks, abundant pollinator species (i.e. *Melissodes spp., Lassioglosum spp.,* and *Bombus spp.*) had higher interactions due to the fact they were encountered more often in the grasslands (Figure 14). However, rare pollinator species had fewer interactions among plant species, just due to their rareness in the landscape. Therefore, I did not compute pollinator specialization in my study because it may not accurately identify true ecological specialists in these grassland systems.

A surprising discovery from my study was that CRP grasslands supported a similar abundance and richness of pollinators as NPAM grasslands. CRP grasslands do not have as many floral resources as NPAM grasslands, especially native plants. Indeed, the predominant floral sources on CRP sites were introduced plant species (Figure 18). Although I found no variation in pollinator abundance and richness between grassland types, I did observe significant variation in the diversity of blooming forbs (Figure 17). This is in contrast with several studies that suggest pollinator abundance and richness are directly influenced by the number of flowering plant species available (Potts et al. 2003, Ebeling et al. 2008). However, Hegland and Boeke (2006) found no effect of plant species richness on pollinator species richness. They made the case that most pollinators are generalists, and increasing plant richness at the local scale would not increase pollinator abundance or richness. They emphasized that blossom density was a better predictor for explaining general patterns of pollinators at the community level. I did not measure blossom density, but both my predominant pollen sources (leadplant, *Amorpha canescens*, on NPAM and perennial sowthistle, *Sonchus arvensis*, on CRP) are plants that produce large inflorescences. However, we know little about the minimal requirement for plant species or their density to support healthy pollinator populations.

I believe there are two explanations for why I found no difference in pollinator abundance and richness, but significantly greater variation in plant species richness between grassland types. One, the blue vane traps could have been more of a visual attractant to pollinators, hence, they may have caught pollinators that do not normally utilize the area immediately surrounding the traps. The majority of pollinators collected

in my vane traps were visibly clean of pollen, suggesting as they were visiting the vane traps seeking a potential food reward. Therefore, vane traps samples may not be an accurate representation of local site level composition, but more of a landscape level composition of species abundance and richness (Figure 12). Secondly, high blossom density among patches of floral resources can influence pollinator abundance and richness (Hegland and Boeke 2006). Although I did not measure this influence in my study, the majority of introduced plant species (i.e. *Melilotus offinalis*, *Cirsium arvense*, *Sonchus arvensis*) I observed on CRP grasslands do have large inflorescences that attract native pollinators. In contrast, the greater diversity of flowering plants I found, especially native species, would not explain why both grassland types had similar pollinator abundance and richness.

My study suggests that CRP grasslands are beneficial and support a pollinator community that has a similar abundance and richness as NPAM grasslands. However, CRP grasslands may not provide stable habitat conditions for native pollinators, as suggested by the higher turnover of species in 2013. My findings also suggest that pollinator community level analysis may conceal underlying and highly dynamic population dynamics (e.g., *Bombus spp*.). This suggests that factors outside the local site level may exert considerable influence on pollinator abundance and richness. Landscape level studies may be required to explain variations in pollinator communities.

In summary, I suggest that as landscapes become less heterogeneous, islands of grasslands will be critical habitats for native pollinators. Findings from studies of native pollinators, including my study, can enhance future grassland restorations and help

identify disturbance regimes important in native pollinator management. During my investigation, NPAM grasslands were more resilient in species turnover and provided a greater diversity of native floral resources than CRP grasslands. Incorporating the native plants found to be predominant pollen sources for native pollinators into future seed mixtures would enhance the overall value of restored grasslands to native pollinators. Likewise, adding native pollinators to ongoing NPAM monitoring efforts would be especially valuable to identify disturbance regimes that enhance plants important to native pollinators to improve management of NPAM and more mature CRP and other grassland restorations.

LITURATURE CITED

Araujo, E.D., M. Costa, J. Chaud-Netto, and H.G. Fowler. 2004. Body size and flight distance in stingless bees (Hymenoptera: Meliponini): inference of flight range and possible ecological implications. Brazilian Journal of Biology 64: 563-568.

Bascompte, J., P. Jordano, C.J. Melian, and J.M. Olesen. 2003. The nested assembly of plant-animal mutualistic networks. Proceedings of the National Academy of Science USA 100: 9383-8387.

Beismeijer, J.C., S.M. Roberts, M. Reemer, R. Ohlemueller, M. Edwards, T. Peeters, A.P. Schaffers, S.G. Potts, R. Kleukers, C.D. Thomas, J. Settele, and W.E. Kunin. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science 313: 351-354.

Bray, J.R., and J.T. Curtis. 1957. An ordination of upland forest communities in southern Wisconsin. Ecological Monographs 27: 325-349.

Cameron, S.A., J.D. Lozier, J.P. Strange, J.B. Koch, N. Cordes, L.F. Solter, and T.L. Griswold. 2011. Patterns of widespread decline in North American bumble bees. Proceedings of the National Academy of Sciences USA 108: 662-667.

Christensen, N.L., A.M. Bartuska, J.H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J.F. Franklin, J.A. MacMahon, R.F. Noss, D.J. Parsons, C.H. Peterson, M.G. Turner, and R.G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecological Applications 6: 665-691.

Cox-Foster, D., and D. vanEngelsdrop. 2009. Saving the honey bee. Scientific American 300:40-47.

Crane, E. 1992. The World's Beekeeping- Past and Present. Chapter 1 in J.M. Graham, editor. The Hive and the Honey Bee. Dadant & Sons, Hamilton, Illinois.

Crompton, C.W., and W.A. Wojtas. 1993. Pollen grains of Canadian honey plants. Agriculture Canada, Research Branch, Publication 1892/E.

Dormann, C.F., B. Gruber, and J. Fruend. 2008. Introducing the bipartite package: analyzing ecological networks. R News 8: 8-11.

Dunne, J., R.J. Williams, and N.D. Martinez. 2002. Food-web structure and network theory: the role of connectance and size. Proceedings of the National Academy of Science USA 99: 12917-12922.

Ebeling, A., A.M. Klein, J. Schumacher, W.W. Weisser, and T. Tscharntke. 2008. How does plant richness affect pollinator richness and temporal stability of flower visits? Oikos 117: 1808-1815.

Euliss, N.H., Jr., R.A. Gleason, A. Olness, R.L. McDougal, H.R Murkin, R.D. Robarts, R.A. Bourbonniere, and B.G. Warner. 2006. North American prairie wetlands are important nonforested land-based carbon storage sites. Science of the Total Environment 361: 179-188.

Farm Service Agency (FSA). 2006. Conservation Reserve Program Continuous Sign-up Fact Sheet. U.S. Department of Agriculture, Washington, D.C. http://www.fsa.usda.gov/Internet/FSA_File/crpcont06.pdf.

Farm Service Agency (FSA). 2008. Grassland Reserve Program Fact Sheet. U.S. Department of Agriculture, Washington, D.C. http://www.fsa.usda.gov/Internet/FSA_File/grpfactsheet08.pdf.

Fish and Wildlife Service (USFWS). 2007. Strategic Plan: The Partners for Fish and Wildlife Program. U.S. Fish and Wildlife Service, Arlington, VA. http://www.USFWS.gov/partners/docs/783.pdf.

Frazier, M., C. Mullin, J. Frazier, and S. Ashcraft. 2008. What have pesticides got to do with it? American Bee Journal 148: 521-523.

Gannon, J.J., C.T. Moore, T.L. Shaffer, and B. Flanders-Wanner. 2011. An adaptive approach to invasive plant management on U.S. Fish and Wildlife Service-owned native prairies in the Prairie Pothole Region: decision support under uncertainty. North American Prairie Conference 22: 136-145.

Gleason, R.A., M.K. Laubhan, and N.H. Euliss Jr. 2008. Ecosystem services derived from wetland conservation practices in the United States Prairie Pothole Region with an emphasis on the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs. U.S. Geological Survey Professional Paper 1745.

Greenleaf, S.S., N.M. Williams, R. Winfree, and C. Kremen. 2007. Bee foraging ranges and their relationship to body size. Oecologia 153: 589-596.

Grixti, J.C., L.T. Wong, S.A. Cameron, and C. Favret. 2009. Decline in bumble bees (*Bombus*) in the North American Midwest. Biological Conservation 142: 75-84.

Haarmann, T., M. Spivak, D. Weaver, B. Weaver, and T. Glenn. 2002. The effects of fluvalinate and coumaphos on queen honey bees (*Apis mellifera*) in two commercial queen rearing operations. Journal of Economic Entomology 95: 28-35.

Haufler, J.B., and B. Jonathan, editors. 2005. Fish and wildlife benefits of the Farm Bill conservation programs: 2000-2005 update. Wildlife Society.

Hegland, S.J., and L. Boeke. 2006. Relationships between the density and diversity of floral resources and flower visitor activity in a temperate grassland community. Ecological Entomology 31: 532-538.

Henry, M., M. Beguin, F. Requier, O. Rollin, J.F. Odoux, P. Aupinel, J. Aptel, S. Tchamitchian, and A. Decourtye. 2012. A common pesticide decreases foraging success and survival in honey bees. Science 336: 348-350.

Iverson, L.R. 1988. Land-use changes in Illinois, USA: the influence of landscape attributes on current and historic land use. Landscape Ecology 2: 45-61.

Jones, G.D., and V.M. Bryant Jr. 2007. A comparison of pollen counts: Light versus scanning electron microscopy. Grana 46: 20-33.

Jordano, P., J. Bascompte, and J.M. Olesen. 2006. The ecological consequences of complex topology and nested structure in pollination webs. Pages 173-199 in N.M. Waser and J. Ollerton, editors. Plant-Pollinator Interactions, from Specialization to Generalization. University of Chicago Press, Chicago, IL.

Karlin, E.F. 1995. Population growth and the global environment: an ecological perspective. Pages 19-37 in W.J. Makofske, and E.F. Karlin EF, editors. Technology, Development and Global Environmental Issues. Harper Collins College Publishers, New York, NY.

Kearns, C.A., and D.W. Inouye. 1993. In C.A. Kearns, and D.W. Inouye DW, editors. Techniques for Pollination Biologist. University Press of Colorado, Niwot, CO.

Kearns, C.A., D.W. Inouye, and N.M. Waser. 1998. Endangered mutualisms: the conservation of plant-pollinator interactions. Annual Review of Ecology and Systematics 29: 83-112.

Kennedy, C.M., E. Lonsdorf, M.C. Neel, N.M. Willaims, T.H. Ricketts, R. Winfree, R. Bommarco, C. Brittain, A.L. Burley, D. Cariveau, L.G. Carvalheiro, et al. 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. Ecology Letters 16: 584-599.

Kindt, R., and R. Coe. 2005. Tree diversity analysis: A manual and software for common statistical methods for ecological and biodiversity studies. World Agroforestry Centre (ICRAF), Nairobi. ISBN 92-9059-179-X.

Klein, A.M., B.E. Vaissiere, J.H. Cane, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen, and T. Tscharntke. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society 274: 303-313.

Knutson, G.A., and N.H. Euliss Jr. 2001. Wetland restoration in the prairie pothole region of North America: a literature review. Biological Science Report, USGS/BRD/BSR-2001-0006, Reston, VA.

Kremen, C., N.M. Williams, and R.W. Thorp. 2002. Crop pollination from native bees at risk from agricultural intensification. Proceedings of the National Academy of Sciences (USA) 99: 16812-16816.

Louveaux, J., A. Maurizio, and G. Vorwohl. 1978. Methods in Melissopalynology. Bee World 59: 39-157.

Marcelo, A.A., and L.D. Harder. 2009. The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. Current Biology 19: 1-4.

Mattila, H.R., and G.W. Otis. 2006. Influence of pollen diet in spring on development of honey bee (Hymenoptera: Apidae) colonies. Journal of Economic Entomology 99: 604-613.

Maurizio, A. 1950. The influence of pollen feeding and brood rearing on the length of life and physiological condition of the honeybee. Bee World 31: 9-12.

Muir, J. 1894. The Bee-Pastures. Chapter 16 in The Mountains of California. John Muir Writings.

Mullin, C.A., M. Frazier, J.L. Frazier, S. Ashcraft, R. Simonds, D. vanEngelsdorp, and J.S. Pettis. 2010. High levels of miticides and agrochemicals in North American apiaries: implications for honey bee health. PLoS ONE 5(3), e9754. doi:10.1371/journal.pone.0009754.

Mullins, B.A., D. Ritchison, D. Schlag, and A. Akyuz. 2012. North Dakota State Climate Bulletin. North Dakota State Climate Office, Fargo, ND.

Mullins, B.A., D. Ritchison, D. Schlag, and W. Vern. 2013. North Dakota State Climate Bulletin. North Dakota State Climate Office, Fargo, ND.

National Agriculture Statistics Service (NASS). 2011. Honey. Agriculture Statistics Board, NASS, USDA. http://usda01.library.cornell.edu/usda/current/Hone/Hone-02-25-2011.pdf.

National Climatic Data Center. 2014. National Oceanic and Atmospheric Administration's National Climatic Data Center. http://www.ncdc.noaa.gov/climate-monitoring/index.php.

National Research Council (NRC). 2007. Status of pollinators in North America. The National Academies Press, Washington, D.C.

Naug, D. 2009. Nutritional stress due to habitat loss may explain recent honeybee colony collapses. Biological Conservation doi:10.1016/j.biocon.2009.04.007.

Petanidou, T., A.S. Kallimanis, J. Tzanopoulous, S.P. Sgardelis, and J.D. Pantis. 2008. Long-term observation of a pollination network: fluctuation in species and interactions, relative invariance of network structure and implications for estimates of specialization. Ecology Letters 11: 564-575.

Pettis, J.S., A.M. Collins, R. Wilbanks, and M.F. Feldlaufer. 2004. Effects of coumaphos on queen rearing in the honey bee, *Apis mellifera*. Apidologie 35: 605-610.

Potts, S.G., B. Vulliamy, A. Dafni, G. Ne'eman, and P. Willmer. 2003. Linking bees and flowers: how do floral communities structure pollinator communities? Ecology 84:2628-2642.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reynolds, R.E., T.L. Shaffer, J.R. Sauer, and B.G. Peterjohn. 1994. Conservation reserve program: benefit for grassland birds in the northern plains. Transactions of the North American Wildlife and Natural Resources Conference 59: 328-336.

Ricketts, T.H., J. Regetz, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen, A. Bogdanski, B. Gemmill-Herren, S.S. Greenleaf, A.M. Klein, M.M. Mayfield, L.A. Morandin, A. Ochieng, and B.F. Viana. 2008. Landscape effects on crop pollination services: are there general patterns? Ecology Letters 11: 499-515.

Skokstad, E. 2007. The case of the empty hives. Science 316: 970-972.

Smith, A.G., J.H. Stoudt, J.B. Gallop. 1964. Prairie potholes and marshes. In J.P. Linduska, editor. Waterfowl Tomorrow. U.S. Govt. Printing Office, Washington, D.C.

Steffan-Dewenter, I. 2002. Importance of habitat area and landscape context for species richness of bees and wasps in fragmented orchard meadows. Conservation Biology 17(4): 1036-1044.

Steffan-Dewenter, I., S.G. Potts, and L. Packer. 2005. Pollinator diversity and crop pollination services are at risk. Trends in Ecology and Evolution 20: 1-2.

Stephen, W.P., and S. Rao. 2005. Unscented color traps for non-Apis bees (Hymenoptera: Apiformes). Journal of the Kansas Entomological Society 78(4): 373-380.

Tiner, R.W., Jr. 1984. Wetlands of the United States: current status and recent trends. U.S. Fish and Wildlife Service, U.S. Government Printing Office, Washington, D.C.

PERSONAL COMMUNICATIONS

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APPENDICES

Appendix A. Families that were not truly potential pollinators were excluded from analysis, including honey bees. TRUE = included in analysis given; FALSE= excluded.

Family	Potential Pollinator
Andrenidae	TRUE
Anthicidae	TRUE
Anthomyiidae	FALSE
Apidae	TRUE
Arctiidae	TRUE
Asilidae	FALSE
Bethylidae	FALSE
Bibionidae	FALSE
Bombyliidae	TRUE
Braconidae	TRUE
Buprestidae	FALSE
Calliphoridae	TRUE
Cantharidae	TRUE
Carabidae	FALSE
Carnidae	FALSE
Cerambycidae	TRUE
Chironomidae	TRUE
Chloropidae	FALSE
Chrysididae	FALSE
Chrysomelidae	FALSE
Cleridae	TRUE
Coccinellidae	TRUE
Colletidae	TRUE
Conopidae	TRUE
Crabronidae	TRUE
Culicidae	TRUE
Curculionidae	TRUE
Cynipidae	FALSE
Dolichopodidae	TRUE
Dytiscidae	FALSE
Elateridae	TRUE
Ephydridae	TRUE
Figitidae	FALSE
Formicidae	FALSE
Geometridae	TRUE
Halictidae	TRUE
Hesperiidae	TRUE
Ichneumonidae	TRUE
Lampyridae	TRUE
Lycaenidae	TRUE
Megachilidae	TRUE
Meglopodidae	FALSE
Meloidae	TRUE
Mordellidae	TRUE
Muscidae	TRUE
Nitidulidae	FALSE
Noctuidae	TRUE
Notodontidae	TRUE
Nymphalidae	TRUE
Phoridae	FALSE
Pieridae	TRUE
Pompilidae	TRUE
Pyralidae	TRUE
Sarcophagidae	FALSE
Scarabaeidae	TRUE
Scathophagidae	FALSE
Scatopisidae	FALSE
Sciaridae	FALSE
Scoliidae	FALSE
Sepsidae	FALSE
Silvanidae	FALSE
Simuliidae	FALSE
Sphecidae	TRUE
Sphingidae	TRUE
Staphylinidae	FALSE
Stratiomyidae	TRUE
Syrphidae	TRUE
Tabanidae	TRUE
Tachinidae	TRUE

Tenthredinidae	TRUE
Thyrecoridae	FALSE
Tiphiidae	TRUE
Tortricidae	TRUE
Torymidae	FALSE
Vespidae	TRUE

Appendix B. List of total taxa discovered and their abundance from vane traps at each site: AC/AN – Arrowwood CRP/NPAM, KC/KN – Kulm CRP/NPAM, SC/SN – Sully's Hill CRP/NPAM, TC/TN – Tewaukon CRP/NPAM. Native bees are identified to species (when able) and other potential pollinators are only listed here at the genus level or "NA" (Not Available).

Bee Taxa	AC	AN	KC	KN	SC	SN	TC	TN
Andrenidae								
Andrena hippotes		2						
Andrena imitatrix							1	
Andrena sp.	2	9	18	8	239	27	3	1
Andrena nigrihirta					1			
Heterosarus sp.		7				5		
Perdita sp.				1				
Perdita swenki	2	1	7		5			
Protandrena sp.	1	1						
Pseudopanurgus labrosiformis	1							
Pseudopanurgus nebrascensis	1	1						
Pseudopanurgus parvus		4						
Pseudopanurgus pauper		4						
Apidae								
Anthophora bomboides	1							
Anthophora edwarsii		1						
Anthophora sp.								1
Anthophora terminalis	2	4		1	3			
Anthophora walshii	13	13	6	13	4	1		2
Bombus auricomus			1					
Bombus bimaculatus		1		1	7	44		
Bombus borealis	60	69	30	82	131	335	3	3

Bombus fervidus	15	54	6	62	7	7		1
Apidae	AC	AN	KC	KN	SC	SN	TC	TN
Bombus griseocollis	32	28	17	23	7	31	1	14
Bombus nevadensis	1	2	2	1	7	24		
Bombus pensylvanicus				1				
Bombus rufocinctus	1	3	1		6	18		1
Bombus ternarius	2	11	6	6	100	296		1
Bombus terricola					1	1		
Bombus vagans	1	27	2		5	8	2	1
Ceratina calcarata				1				
Ceratina dupla		56		2	9	72	94	8
Ceratina dupla/calcarata	5	138		10	21	88	22	5
Diadasia australis							1	
Diadasia diminuta			3	4				
Epeolus minimus		1		1				
Eucera sp.	2	3	18	5	4	12	5	1
Holcopasites pulchellus			1					
Melissodes agilis		3						
Melissodes bimaculata	1				1		3	2
Melissodes sp.	2714	1484	595	636	620	516	1061	440
Nomada florilega			1					
Nomada imbricata					1			
Nomada sp.	2	2	5	2	44	4	2	
Nomada superba							1	
Svastra sp.			4	2		2		
Svastra obliqua	7	6	6	6	1		6	
Tetraloniella sp.			8		1			
Triepeolus cressonii		1	1					

Triepeolus helianthi	9	8	7	3		5	3	
Apidae	AC	AN	KC	KN	SC	SN	TC	TN
Triepeolus lunatus								1
Triepeolus sp.	1			1				
Triepeolus pectoralis	1							
Triepeolus simplex	1			1				
Xenoglossa kansensis				1			2	
Xeromelecta interrupta		1						
Colletidae								
Colletes brevicornis		3						
Colletes inequalis		2						
Colletes solidaginis	1							
Colletes sp.		10						
Hylaeus affinis	49	13	104	28	41	1	4	14
Hylaeus annulatus	2				3	14		
Hylaeus leptocephalus	1	3		2		2		
Hylaeus mesillae		2	1	2	12	38	6	
Hylaeus modestus					4		2	
Hylaeus sp.			1		1			2
Hylaeus nelumbonis							1	1
Hylaeus saniculae					1			
Halictidae								
Agapostemon sp.		10						
Agapostemon sericeus	1							2
Agapostemon texanus/angelicus	56	28	94	24	70	33	13	1
Agapostemon virescens	222	968	1379	653	416	679	192	32
Augochlora pura							8	

Augochlorella aurata		7				11	2	1
Halictidae	AC	AN	KC	KN	SC	SN	TC	TN
Augochloropsis sumpuosa	1							1
Dieunomia triangulifera	5	1						
Dufourea marginata	5	1	1	1				
Dufourea maura	2	1			5	8		
Halictus confusus	4	38	33	35	138	99	6	1
Halictus ligatus	6	13	6	10	1	3	28	
Halictus sp.								1
Halictus parallelus	4	8	2	2	94	4		
Halictus rubicundus		17	15	12	47	27		
Halictus tripartitus		3		1	10		2	1
Lasioglossum fuscipenne		2						
Lasioglossum (Dialictus) sp.	106	291	313	338	231	1246	109	60
Lasioglossum (Evylaeus) sp.	1	27	1		14	13	5	
Lasioglossum (s.str.) sp.	82	115	56	85	229	118	4	
Lasioglossum (Sphecodogastra)		10		2		2		
Lasioglossum sp.	11	22	5	19	185	257		3
Nomia universitatis				1				
Sphecodes atlantis							2	
Sphecodes carolinus	15	6	1		2	4	3	
Sphecodes coronus		2			7	2		
Sphecodes dichrous						1		
Sphecodes minor	1							
Sphecodes sp.	2	7	6	4	45	9		
Sphecodes prosphorus					1			
Megachilidae								

Coelioxys octodentata							1	
Heriades carinata						4		
Megachilidae	AC	AN	KC	KN	SC	SN	TC	TN
Heridas variolosa							1	
Hoplitis pilosifrons	19	20	28	69	72	15	49	12
Hoplitis producta		4	1					
Hoplitis truncata		1						
Megachile brevis	3	4	2	1	1	2	1	
Megachile centuncularis	1				1	1		
Megachile inermis		2			1	1		
Megahcile latimanus	8	15	13	22	7	2	11	1
Megachile melanophaea						1		
Megachile mendica		1						
Megachile montivaga				1		1		
Megachile sp.		2						
Megachile parallela				1		2		
Megachille pugnata				1				
Osmia bucephala						1		
Osmia inermis			1	1				
Osmia sp.		2	3	3		2		
Osmia simillima		1	1					
Osmia targata			1					
Stelis laterlis				1			2	

Other Taxa	AC	AN	KC	KN	SC	SN	TC	TN
Coleoptera								
Aptopus								4
Atalantycha	1							
Brachiacantha					1	1		
Coleoptera	AC	AN	KC	KN	SC	SN	TC	TN
Chauliognathus							3	21
Coccinella	2	1			4		1	
Cremastocheilus					2			
Dipropus	2				1			
Ellychnia		1						
Epicauta	1	12	6	3	22	35		4
Harmonia		1						
Hippodamia	1							
Judolia						1		
Lytta	1		7	1	4	34		
Megacyllene		3			1			
Mordella		2				6		
Mordellistena		1						
NA	12	139	20	24	9	94	6	3
Nemognatha			2					1
Onthophagus					1			
Prionus		1						
Pyractomena	37	2	1	6	23	29		1

Trichodes	1	1	1		1	1		
Diptera								
Allognosta	1							
Allograpta			3					
Anastoechus			14					
Bombylius			2					
Bufolucilia	18	1						
Chironomus	1							
Chrysops	11		6	2	2		6	1
Diptera	AC	AN	KC	KN	SC	SN	TC	TN
Cylindromyia			1					
Dolichopus								1
Eristalis	10	8	52	38	14	14	5	2
Eucalliphora	2							
Eupeodes	73	46	50	63	34	59	10	9
Hamatabanus								1
Hedriodiscus	6	2	1	1	2		3	8
Helophilus	242	67	197	27	44	25	20	14
Hermetia		1						
Lejops	18		15	1	11		6	8
Lucilia							4	
Melanostoma								1
Microdon		1						
Myolepta							1	
NA	62	92	39	316	86	18	18	22
Nemotelus	2							
Neoascia			1	1	1			

Ocyptamus		1						
Odontomyia	16				6	1	13	
Paragus		1						
Parasyrphus					1		1	
Paravilla	1							
Parhelophilus	10	1	16	2	5		10	
Peleteria		1						
Phaenicia	3	3						
Phthiria	1	1	1					
Poecilognathus	1	3	8	1	17			
Diptera	AC	AN	KC	KN	SC	SN	TC	TN
Sphaerophoria	20	4	26	8	53		1	
Stratiomys	5	1	9	6	15		2	
Syritta		2						
Syrphus	2	5		2		1		3
Systoechus		1	2		1			
Toxomerus	152	68	133	109	68	23	37	6
Tropidia	21	7	59	4			2	2
Volucella		1						
Xylota					2			
Lepidoptera								
Anagrapha	1	1		1				
Anatartone		1						
Autographa	1							
Boloria			1					
Cercyonis					2	1		
Coenonympha		1		1				

Colias	1	1	30	17	3	2	3	1
Feltia	20	1			1			
Glaucopsyche				1	10			
Grammia				1		1		
Hemaris		2				1		
Hyles	1						2	1
Mythimna	1							
NA	8	28	38	20	12	47	25	9
Pieris			1		1			
Plusia	4							
Polites				3	2	1	1	1
Lepidoptera	AC	AN	KC	KN	SC	SN	TC	TN
Speyeria						1		
Sphinx		1						
Trichoplusia	1							
Vanessa			1					

Appendix C. Plants that were visited by native bees in 2012 and 2013 within native prairie grasslands (NPAM) and restored prairie grasslands (CRP). Plants are also marked with an "X" if native to eastern North Dakota and left blank if exotic.

Family	Taxa	PLANT	NPAM	CRP	NATIVE
Apiaceae	*Zizia aurea*	Golden Alexander	X		X
Apocynaceae	*Asclepias syriaca*	Common Milkweed	X		X
Apocynaceae	*Asclepias ovalifolia*	Dwarf Milkweed	X		X
Apocynaceae	*Apocynum cannabinum*	Indianhemp Dogbane	X		X
Apocynaceae	*Asclepias speciosa*	Showy Milkweed	X		X
Apocynaceae	*Apocynum androsaemifolium*	Spreading Dogbane	X		X
Asteraceae	*Gaillardia aristata*	Blanket Flower	X		X
Asteraceae	*Liastris spp.*	Blazing Star	X		X
Asteraceae	*Lactuca oblongifolia*	Blue Lettuce	X		X
Asteraceae	*Solidago canadensis*	Canada Goldenrod	X		X
Asteraceae	*Cirisium arvense*	Canada Thistle	X	X	
Asteraceae	*Grindelia squarrosa*	Curlycup Gumweed	X		X
Asteraceae	*Erigeron strigosus*	Daisy Fleabane		X	X
Asteraceae	*Taraxacum officinale*	Dandelion	X		X
Asteraceae	*Cirsium flodman*	Floodmans Thistle	X		X
Asteraceae	*Tragopogon dubis*	Goatsbeard	X	X	
Asteraceae	*Heterotheca villosa*	Hairy Gold Aster	X		X
Asteraceae	*Liastris ligulistylis*	Meadow Blazingstar	X		X
Asteraceae	*Solidago missouriensis*	Missouri Goldenrod	X		X
Asteraceae	*Sonchus arvensis*	Perennial Sow Thistle		X	
Asteraceae	*Ratibida columnifera*	Prairie Coneflower	X		X
Asteraceae	*Echinacea angustifolia*	Purple Coneflower	X		X
Asteraceae	*Lygodesmia juncea*	Skeletonweed	X		X
Asteraceae	*Helianthus rigidus*	Stiff Sunflower	X		X

Asteraceae	*Cirisium undulatum*	Wavy-leaf Thistle	X		X
Asteraceae	*Achillea millefolium*	Yarrow	X		X
Brassicaceae	*Erysimum capitatum*	Western Wallflower	X	X	X
Campanulaceae	*Campanula rotundifolia*	Harebell	X		X
Caprifoliaceae	*Symphoricarpos occidentalis*	Western Snowberry	X		X
Convolvulaceae	*Calystegia sepium*	Hedge Bindweed	X	X	X
Elaeagnaceae	*Elaeagnus commutata*	American Silverberry	X		X
Elaeagnaceae	*Elaeagnus angustifolia*	Russian Olive	X		
Euphorbiaceae	*Euphorbia esula*	Leafy Spurge	X	X	
Fabaceae	*Medicago sativa*	Alfalfa	X	X	
Fabaceae	*Vicia americana*	American Vetch	X		X
Fabaceae	*Amorpha canescens*	Leadplant	X		X
Fabaceae	*Dalea purpurea*	Purple Prairie Clover	X		X
Fabaceae	*Astragalus bisulcatus*	Two-grooved Milkvetch	X		X
Fabaceae	*Petalostemon candidum*	White Prairie Clover	X		X
Fabaceae	*Melilotus officinalis*	Yellow Sweet Clover	X	X	
Lamiaceae	*Monarda fistulosa*	Western Wild Bergamot	X	X	X
Liliaceae	*Zigadenus elegans*	Showy Deathcamas	X		X
Poaceae	*Bromus inermis*	Smooth Brome		X	
Ranunculaceae	*Anemone canadensis*	Canada Anemone	X		X
Rosaceae	*Spiraea alba*	Narrow-leaved Meadowsweet	X		X
Rosaceae	*Rosa arkansana*	Prairie Rose	X		X
Rosaceae	*Potentilla arguta*	White Cinquefoil	X		X
Rubiaceae	*Galium boreale*	Northern Bedstraw	X		X
Verbenaceae	*Verbena hastata*	Blue Vervain	X		X

Appendix D. Plant pollen key created from identifying and measuring a minimum of 10 pollen grains for each plant species and with the aid of literature.

Family	**Scientific Name**	**Common Name**	**Pollen Grain Class**	**Polar Length (µm)**	**Equatorial Length (µm)**	**Exine Thickness (µm)**
Apiaceae	*Cicuta maculata*	Water Hemlock	Tricolporate	31.2-36.2	16.7-17.5	2-2.6
Apiaceae	*Zizia aurea*	Golden Alexander	Tricolporate	22.8-34.4	12.8-16	1.4-1.8
Apocynaceae	*Apocynum androsaemifolium*	Spreading Dogbane	Tetrads	17.5-21.8	NA	1.6-2.1
Apocynaceae	*Apocynum cannabinum*	Indianhemp Dogbane	Tetrads	13.8-26.3	NA	1.7-2.6
Apocynaceae	*Asclepias syriaca*	Common Milkweed	Tetrads	NA	NA	NA
Asteraceae	*Achillea millefolium*	Yarrow	Tricolporate	21.5-30.1	NA	> 3
Asteraceae	*Antennaria neglecta*	Field Pussytoes	Tricolporate	20.7-23.6	NA	1.8-2.9
Asteraceae	*Arnica fulgens*	Arnica	Tricolporate	22.6-26	NA	2.3-2.8
Asteraceae	*Aster ericoides*	White Aster	Tricolporate	21.8-25.8	NA	2.8-3.8
Asteraceae	*Aster novae-angliae*	New England Aster	Tricolporate	24.3-31.6	NA	1.5-2.5
Asteraceae	*Cirisium arvense*	Canada Thistle	Tricolporate	37.2-47.5	NA	3.3-3.9
Asteraceae	*Cirisium undulatum*	Wavy-leaf Thistle	Tricolporate	41-50	NA	NA
Asteraceae	*Cirsium flodman*	Floodmans Thistle	Tricolporate	50.7-56.8	NA	NA
Asteraceae	*Echinacea angustifolia*	Purple Coneflower	Tricolporate	27.5-29.4	NA	1.8-3.5
Asteraceae	*Erigeron philadelphicus*	Common Fleabane	Tricolporate	NA	NA	NA
Asteraceae	*Erigeron sp.*	Fleabane (genus)	Tricolporate	21.8-28.4	NA	NA
Asteraceae	*Erigeron strigosus*	Daisy Fleabane	Tricolporate	15.5-19	NA	1.5-1.8
Asteraceae	*Gaillardia aristata*	Blanket Flower	Tricolporate	34.3-36.1	NA	NA
Asteraceae	*Grindelia squarrosa*	Curly-cup Gumweed	Tricolporate	23-31.2	NA	2-3.9

Asteraceae	*Helianthus maximiliani*	Maximillian Sunflower	Tricolporate	22.4-26.2	NA	< 4
Asteraceae	*Helianthus petiolaris*	Prairie Sunflower	Tricolporate	25.6-27.9	NA	< 3
Asteraceae	*Helianthus rigidus*	Stiff Sunflower	Tricolporate	26-30	NA	2.2-3.1
Asteraceae	*Heterotheca villosa*	Hairy Gold-Aster	Tricolporate	25.4-26.4	NA	1.8-3.3
Asteraceae	*Lactuca oblongifolia*	Blue Lettuce	Echinolophate-Tricolporate	29-36	NA	NA
Asteraceae	*Liatris ligulistylis*	Meadow Blazingstar	Tricolporate	24.1-26.5	NA	2.8-4.1
Asteraceae	*Liatris punctata*	Dotted Blazingstar	Tricolporate	26.8-30	NA	1.6-2.4
Asteraceae	*Lygodesmia juncea*	Skeletonweed	Echinolophate-Tricolporate	40-45	NA	NA
Asteraceae	*Ratibida columnifera*	Prairie Coneflower	Tricolporate	19.4-22.5	NA	1.5-2.2
Asteraceae	*Rudbeckia hirta*	Black-eyed Susan	Tricolporate	25.6-30.8	NA	2.3-3.7
Asteraceae	*Solidago canadensis*	Canada Goldenrod	Tricolporate	19.5-23.7	NA	2.4-3.8
Asteraceae	*Solidago missouriensis*	Missouri Goldenrod	Tricolporate	18.2-21	NA	< 3
Asteraceae	*Solidago rigida*	Rigid Goldenrod	Tricolporate	21.5-25.3	NA	2.1-3.3
Asteraceae	*Sonchus arvensis*	Perennial Sow-thistle	Echinolophate- Tricolporate	34.2-38	NA	6.0-9.0
Asteraceae	*Taraxacum officinale*	Dandelion	Echinolophate- Tricolporate	30.4-38	NA	6.9-7.1
Asteraceae	*Tragopogon dubis*	Goatsbeard	Echinolophate- Tricolporate	38-46	NA	7.9-8.3
Boraginaceae	*Lithospermum canescens*	Hoary Puccoon	Tricolpate	14.9-16.7	5.7-7.5	1.3-2.1
Boraginaceae	*Onosmodium molle*	False Gromwell	Tricolpate	NA	NA	NA
Brassicaceae	*Brassica kaber*	Wild Mustard	Tricolpate	36-38	28.8-29.7	2.8-3.4
Brassicaceae	*Raphanus raphanistrum*	Wild Radish	Tricolpate	22.8-23.8	16.9-19	2.3
Campanulaceae	*Campanula rotundifolia*	Harebell	Stephanoporate	28.5-40.6	NA	NA

Caprifoliaceae	*Symphoricarpos occidentalis*	Western Snowberry	Tricolporate	49-57.5	NA	3-3.5
Caryophllaceae	*Cerastium arvense*	Field Chickweed	Periporate	30.6-36.8	NA	NA
Caryophllaceae	*Silene cserei*	Smooth Campion	Periporate	44-46	NA	NA
Convolvulaceae	*Calystegia sepium*	Hedge Bindweed	Periporate	75-92	NA	NA
Convolvulaceae	*Convolvulus arvensis*	Field Bindweed	Periporate	58.9-69.7	NA	NA
Elaeagnaceae	*Elaeagnus angustifolia*	Russian Olive	Tricolporate	42.8-46.1	NA	1.2-1.5
Elaeagnaceae	*Elaeagnus commutata*	American Silverberry	Tricolporate	32.3-41.8	NA	1.3-2.1
Elaeagnaceae	*Shepherdia argentea*	Silver Buffaloberry	Tricolporate	34.3-38.2	NA	1.2-1.8
Euphorbiaceae	*Euphorbia esula*	Leafy Spurge	Tricolporate	24.7-30.4	28.5-36.1	< 3.5
Fabaceae	*Amorpha canescens*	Leadplant	Tricolporate	16.5-20.3	NA	1-2.8
Fabaceae	*Astragalus bisulcatus*	Two-grooved Milkvetch	Tricolporate	18-23.7	21-24	1.5-2.2
Fabaceae	*Dalea purpurea*	Purple Prairie Clover	Tricolporate	41-47.5	23-26.7	1.5-2.8
Fabaceae	*Glycyrrhiza lepidota*	Wild Licorice	Tricolporate	26.4-32.8	NA	1.2-1.3
Fabaceae	*Medicago sativa*	Alfalfa	Tricolporate	30.4-37.1	24.7-28.5	1.6-2.5
Fabaceae	*Melilotus alba*	White Sweet-clover	Tricolporate	20.9-22.8	15.2-17.1	1.1-2.8
Fabaceae	*Melilotus officinalis*	Yellow Sweet-clover	Tricolporate	24.7-26.6	14-21.5	2.2-2.9
Fabaceae	*Petalostemon candidum*	White Prairie Clover	Tricolporate	29.4-34.1	16-24.7	1.1-1.4
Fabaceae	*Psoralea agrophylla*	Silverleaf Scurfpea	Tricolporate	23.8-28.1	21.7-24.1	0.9-1.3
Fabaceae	*Psoralea esulenta*	Breadroot Scurfpea	Tricolporate	NA	NA	NA
Fabaceae	*Trifolium repens*	White Clover	Tricolporate	25.7-32.6	24.7-26.7	1-2.2
Fabaceae	*Vicia americana*	American Vetch	Tricolporate	30.4-38	20-23.9	2.6-3.7
Gentianaceae	*Gentiana andrewsii*	Bottled Gentian	Tricolporate	32.5-37.3	25.8-30.2	1.9-3.2
Iridaceae	*Sisyrinchium montanum*	Mountain Blue-eyed Grass	Monocolpate	NA	NA	NA

Lamiaceae	*Agastache foeniculum*	Giant-Hyssop	Hexacolpate	32-36	NA	NA
Lamiaceae	*Monarda fistulosa*	Western Wild Bergamot	Hexacolpate	43-47	48.8-54	1.4-2.4
Lamiaceae	*Stachys palustris*	Marsh Hedge-Nettle	Hexacolpate	29.6-34.6	16.7-25.3	1.3-2.1
Liliaceae	*Allium stellatum*	Pink Wild Onion	Monocolpate	30.8-35.9	19.7-21.9	0.9-1.3
Liliaceae	*Hypoxis hirusta*	Common Goldstar	Monocolpate	NA	NA	NA
Liliaceae	*Lilium philadelphium*	Prairie Lily	Monocolpate	86.9-94.3	42.5-50	NA
Liliaceae	*Zigadenus elegans*	Showy Deathcamas	Monocolpate	36.4-45.6	26.1-32.4	NA
Linaceae	*Linum perenne*	Blue Flax	Tricolporate	49.3-50.1	24.5-25	2-2.6
Onagraceae	*Chamerion angustifolium*	Fireweed	Triporate	84.6-91.3	NA	1.9-3.3
Onagraceae	*Gaura coccinea*	Scarlet Gaura	Triporate	120.5-131.8	77.8-98.2	1.7-3
Onagraceae	*Oenothera biennis*	Gray Common Evening Primrose	Triporate	108.1-122.8	NA	NA
Onagraceae	*Oenothera nuttalli*	White-stem Evening Primrose	Triporate	105.5-113.3	77.3-80.1	1.2-1.8
Onagraceae	*Oenothera serrulata*	Shrubby Evening Primrose	Triporate	85.3-87.9	54.5-55.4	1.9-3.7
Poaceae	*Zea mays*	Corn	Monoporate	66.5-77.9	66.5-77.9	2
Polygonaceae	*Polygonum amphibium*	Swamp Smartweed	Tricolporate	57-62	NA	NA
Primulaceae	*Lysimachia ciliata*	Fringed Loosestrife	Tricolporate	23.1-26.8	19.2-22.9	1-1.6
Ranunculaceae	*Anemone canadensis*	Canada Anemone	Pericolpate	18.5-22.6	NA	1.3-2.4
Ranunculaceae	*Anemone multifida*	Cut-leaved Anemone	Pericolpate	21.2-25.3	NA	0.9-1.8
Rosaceae	*Geum aleppicum*	Yellow Avens	Tricolpate	36-38.5	33.8-38.5	< 3
Rosaceae	*Geum trifolrum*	Prairie Smoke	Tricolpate	33.8-39.7	22.9-27.4	2.3-3.1
Rosaceae	*Potentilla arguta*	White Cinquefoil	Tricolpate	18-24.9	15.4-17.2	0.9-1.8

Rosaceae	*Rosa acicularis*	Prickly Rose	Tricolpate	NA	NA	NA
Rosaceae	*Rosa arkansana*	Prairie Rose	Tricolpate	33.7-41.4	31.4-35.7	< 2
Rosaceae	*Spiraea alba*	Narrow-leaved Meadowsweet	Tricolpate	18.8-25	17.5-18.5	< 4
Rubiaceae	*Galium boreale*	Northern Bedstraw	Hexacolpate	18-19.2	19-20	NA
Saxifragaceae	*Heuchera richardsonii*	Prairie Alumroot	Periporate	14.5-18.4	11.4-15	< 2
Tiliaceae	*Tilia americana*	American Basswood	Tricolporate with vestibulate pores	24.7-29.5	34.2-40	2.3-2.6
Verbenaceae	*Verbena hastata*	Blue Vervain	Tricolporate	22.8-28.5	22.8-26.6	1.9-2.3
Violaceae	*Viola nuttalli*	Nuttall's Violet	Tricolpate	22.4-25.5	18.3-22.4	< 1.5

Appendix E. Look-up table for native bee codes on bipartite graphs.

Code	Taxa	Code	Taxa
AGAVIR	*Agapostemon virescens*	HERVAR	*Heriades variolosa*
Andren	*Andrena sp.*	Hetero	*Heterosaurus sp.*
ANTWAL	*Anthophora walshii*	HYLAFF	*Hylaeus affinis*
AUGPU	*Augochlora pura*	HYLANN	*Hylaeus annulatus*
BOMBIM	*Bombus bimaculatus*	HYLLEP	*Hylaeus leptocephalus*
BOMBOR	*Bombus borealis*	HYLMES	*Hylaeus mesillae*
BOMGRI	*Bombus griseocollis*	LASdia	*Lasioglossum (Dialictus)*
BOMRUF	*Bombus rufocinctus*	LASstr	*Lasioglossum* (s.str.)
BOMTER	*Bombus ternarius*	Megach	*Megachile sp.*
BOMVAG	*Bombus vagans*	MEGINE	*Megachile inermis*
CERDCA	*Ceratina dupla/calcarata*	MEGLAT	*Megachile latimanus*
CERDUP	*Ceratina dupla*	MEGPAR	*Megachile parallela*
DUFMAR	*Dufourea marginata*	Meliss	*Mellisodes sp.*
DUFMAU	*Dufourea maura*	PSELAB	*Pseudopanurgus labrosiformis*
HALCON	*Halictus confusus*	Spheco	*Sphecodes sp.*
HALTRI	*Halictus tripartitus*		