

**Diversity and Abundance of Bees in Canadian Prairie Agroecosystems: Understanding the
Role of Remnant and Restored Habitat in Supporting Native Bee Populations**

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Abstract

Habitat loss due to agricultural intensification has negative implications for native bee communities throughout Western Canada. Wetland remnants are a common feature within the Prairie Pothole Region of Saskatchewan and are threatened due to continued conversion to agricultural land. Approximately sixty-one million acres of land are dedicated to agriculture in Saskatchewan. Wetlands and field margins in this region are embedded in these agricultural matrices and may act as important nesting and floral resources for many native bee taxa.

The purpose of this study was to determine whether conserved habitats, such as wetlands and field margins, in highly cultivated landscapes support native bee and pollinator diversity, which is expected to be ecologically and economically beneficial. I also examined differences in bee abundance and diversity across three crop types to explore the roles different crop types might play as a habitat or feeding resource for native bees. Bees were sampled from wetland and field margins into the surrounding cropland across two growing seasons in three crop types (canola, cereals and semi-natural re-seeded forage) to quantify the role that wetlands, field margins and crop types play in supporting native bee populations.

I found that the diversity and abundance of native bees collected from natural and semi-natural edge habitat was higher than that collected in-field. Areas with a higher availability of nesting resources tended to support a higher diversity of bee genera. Unmanaged semi-natural re-seeded forage sites supported a higher abundance and diversity of bees than canola and cereal crops. Finally, we found that bee community structure differed significantly between years, likely due to differences in temperature and precipitation.

Results of this study suggest that native bees may be using edge habitat for nesting and floral resources. Bees nesting in these areas may in turn provide pollination to agricultural crops through a “spill-over” effect. This project has improved our understanding of native bee communities and the value of management practices that promote sustainable agricultural production through pollination services. These results further support the need for management of agricultural cropland that preserves semi-natural habitat that is integral to native bee functional diversity.

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List of Abbreviations

ANOVA	Analysis of Variance
df	Degrees of Freedom
LMM	Linear mixed models
PCoA	Principal Component Analysis
PERMANOVA	Multivariate analysis of Variance

1. Introduction

1.1 Introduction

Wetlands in Saskatchewan are threatened due to environmental changes, both natural and anthropogenic (Bartzen et al. 2015). The prairie landscape is dominated by oilseed crops, such as canola, and cereal crops, such as wheat and barley. Wetland disappearance from the Saskatchewan prairie landscape is primarily due to agricultural intensification perpetuated by the production of these crops. Management of agricultural land includes practices such as draining and ploughing, which are detrimental to the health and persistence of wetlands. Very little is known about the abundance and diversity of native bees in wetland habitats situated within agroecosystems, although they may provide integral floral resources and nesting sites for many native bee genera.

Native bees provide pollination services for both the agricultural and native plant species in the Saskatchewan prairie. The pollination services they provide are important for biological diversity, economic stability of agricultural land, and also maintaining diversity of flowering plants in natural systems (Stanley and Stout 2014; Winsa et al., 2017). Pollination services provided by native bees increase the yield potential of certain flowering crops and ensure pollination for wild flowering plants (Garibaldi et al. 2014; Klein et al. 2007; Marcello et al. 2009). These services may not be sustained by commercial honeybees (*Apis mellifera*) (Broussard et al. 2011; Garibaldi et al. 2011; Holzschuh et al. 2012; Morandin and Winston 2006). Agricultural intensification and habitat loss have led to a widespread loss of insect biodiversity including, a loss of pollinator diversity.

Due to a continued risk of further habitat loss, there is a need to develop a better understanding of how size, quality and distribution of semi-natural habitat features within a landscape affects bee diversity. The conservation of wetlands within restored grassland sites, as well as the preservation of wetlands within agricultural landscapes, may play a pivotal role in re-establishing populations of native bees that are declining due to anthropogenic disturbances. This information is valuable from both a conservation and economic perspective. A comprehensive database of native bee abundance and diversity, especially in the Prairie Pothole region, is limited. No extensive survey has ever been conducted in this region of Saskatchewan. Many species may be in decline throughout this landscape, and a survey of this magnitude may serve as a benchmark to track detrimental changes in native bee population metrics in the future. This project focused on native bee communities in edge habitat surrounding wetlands (remnant habitat) within re-seeded semi-natural forage grasslands and cropland, as well as buffer strips adjacent to cropland. This

research was intended to determine the structure of native bee communities and populations within Saskatchewan agroecosystems to inform management strategies that benefit native pollinators.

1.2 Objectives and Hypothesis

The first objective of this study was to quantify the diversity of native bee genera present in cropland-dominated agroecosystems and semi-natural forage. The second was to determine if there are differences in bee communities among crop types, and with different habitat matrices. Finally, the third was to determine if bee communities in field margins differ from communities within the field. I hypothesized that:

- 1) Native bee communities would differ among crop types.
- 2) Bee abundance and richness would differ between transects originating from the wetland and field edge margins
- 3) Bee abundance and richness would be higher near margins than the interior of the field

1.3 Thesis organization

This thesis is organized in a traditional format. In Chapter 1, I provide a general introduction to the whole work. In chapter 2, I provide an overview of the importance of wetland and edge habitat on bee diversity. Chapter 3 is the sole data chapter and in it I present data on native bee diversity and abundance collected from agroecosystems in Saskatchewan. In chapter 4, I discuss major findings from three concluding the thesis as a whole and indicating future work pathways. The literature cited in this thesis is located in Chapter VI. Supplemental material is presented in Chapter 5.

2. Literature Review

2.1 The Prairie Pothole Region and Native Bee Diversity

The Prairie Pothole Region of Saskatchewan is characterized by shallow depressions that formed as a result of scouring action during the Pleistocene glaciation (Batzner et al. 1999). These depressions now form a variety of wetlands. Wetland remnants are a common feature found in cropland matrices throughout the cultivated landscape of Saskatchewan (Vickruck et al. 2019). Wetlands are highly ecologically significant, and the Prairie Pothole Region is one of the richest and most diverse wetland-grassland ecosystems in the world (Doherty et al. 2016). Less than 9% of the earth's land area is covered by wetlands, but they support significantly high numbers of species (Bartzen et al. 2015; Verhoeven et al. 2010). As agricultural land expands, wetlands are drained, filled, and cultivated, resulting in an estimated 40-70% reduction in the number of wetlands on the landscape (Bedford 2000; Bartzen et al. 2015; Heneberg et al. 2018). Conservation efforts are being taken on a global scale to prevent further degradation and destruction of wetland habitat (Bartzen et al. 2015). Very few studies have examined the importance of landscape composition on the species richness and abundance of insects, specifically bees in intensely farmed and fragmented habitats (Ockinger and Smith 2007). No comprehensive inventory or monitoring programs have been established for wetlands, therefore impact trends in Canada are still unclear (Dahl and Watmough 2007).

Wetlands found in this region possess unique environmental and biotic characteristics. Ecosystem services provided by wetlands include water quality improvement, flood control, nutrient cycling and carbon sequestration (National Research Council 1996). These unique characteristics enhance regional diversity and production of aquatic invertebrates (Batzner et al. 1999), and may also influence pollinator community structures in the surrounding landscape. The Prairie Pothole Region is situated in a geographic region that experiences harsh environmental conditions. Winter temperatures freeze the wetlands and sediments, and summer temperatures are hot, fostering drought conditions and high salinity gradients (Batzner et al. 1999). Due to these environmental conditions, invertebrates that are known to inhabit these wetlands tend to be generalists with adaptations necessary for surviving in extreme environments (Batzner et al. 1999). Wetlands are geographically sparse and are only found in certain regions of the world, therefore it is reasonable to assume that wetlands may foster native bee species that are rare and possibly of

concern with regards to conservation efforts. The preservation of viable populations of pollinators in farmland may depend on the preservation of more or less permanent semi-natural habitats in agricultural landscapes that are otherwise subject to repeated disturbances (Tschardt et al. 2005).

Agricultural conversion has led to a decline in native grassland habitat, which includes wetland habitat in Saskatchewan. Declines in native grassland decrease the natural resources that are critical to beneficial insects such as native bees (Mogren et al. 2016) and studies have indicated that agricultural landscapes possessing large areas of semi-natural habitat have higher species richness and abundance (Kennedy et al. 2013). There is a growing body of research that is concerned with wild pollinators, their life history traits, and also their ecology in wetland habitats, but there are still gaps in the knowledge about their community composition. A comprehensive survey of native bee species in the Prairie Pothole Region of Saskatchewan has never been conducted, but is necessary to adequately assess their ecological requirements. Studies have suggested that habitat heterogeneity in the form of semi-natural grasslands is a key for maintaining farmland biodiversity (Ockinger and Smith 2007). Wetlands also increase habitat heterogeneity and are therefore also fundamental in promoting and preserving biodiversity.

2.2 Wetlands as Habitat for Native Bees

The drainage and degradation of wetlands presents a primary conservation concern for many species, including insects, such as bees (Vickruck et al. 2019). Wetlands are increasingly threatened due to water diversion for irrigation and conversion for development. These changes to wetland habitat result in habitat loss and fragmentation for bees and other pollinators that use them (Moron et al. 2008; Winfree et al. 2009). A global pollinator crisis is already at hand, there is a need to improve pollinator habitat (Hopwood 2008), this includes wetland habitat. The negative effects of habitat loss include direct measures of biodiversity such as species richness, population abundance and distribution, as well as genetic diversity (Fahrig et al. 2003).

Bees that are associated with wetland habitat are generally poorly understood, and few studies have examined the community diversity associated with these wetlands in arable fields (Heneberg et al. 2018). Some studies have looked at bee assemblages in wet meadow and newly formed wetlands in Northern Europe, but the only comprehensive study conducted in wetlands in Canada was conducted by Vickruck et al. (2019). Wetland margins positioned within cropland matrices may become a primary source of habitat for many aquatic and terrestrial invertebrates and

may contribute to integral pollinator habitat (Evans et al. 2018; Vickruck et al. 2019). Prairie wetlands are typically surrounded by agriculture which has been shown to have negative effects on pollinator abundance (Vickruck et al. 2019). In the intensively cultivated landscape of the Saskatchewan prairie, wetlands have the potential to act as in-field habitats and reservoirs for native bees (Vickruck et al. 2019). Undisturbed wetland margins within crop fields can act as a source of nesting and floral resources for native bees within the landscape (Vickruck et al. 2019). Wetlands of classes III (seasonal ponds and lakes), IV (semi-permanent ponds and lakes) and V (permanent ponds and lakes) provide sedges, rushes, cattails, and various other flowering plants within the low-prairie zone (Stuart and Kantrud 1971). Many flowering plants and forms of vegetation located within this zone are not found in any other habitat type throughout the landscape, therefore, they may provide key floral and nesting resources for various genera of native bees.

A survey was conducted by Vickruck et al. (2019) of native bee abundance and diversity in a series of wetlands in Alberta. These wetlands were situated in restored perennial grasslands, canola and cereal fields. Differences in bee community composition were found to be significant across site types. Communities associated with wetlands in cereal and canola fields were different from those found in perennial grasslands. This is likely due to the fact that disturbances, such as those associated with agricultural practices, are known to negatively affect the community composition of native bees (Harmon-Threatt and Hendrix 2015). Bee trapping rates decreased further away from the wetland in canola and cereal fields, but they did not differ based on distance from wetland within the perennial grassland sites. There was a decrease in the number of species trapped moving further away from the wetland in cereal and canola fields, but an increase in grassland sites.

Vickruck et al. (2019) also found that bees sampled from wetland habitats represented a variety of different nesting guilds. Many of the bees sampled were of the ground nesting variety, specifically belonging to the families Halictidae and Andrenidae. Vickruck suggests that bees are using wetlands as a nesting resource, therefore wetlands located within field crops have the potential to be a source of pollination ecosystem services. Community composition did not change further away from the wetlands, and this was likely due to the foraging range of most bee species being within the sampling distance. The average foraging distance between nesting site and food patch for most bees is between 150-600m (Gathmann and Tscharrntke 2002). Solitary and social bees provision their broods by central place foraging from their nest (Cresswell et al. 2000). Female

bees are central foragers, and once nests are established, females make multiple trips to provision resources for their offspring, constantly returning to the same place (Cresswell et al. 2000). In fragmented landscapes, the home range of bees may cover a habitat matrix consisting of several patches, and each patch may only provide a single resource or function (Heneberg et al. 2018). Fragmentation has been shown to negatively impact solitary bees due to their small foraging range. Bees with a small foraging range, such as solitary bees, require a more diverse set of resources per unit area than those with similar needs, but greater foraging distance, such as bumblebees (Cresswell et al. 2000; Ockinger et al. 2018; Osborne et al. 2008). Local habitat structure appears to be of more importance than large-scale landscape structure (Gathmann and Tscharntke 2002). It is necessary to maintain and restore a dense network of habitat patches in landscapes to ensure long-term sustainability of wild bee diversity and their ecological function as pollinators (Gathmann and Tscharntke 2002; Kennedy et al. 2013; Ricketts et al. 2008).

The beneficial impacts of wetland conservation secure pollination services to both farmers and the surrounding landscape (Vickruck et al. 2019). Maintaining wetland habitats within agricultural landscapes provides important resources for native pollinators that would not otherwise be available. Results from this study show that small in-field wetland remnants play an important role in supporting native pollinator communities in agricultural landscapes. Small semi-natural wetlands appear to support a high diversity of native bees and should be seen as important nesting and foraging resources.

Moron et al. (2008) conducted a study of wet meadows surrounding Krakow, Poland. The researchers found that wet meadows maintained a high gamma diversity of wild bees and that species composition between wet meadows was not variable (indicated by low beta-diversity). They also found that bee species richness was highest in less intensively managed grasslands. A study conducted by Henneberg et al. (2018) also found that the wetlands that have formed *de novo* in the Czech Republic within arable fields hosted a highly diverse assemblage of bee species that were specialized for wetlands, wet meadows, and habitats with open sand or loess. Threatened species were also found to be characteristic of wetlands, which is concerning because wetlands themselves are disappearing. Studies have found that species showing declining trends in global abundance are more likely to occur in areas with high habitat loss than species with increasing or stable trends (Burkle et al. 2013; Fahrig et al. 2003). Without considerable restoration and conservation efforts, these species may become extirpated.

2.3 Pollination Services in Agroecosystems

Many crop plants and native flowering plants require pollination from animals for successful yield and seed set (Stanley and Stout 2014). Pollination services provided by animals ensure genetic diversity, which in turn secures healthy plant populations (O'Brien and Arathi 2018; Cranmer et al. 2012). Bees are known to be among the most effective pollinators of flowering plants within agroecosystems (DePalma et al. 2016; Halinski et al. 2018). Cross-pollination provided by bees accounts for more than 33% of pollination services in food crops (Klein et al. 2007). Studies have shown that the presence of bees in canola crops can increase grain yield by up to 47% (Bommarco et al. 2012; Morandin and Winston 2006; Woodcock et al. 2019).

There is a growing body of research that demonstrates that native bees are equally as efficient as honeybees at performing pollination services in commercial agriculture (Garibaldi et al. 2014). Bees have been proven to contribute to the economic stability of crops, yet they are often forgotten when agricultural landscape planning takes place (Losey and Vaughan 2006; Winfree 2010). The community composition of native bees within a landscape must be surveyed and assessed in order to implement management strategies that not only increase crop pollination, but also support habitat conservation (Halinski et al. 2015).

Different species exhibit different functional traits, and greater pollinator richness can lead to reciprocal foraging that improves the quality and quantity of pollination (Garibaldi et al. 2014). Managing for wild pollinator communities and services in agricultural landscapes could help to increase the reliability of pollination services, but a full analysis of the costs and benefits is needed (Begosh et al. 2020; Kremen et al. 2007; Morandin and Winston 2006). Practices that promote species richness are expected to improve the aggregate abundance of pollinators (Garibaldi et al. 2014). Research demonstrates that farmland in proximity to natural habitat can receive all of its pollination from wild bees alone (Wratten et al. 2012). Pollinators use a combination of resources, therefore, increasing farmland heterogeneity will in turn increase pollinator richness (Andersson et al. 2014; Garibaldi et al. 2014; Mogren et al. 2016). A study done by Morandin and Winston (2006) found that bee abundance in canola fields was greatest when there was more uncultivated land within 750m of field edges. Seed set was also higher with greater bee abundance. Analysis of land within 750m of field edges in canola fields indicated that seed production and crop yield could be increased by greater amounts of uncultivated habitat.

2.4 Effects of Land Use on Native Bee Diversity

Historic environmental factors impact the successional response and patterns in biodiversity of pollinator communities. What was once “natural” habitat has been significantly fragmented and is now primarily large monocultured sections of agricultural land (Odanaka and Rehan 2019). Habitat fragmentation can increase the likelihood of decline and possibly extinction of isolated populations due to a reduction in gene flow and inbreeding (Cranmer et al. 2012; Winfree 2010), consequently increasing further susceptibility to environmental change. Agricultural intensification from local to landscape scales is generally correlated with a decline in abundance, diversity and services provided by wild pollinators (DePalma et al. 2016; Kremen et al. 2007; O’Brien and Arathi 2018). The seeding and harvesting of crops are disturbances to which the successional changes of pollinator communities have not been thoroughly studied.

Land use intensification is considered to be one of the foremost drivers of changes to wild bee structural assemblage (Brown et al. 2016). Changes in land-use and landscape structure influence pollinators and their interactions at individual, population and community levels (Kremen et al. 2007; Mogren et al. 2016). Agricultural farming introduces environmental changes that alter the quality and spatial and temporal distribution of floral resources, in turn influencing pollinator community composition (Begosh et al. 2020; Goulson et al. 2008). Individual pollinators alter their foraging behavior in response to changes in landscape structure, and these responses are taxonomically specific (Kremen et al. 2007). The susceptibility to land-use change and intensification can differ between taxa due to differences in functional response traits (Depalma et al. 2017; Hines et al. 2005). The ecological traits that contribute to the sensitivity of a species to environmental change offer insight into community responses to disturbance (Tucker and Rehan 2017). An example of one such ecological trait is body size which is correlated with foraging flight distance. Therefore, body size would be expected to strongly influence the scale over which bees can access resources and their ability to recolonize disturbed sites (Benjamin et al. 2014; Greenleaf et al. 2007; Williams et al. 2010). Small-bodied species require fewer resources to produce offspring and may be better able to maintain population sizes in disturbed or degraded habitats (Greenleaf et al. 2007).

Any environmental disturbance that affects the nesting habits of bees (tunnelling in bare ground, nesting in pre-existing cavities, excavating dead wood) will have an impact on the

community structure (Odanaka and Rehan 2019). Williams et al. (2010) found that the location of nests significantly affected response to agricultural intensification and tillage regime. An example of such a disturbance would include the process of seeding crops, which involves disturbing the ground in which bees have nested over the winter months. Social species were more strongly affected than were solitary species by tilling and pesticide use within agricultural landscapes (Williams et al. 2010). Williams et al. (2010) also found that the abundances of above-ground nesting species were, on average, six times more reduced by disturbance than those of bees nesting below ground. Bees that nest above ground are generally more negatively affected by agricultural intensification, while bees that nest below-ground are more affected by tilling (Williams et al. 2010).

Pollinator species likely to benefit from a moderate level of disturbance include those that use resources that occur in human dominated matrices, which include agricultural or urban/suburban areas, and ground nesting bees that require patchy vegetation characteristic of early successional stages (Kremen et al. 2007). There are only a small number of studies that have been conducted regarding the legacy effects of land-use change despite the fact that past work indicates that historic land-use can have long lasting effects.

Tucker et. al (2018) studied the annual variations in pollinator populations across agricultural landscapes and found that there is a need for more regionally and taxonomically specific studies on the habitat requirements and environmental factors affecting wild bees across agricultural and unmanaged landscapes. Moderately managed landscapes were found to positively influence the bee community, and habitat heterogeneity and floral diversity generally promoted wild bee diversity (Tucker et al. 2018). This is not always the case though, as not all bee taxa respond the same way to certain types of land management.

2.5 Knowledge Gaps

Bee diversity within the Prairie Pothole Region of Saskatchewan is poorly studied. Minimal research has been conducted, and literature concerning the role of wetlands as habitat for pollinators within the Prairie Pothole Region is limited. A more comprehensive understanding of the native bee community structure surrounding wetland habitat may improve the quality of conservation efforts in relation to native bee diversity and abundance.

Studies focused on bee diversity in wetland habitats consistently observe that wetlands host and promote an ecologically significant level of native bee diversity. Wetlands are a unique and valuable habitat for bees and other pollinators within the highly cultivated landscape of Saskatchewan. Habitat loss, in this case of wetlands, has large, consistently negative effects on biodiversity within the Prairie Pothole Region. Many studies mention the importance of linear habitat and semi-natural habitat patches as a necessity for pollinators as nesting and food sources. Wetland patches within the prairie landscape secure natural resources that are otherwise unavailable. Natural patches in agroecosystems, such as wetland habitat, are also known to enhance pollinator services and crop yield. Wetlands should therefore continue to be studied, conserved and restored to secure pollinator diversity.

Natural patches provide biodiversity refuges and habitat corridors for native bees. It is important to understand how landscape features, such as wetlands, affect the abundance and diversity of pollinators such as native bees. Information regarding the diversity of native bee species in the Prairie Pothole Region is insufficient. Future studies should examine and document this information for conservation efforts with a focus on what is required for the preservation and re-establishment of their community diversity. A comprehensive inventory and monitoring program must be implemented for the Prairie Pothole Region in Canada in order for impact trends to be tracked and studied, and to secure the ecosystem services provided by wetlands.

Several questions regarding native bees in wetland habitats remain unanswered. There are no conclusive answers as to whether there are native bee species that are specific to wetland habitats in the Prairie Pothole region. No study has specifically addressed how the presence or absence of a wetland in a specific landscape affects the diversity and abundance of native bees. Additional information gathered from future research has the potential to secure the ecological resources that wetland habitats provide, as well as secure native bees providing pollination services to agricultural land. Increased knowledge regarding the biodiversity that is found in wetlands within the Prairie Pothole Region will enhance resources for growers and the public and allow for better management and conservation strategies to be established.

3. Diversity and Abundance of Bees in Canadian Prairie Agroecosystems: Understanding the Role of Remnant and Restored Habitat in Supporting Native Bee Populations

3.1 Introduction

Several studies have documented a global decrease in the native bee biodiversity (Gixti et al. 2009; M’Gonigle et al. 2015; Ollerton et al. 2011; Winfree et al. 2009). These decreases are linked to multiple factors, but chief among them is the loss of suitable habitat associated with agricultural practices. This is accentuated by agricultural practices such as tilling, mowing and pesticide application which are also known to negatively affect bee abundance and fitness (Williams et al. 2010; Galpern 2017). It is therefore assumed that semi-natural non-cultivated areas such as margins, hedge rows and windbreaks that are not subject to these practices may provide habitat and increase biodiversity. Pollinator loss in agricultural regions is concerning, as many crops require pollination for yield success (Fahrig et al. 2003; Foley et al. 2005; Marcelo et al. 2009; Woodcock et al. 2019).

Bees are considered the most efficient pollinators of wild plants and managed food crops, ensuring floral reproduction and increasing yield potential (Garibaldi et al. 2014; Klein et al. 2007; Marcello et al. 2009). Approximately one third of the food humans consume is pollinated primarily by bees (Buchman and Nabhan 1996; Klein et al. 2007; Stanley and Stout 2014). Many studies have shown that native bees may even be more efficient than honeybees in pollinating many crops (Broussard et al. 2011; Garibaldi et al. 2011; Holzschuh et al. 2012; Morandin and Winston 2006). Despite on-going conservation efforts, there has been overwhelming evidence of native bee population declines for over a two decades (Cameron et al. 2011; Potts et al. 2010; Weiner et al. 2014). To successfully provide these services, native bees require a diversity of floral resources and an adequate amount of bare ground for nesting (Steffan-Dewenter and Tscharntke 1999; Gathmann and Tscharntke 2002; Knight et al. 2009). Many of the native bee genera present in Saskatchewan are small, ground-nesting, central-place foragers that require essential resources within a 600m radius of their nest (Cresswell et al. 2000; Sheffield et al. 2014). Therefore, they require undisturbed natural or semi-natural habitat in close proximity to their nests (Kohler et al. 2008; Kwaiser and Hendrix 2008; Tucker et al. 2018; Wright et al. 2015).

Native bee community structures are often studied in orchards and horticultural crops, yet fewer studies have examined their structure in specific field crops such as cereals and canola. Further, no study to date has directly examined bee communities within crops of the Prairie Pothole region in Saskatchewan. Although bees are known to be pollinators of canola plants, studies generally focus on the yield success of canola when bees are present and not the bee community structure (Bommarco et al. 2012; O'Brien and Arathi 2018). Canola crops may also provide a valuable additional food source to native bees during their flowering period in areas where habitat fragmentation has increased foraging distances (Heneberg et al. 2018; Ricketts et al. 2008). Similarly, little is known about the effects of cereal crops on native bee communities as cereals are not insect pollinated and do not provide foraging resources for pollinators. Much of the research regarding pollinators in cereal crops investigates the effects of pesticides and other management practices on the health of bees, but less so on fields of these crops as a habitat resource (Happe et al. 2018; Holzschuh et al. 2007). Cereal crops may not provide a food source for native bees; however, the edge habitat surrounding cereal fields may provide important nesting resources thereby providing pollination services to neighbouring flowering crops.

In the Prairie Pothole Region of Saskatchewan, the mass production of crops such as canola, wheat and barley are commonplace. The Prairie Pothole Region receives its name due to the presence of post-glacial depressions that form numerous wetlands in this area (Batzner et al. 1999). These wetlands are likely to provide invaluable habitat to insect pollinators, promoting biodiversity (Begosh et al. 2020; Vickruck et al. 2019). However, it is estimated that 40-70% of the wetlands in this area have been drained, filled, or cultivated as a result of agricultural land expansion (Bedford 2000; Bartzen et al. 2015; Heneberg et al. 2018; Verhoeven et al. 2010).

Previous studies have shown that conservation of wetland habitat has the potential to secure pollination services not only for native flowering plants, but also agricultural crops surrounding it (Vickruck et al. 2019). Natural edge habitat matrices embedded in agricultural landscapes, such as those surrounding field edges and wetlands, are known to provide refuge for many pollinating insects, specifically native bees (Kennedy et al. 2013; Purvis et al. 2019; Ricketts et al. 2008; Rollin et al. 2013; Tscharntke et al. 2005). These patches provide increased resources and integral corridors for connectivity to other suitable habitat patches (Cresswell et al. 2000; Gathmann and Tscharntke 2002; Olynyk 2021). Hedgerows, ditches and floral strips adjacent to forests and fields have been shown to contribute to higher diversity and community richness of many native bee

genera via the edge effect (Bennett et al. 2014; Griffin and Haddad 2021). Additionally, large patches of native and semi-natural re-seeded grassland habitat in intensive agricultural landscapes have also been found to positively impact the abundance and diversity of bees (Ockinger and Smith 2007; Williams et al 2015).

The focus of this study was to: (1) quantify the diversity of native bee genera present in agroecosystems and semi-natural re-seeded forage, (2) determine if there are differences in bee communities among site types, with different habitat matrices, (3) examine whether bee communities in margins differ from communities within the field, and (4) determine if wetlands change the structure of bee communities. I hypothesized that native bee communities would differ among site and crop types based on availability of nesting and floral resources and that community composition within crops differs from that within margins. Based on these hypotheses I predicted that richness and abundance of bee genera would be highest in untouched field and wetland margins as well as in semi-natural forage sites with no disturbance.

3.2 Materials and Methods

3.2.1 Study Sites

This survey took place in the summers of 2018 and 2019. Across the two field seasons bees were sampled from fifteen field sites between Peterson and Humboldt, in the Prairie Pothole Region of Saskatchewan (Table 1.1). Each sample site was one quarter section of land, five of which were re-seeded semi-natural forage grassland, five were seeded with insect-pollinated crops and five contained wind-pollinated crops. Sites were chosen using the Ducks Unlimited Canada conservation program database based on a series of criteria (Figure 1.1). Criteria considered in site selection included: the estimated proportion of wetland habitat within 1km buffer of a point at the center of each quarter section, that the location was adjacent to the road, the intended crop for that field at time of selection, and finally farmer participation. Crops were classified by their pollination mechanism and crop rotation took place between the 2018 and 2019 field seasons, therefore site classification changed between years. Sites where canola was planted were classified as insect pollinated, wheat and barley were classified as wind pollinated and forage sites were classified as mixed pollination.

Table 1.1. Summary of crop type in each study site in 2018 and 2019. Site numbers correspond to the location of the study fields shown in Figure 1.1.

Site	Crop Type	
	2018	2019
1	Forage	Forage
2	Forage	Forage
3	Forage	Forage
4	Forage	Forage
5	Forage	Forage
6	Cereal	Canola
7	Cereal	Canola
8	Cereal	Canola
9	Cereal	Canola
10	Cereal	Canola
11	Canola	Corn
12	Canola	Cereal
13	Canola	Cereal
14	Canola	Cereal
15	Canola	Cereal

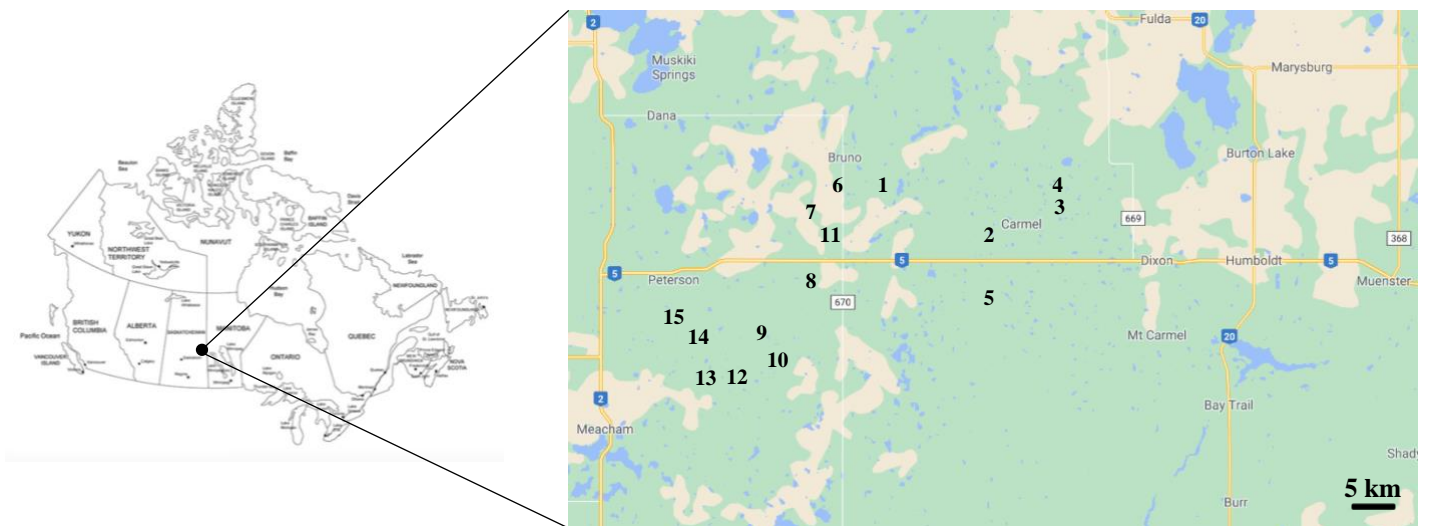


Figure 1.1. Map of the study location within Canada. Inset indicates location and numerical designation of study sites. All 15 sites are located between Peterson and Humboldt, Saskatchewan, Canada. This map corresponds to information located in Table 1.1.

3.2.2 Field Sampling

To measure the diversity and abundance of native bees, field surveys were conducted with the use of passive sampling methods to collect bees present in re-seeded semi-natural forage grassland and agricultural settings containing a wetland habitat in the summers of 2018 and 2019. Passive sampling methods included standard blue, yellow and white pan traps painted with UV paint (New Horizons, Upper Marlboro, MD) (Droege et al. 2017) and blue/yellow vane traps (Springstar Inc., St. Louis, MO, USA) (Appendix 1). Pan traps were sampled using adapted versions of the standardized method of monitoring bee populations by LeBuhn et al. (2015), the National Protocol Framework for Inventory and Monitoring of Native Bees (Droege et al. 2017), and sampling protocols from the Canadian Pollination Initiative by Corey Sheffield (2009). As there are biases in the genera caught by each trap type, both trapping methods were used to ensure adequate sampling of genera present in the area (Mogren et al. 2016). Blue/yellow vane traps are known to be attractive to large and common bees such as *Bombus* spp. and are also known to capture a high volume (Hall 2018). Blue, yellow and white pan traps, on the other hand, are known to capture smaller and more rare species of bee (Joshi et al. 2015). Abundance was quantified as the sum of individuals collected in the three pans (one of each colour) and vane traps at each position of the transect.

Within each site, traps were spaced at 0m, 75m and 150m along two linear transects starting at the field or wetland margin extending into the field. During the 2018 field season, traps were also set at a 25m position, but were omitted in the 2019 season to minimize unnecessary destructive sampling. Transects extended into the field such that the 150m traps were positioned within the crop (see Appendix 2 for site diagram). Wetlands chosen for this research were of Class III and Class IV as defined by Stuart and Kantrud (1971). Wetland margins were defined as the vegetation located within the low-prairie zone of a seasonal (Class III) or semi-permanent (Class IV) wetland. Wetland margins were undisturbed by agricultural management over the course of this research. Field margins were defined as a strip of natural or semi-natural vegetation located adjacent to a field, between a field and a road or along a fence line. Pan and vane traps were placed on two separate poles spaced 1m adjacent to one another. Pan traps were secured to poles by custom 3D printed holders that allowed height adjustment with respect to the crop canopy (Appendix 3). Pan traps remained in the field for twenty-four hours, while vane traps remained in the field for a seven-day period prior to collection. Collection took place over five sample periods throughout the

growing season: pre-seed, post-seed, flowering, post-flowering and post-harvest. Bees from the pre-seed (May) and flowering period (July) from both seasons were used in the analysis for this project. Timing of sample periods was dependent upon the growth of vegetation (percentage of crop flowering) and weather restrictions. The pre-seed period was defined as the period prior to a grower seeding the site and the flowering period was defined as the time in which >50% of flowers were present in sites with flowering crops. Only zero metre traps were sampled in canola and cereal crops in the pre-seed period of both years, as seeding had not yet taken place and traps could not be set along the rest of the transect until this was complete. Therefore, only bees captured in 0m traps across all crop types were used for pre-seed analysis. Differences in the community composition between bees found in edge habitat to those found in the field were the primary interest for the flowering period, therefore, only bees captured in 0m and 150m traps were used for this analysis (bees captured in 75m traps were omitted).

3.2.3 Native Bee Identification

Bees collected from pan and vane traps were washed and pinned using methods adapted from Sam Droege (Droege et al. 2010) and the CANPOLIN Survey of Pollinator Diversity in Canada by Corey Sheffield (2009). Bees were then rinsed and stored in 70% ethanol until they were ready to be processed and identified.

Bees were identified to genus as very few species keys have been formed for western Canada, particularly for bees found in this study region. Additionally, most of the commonly used taxonomic keys for bees are to genus, and bee identification to genus is common for this type of study (Happe et al. 2018; Potts et al. 2005, O'Brien and Arathi 2018; Martins et al. 2018). Identification of bees to genus was performed using several taxonomic keys and identification tools including: The Bee Genera of Eastern Canada (Packer et al. 2007), The Bees of the World (Michener 2000), Bumble Bees of North American (Williams et al. 2014), The Bees in Your Backyard (Wilson and Carril 2016), The Bees of the Eastern United States (Mitchell 1960 and 1962), The Solitary Bees (Danforth, Minckley and Neff 2019), and Discoverlife (Ascher and Pickering 2015). All specimens are stored in either the Prager Lab at the University of Saskatchewan or the Rehan lab at York University.

3.2.4 Statistical Analysis

Data analyses and generation of graphs was conducted using R version 4.0.5 (R Core Team, 2021). This dataset is based on count data acquired from survey sampling over two years. Data collected from pan and vane traps were pooled as trap type was not of interest and this eliminated excessive zeros, thereby decreasing unnecessary zero-inflation.

Terms used in statistical analyses are defined as follows: (1) crop type refers to the crop grown in each quarter section of land used in this study site (See table 1.1), (2) year refers to the year (2018 or 2019) in which collection took place, (3) transect refers to the origin of a transect as starting at either a field edge extending into the crop or at a wetland edge extending into the crop, (5) position is defined as either the 0m traps (margin) or the 150m traps (within the field), (6) sample period refers to the time of sample collection (pre-seed or flowering, see 3.3.2 Field Sampling) during a field season. Each sampling period was analyzed separately as only traps positioned at an edge (0m traps) were collected during the pre-seed period due to growers seeding at this time.

Abundance and Diversity Analysis

Bee community composition was reported using abundance, relative abundance and species richness. Linear mixed effects models (LMMs) were used to evaluate differences in bee abundance and richness. LMMs allow for the inclusion of fixed and random effects as predictor variables, thereby modelling non-independence in the data and reducing inference about the fixed effects (Harrison et al. 2018). In LMMs the effects of crop type, transect, year, position, and all interactions on the abundance and richness of bees collected were examined. LMMs were performed with Gaussian error distribution and log(1p) using R package *lme4* (v1.1-26; Bates et al. 2015). Transect, crop type, year and position were entered as fixed effects and were treated as factors rather than continuous variables, year and site were treated as random effects (subject=year, repeated measure=site). Although bee samples were collected at 0m, 75m and 150m along both transects during the flowering period, differences in community composition between habitat matrices (semi-natural habitat edge or in-field) were the primary interest and these were represented by the 0m and 150m locations within the transect. Consequently, the 75m samples were removed from the analysis. Significant factors from LMMs also functioned in

reducing the total number of potential factors in subsequent analyses. Given the complicated structure of these data where many samples contained no bees and it was therefore necessary to reduce this complexity.

Community Analysis

Permutational multivariate analysis of variance (PERMANOVA) (Oksanen et al. 2018) was performed to examine differences in overall community structure. PERMANOVA performs distance-based multivariate analysis of variance and hypotheses are evaluated with permutation tests, rather than by reference to an assumed (normal) distribution (Anderson 2017). This data set is zero-inflated and not normally distributed, therefore PERMANOVA was the best fit for this analysis (Legendre and Gallagher 2001). PERMANOVA was performed in R with the function *Adonis* from package *vegan* using Bray-Curtis distances (Solymos et al. 2018). PERMANOVA used models based on effects that were indicated to significantly affect abundance and richness from the LMMs. Results of the LMMs for the pre-seed period indicated only year as significant factor impacting bee abundance and richness. Therefore, year was only included as a fixed effect in PERMANOVA. Based on significant factors indicated in LMMs for the flowering period, crop type, transect, position and year were used as fixed effects, while year was used as a random effect in PERMANOVA.

Principal Coordinate Analysis (PCoA) was used to visualize differences in community composition between crop types and years. PCoA was performed using Bray-Curtis distance in the R package *phyloseq* (McMurdie and Holmes 2013). PCoA, also known as metric multidimensional analysis, is an unconstrained scaling or ordination method that allows a Euclidean representation of a set of samples whose relationships are measured by any similarity or distance coefficient to be obtained (Ruokolainen & Blanchet 2014). Genera with fewer than ten individuals collected during a sample period in each year were removed from this analysis.

3.3 Results

3.3.1 Overall Diversity, Abundance and Community Trends

A total of 17,442 bees were collected, washed, pinned and identified to genus across the 2018 and 2019 field seasons. Of those bees, 7,906 bees from 23 genera collected from pan and

vane traps for both years were used in this study (Table 1.2, a list of all genera collected in this study can be found in Appendix 6). *Lasioglossum* spp. was the most abundant genus across both years and sample periods (n=4240) followed by *Bombus* spp. (n=2347; Table 1.3 and 1.4), together comprising 83% of the total number of bees collected.

Table 1.2. Abundance and richness of bees collected from pan and vane traps in canola, cereal and forage fields located between Peterson and Humboldt, Saskatchewan during the growing seasons of 2018 and 2019.

	Abundance (n)	Mean	Standard Deviation	Richness of Bee Genera (S)
Canola - 2018	1991	199.1	196.93	18
Canola - 2019	650	65.0	51.30	13
Total	2641			
Cereal - 2018	2214	221.4	163.43	23
Cereal - 2019	409	40.9	29.54	14
Total	2623			
Forage - 2018	1931	193.1	228.05	18
Forage - 2019	711	71.1	58.33	14
Total	2642			

Table 1.3. Count and relative abundance of each bee genus relative to crop type collected from pan and vane traps in 2018. (A) Bees collected during the pre-seed period in May, (B) Bees collected during the flowering period in July.

(A) Pre-Seed						
Genus	Canola	Relative Abundance (%)	Cereal	Relative Abundance	Forage	Relative Abundance (%)
<i>Apis mellifera</i>	0	0.0	4	0.2	22	1.2
<i>Andrena</i>	3	0.2	6	0.4	10	0.6
<i>Anthophora</i>	0	0.0	0	0.0	1	0.1
<i>Bombus</i>	360	20.3	440	26.6	553	31.1
<i>Colletes</i>	1	0.1	1	0.1	0	0.0
<i>Eucera</i>	8	0.5	10	0.6	3	0.2
<i>Halictus</i>	69	3.9	107	6.5	47	2.6
<i>Hoplitis</i>	0	0.0	0	0.0	0	0.0
<i>Lasioglossum</i>	1291	72.9	1046	63.1	1114	62.7
<i>Megachile</i>	0	0.0	0	0.0	0	0.0
<i>Melissodes</i>	0	0.0	0	0.0	1	0.1
<i>Nomada</i>	19	1.1	17	1.0	5	0.3
<i>Osmia</i>	11	0.6	11	0.7	16	0.9
Other	8	0.5	15	0.9	5	0.3
Total	1770		1657		1777	
(B) Flowering						
<i>Apis mellifera</i>	6	2.7	2	0.4	36	23.4
<i>Andrena</i>	4	1.8	91	19.1	1	0.6
<i>Anthophora</i>	3	1.3	7	1.5	1	0.6
<i>Bombus</i>	42	18.8	48	10.1	49	31.8
<i>Colletes</i>	7	3.1	115	24.2	1	0.6
<i>Eucera</i>	1	0.4	4	0.8	2	1.3
<i>Halictus</i>	21	9.4	42	9.0	8	5.2
<i>Hoplitis</i>	21	9.4	4	8.8	11	7.1
<i>Lasioglossum</i>	81	36.3	128	26.9	30	19.5
<i>Megachile</i>	7	3.1	4	0.8	2	1.3
<i>Melissodes</i>	22	9.9	9	1.9	10	6.5
<i>Nomada</i>	1	0.4	6	1.3	0	0.0
<i>Osmia</i>	0	0.0	0	0.0	0	0.0
Other	7	3.1	16	3.4	3	1.9
Total	223		476		154	

Table 1.4. Count and relative abundance of each bee genus relative to crop type collected from pan and vane traps in 2019. (A) Bees collected during the pre-seed period in May, (B) Bees collected during the flowering period in July.

(A) Pre-Seed						
Genus	Canola	Relative Abundance (%)	Cereal	Relative Abundance	Forage	Relative Abundance (%)
<i>Apis mellifera</i>	0	0.0	0	0.0	2	0.4
<i>Andrena</i>	5	1.2	2	0.7	7	1.3
<i>Anthophora</i>	0	0.0	0	0.0	0	0.0
<i>Bombus</i>	171	42.6	201	74.7	343	65.0
<i>Colletes</i>	0	0.0	2	0.7	0	0.0
<i>Eucera</i>	0	0.0	0	0.0	1	0.2
<i>Halictus</i>	19	4.7	12	4.5	8	1.5
<i>Hoplitis</i>	0	0.0	0	0.0	0	0.0
<i>Lasioglossum</i>	197	49.1	48	17.8	157	29.7
<i>Megachile</i>	0	0.0	0	0.0	0	0.0
<i>Melissodes</i>	0	0.0	0	0.0	0	0.0
<i>Nomada</i>	4	1.0	3	1.1	3	0.6
<i>Osmia</i>	3	0.7	0	0.0	5	0.9
Other	2	0.5	1	0.4	2	0.4
Total	401		269		528	
(B) Flowering						
<i>Apis mellifera</i>	1	0.4	0	0.0	28	15.3
<i>Andrena</i>	21	8.4	7	5.0	2	1.1
<i>Anthophora</i>	5	2.0	2	1.4	17	9.3
<i>Bombus</i>	63	25.3	33	23.6	44	24.0
<i>Colletes</i>	45	18.1	52	37.1	11	6.0
<i>Eucera</i>	0	0.0	1	0.7	0	0.0
<i>Halictus</i>	9	3.6	3	2.1	0	0.0
<i>Hoplitis</i>	4	1.6	9	6.4	2	1.1
<i>Lasioglossum</i>	86	34.5	12	8.6	50	27.3
<i>Megachile</i>	3	1.2	2	1.4	13	7.1
<i>Melissodes</i>	2	0.8	0	0.0	0	0.0
<i>Nomada</i>	8	3.2	15	10.7	2	1.1
<i>Osmia</i>	1	0.4	0	0.0	1	0.5
Other	1	0.4	4	2.9	13	7.1
Total	249		140		183	

During the pre-seed period, bee abundance and richness were found to only be significantly impacted by the collection year (Table 1.5a and Table 1.6a). Bee abundance during the flowering period was influenced by crop type, position, year and the four-way interaction between crop type, transect, position and year (Table 1.5b). Bee richness was also found to be influenced by crop type, position and year, but unlike abundance, a four-way interaction was not found to be significant (Table 1.6b).

Table 1.5. ANOVA table for mixed models of abundance during each collection period: (A) Pre-seed period in May and (B) Flowering period in July.

Collection Period	<i>Chisq</i>	<i>df</i>	<i>p</i>
(A) Pre-seed			
Year	79.98	1	< 0.001
Crop Type	0.01	2	0.996
Transect	0.06	1	0.811
Year:Crop Type	2.38	2	0.304
Year:Transect	0.02	1	0.878
Crop Type:Transect	1.06	2	0.589
Year:Crop Type:Transect	0.67	2	0.715
(B) Flowering			
Crop Type	11.84	2	0.003
Transect	0.119	1	0.729
Position	8.41	1	0.004
Year	13.41	1	< 0.001
Crop Type:Transect	0.65	2	0.723
Crop Type:Position	2.57	2	0.276
Transect:Position	2.62	1	0.105
Crop Type:Year	2.05	2	0.359
Transect:Year	0.00	1	0.986
Position:Year	0.91	1	0.340
Crop Type:Transect:Position	2.47	2	0.290
Crop Type:Transect:Year	0.38	2	0.828
Crop Type:Position:Year	2.44	2	0.294
Transect:Position:Year	1.98	1	0.159
Crop Type:Transect:Position:Year	7.63	2	0.022

Table 1.6. ANOVA table for mixed models of genus richness during each collection period with (A) Pre-seed period in May and (B) Flowering period in July.

Collection Period	<i>Chisq</i>	<i>df</i>	<i>p</i>
(A) Pre-seed			
Year	25.95	1	<0.001
Crop Type	1.58	2	0.455
Transect	3.84	1	0.050
Year:Crop Type	2.04	2	0.361
Year:Transect	0.21	1	0.646
Crop Type:Transect	3.43	2	0.180
Year:Crop Type:Transect	2.10	2	0.349
(B) Flowering			
Crop Type	10.12	2	0.006
Transect	0.005	1	0.924
Position	5.79	1	0.016
Year	19.70	1	<0.001
Crop Type:Transect	2.20	2	0.332
Crop Type:Position	2.16	2	0.340
Transect:Position	1.09	1	0.298
Crop Type:Year	0.868	2	0.648
Transect:Year	0.001	1	0.973
Position:Year	0.901	1	0.343
Crop Type:Transect:Position	1.51	2	0.471
Crop Type:Transect:Year	1.95	2	0.378
Crop Type:Position:Year	1.52	2	0.467
Transect:Position:Year	1.14	1	0.285
Crop Type:Transect:Position:Year	5.74	2	0.057

Year was the only factor tested in PERMANOVA for the pre-seed period. In LMMs, year significantly affected bee abundance and richness, while the PERMANOVA indicated that it also significantly influenced community composition (Table 1.7, Figure 1.6). Results of PERMANOVA for the flowering period revealed that crop type, year and their interactions significantly affected bee community composition (Table 1.7, Figure 1.7). Transect and position were not found to have effects when tested as individual factors, although there was a significant transect by position interaction influencing community structure. Similar to what LMMs indicated for abundance, there was a four-way interaction between crop type, transect, year and position influencing community composition.

Table 1.7. PERMANOVA results based on Bray-Curtis distance using bee community data in relation to year during the pre-seed and flowering period (2018 and 2019), and crop type (cereal, wheat, canola and semi-natural re-seeded forage), transect (wetland or field) and position along the transect (0m or 150m) during the flowering period. (A) Pre-seed period in May. (B) Flowering period in July.

Collection Period	df	Sum Sqs	R ²	F	p
(A) Pre-Seed					
Year	1	2.96	0.26	20.36	<0.001
Residuals	58	8.43	0.74		
Total	59	11.39	1.00		
(B) Flowering					
Crop type	2	905.70	0.07	4.76	0.002
Transect	1	119.14	0.01	1.25	0.277
Year	1	250.79	0.02	2.64	0.003
Position	1	129.63	0.01	1.36	0.240
Crop Type:Transect	2	72.53	0.01	0.38	0.890
Crop Type:Year	2	909.18	0.07	4.78	0.001
Transect:Year	1	21.24	0.00	0.22	0.918
Crop Type:Position	2	61.56	0.00	0.32	0.945
Transect:Position	1	436.52	0.03	4.59	0.004
Year:Position	1	51.88	0.00	0.55	0.620
Crop Type:Transect:Year	2	69.44	0.00	0.36	0.933
Crop Type:Transect:Position	2	343.74	0.03	1.81	0.107
Crop Type:Year:Position	2	105.71	0.01	0.56	0.756
Transect:Year:Position	1	185.13	0.01	1.94	0.119
Crop Type:Transect:Year:Position	2	603.32	0.05	3.17	0.009
Residuals	95	9032.90	0.68		
Total	118	13298.42	1.00		

df - degrees of freedom; Sum Sqs - sum of squares; F - F value by permutation, boldface indicates statistical significance with $p < 0.05$, p-values based on 999 permutations

3.3.2 Effects of Crop Type on Bee Community

Overall, the highest number of individuals were collected in forage sites (n=2642), followed by canola (n=2641) and cereal (n=2623; Table 1.2, Figure 1.2 and 1.4). Richness was calculated based on the combined abundance of bees of each genus collected in 2018 and 2019. Cereal crops were found to have the highest richness of bee genera, while forage and canola were similar in richness (Table 1.2, Figure 1.3 and Figure 1.5). Crop type was not found to influence the

abundance, richness or community structure of bees during the pre-seed period, although it was one of the strongest effects in the flowering period (Table 1.5, Table 1.6, Table 1.7; Figure 1.4, Figure 1.5 and Figure 1.7). Additionally, the crop type by year interaction was not found to influence abundance or richness although it was found to influence the community composition (Table 1.5, Table 1.6 and Table 1.7).

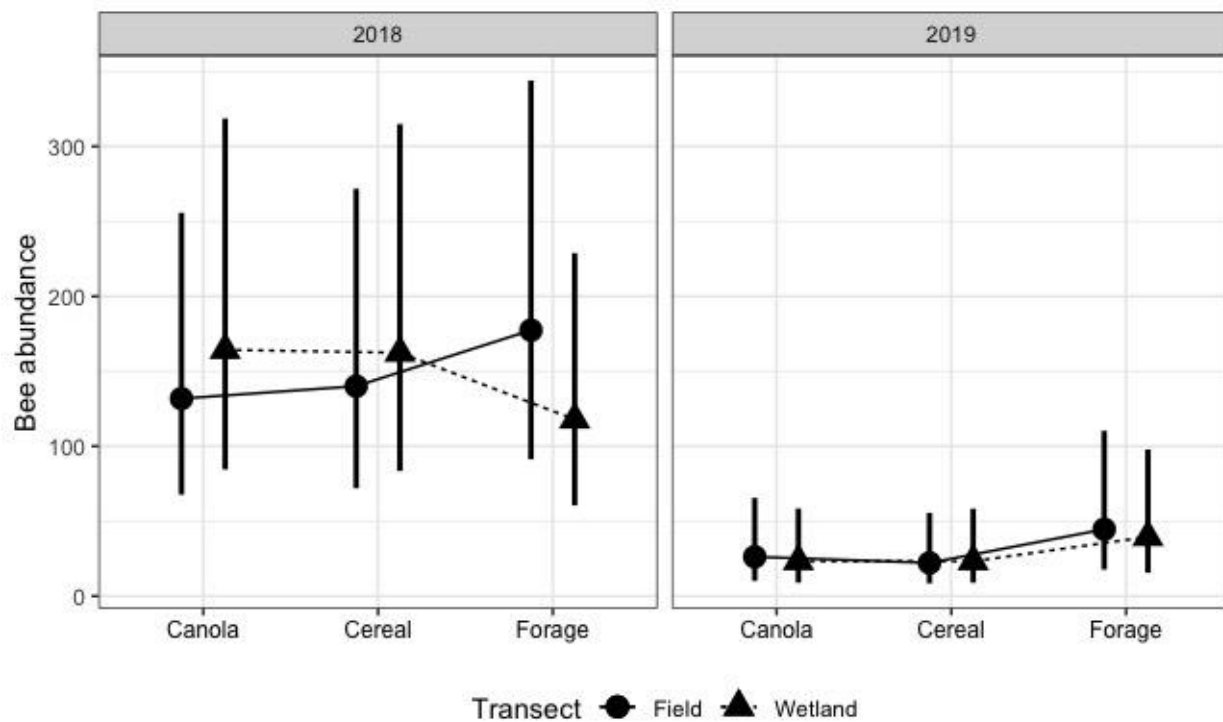


Figure 1.2. Relationship between bee abundance (no. of individuals) by crop type and transect location during the pre-seed period (May) in 2018 and 2019. Points denote model estimated means and bars indicate standard error.

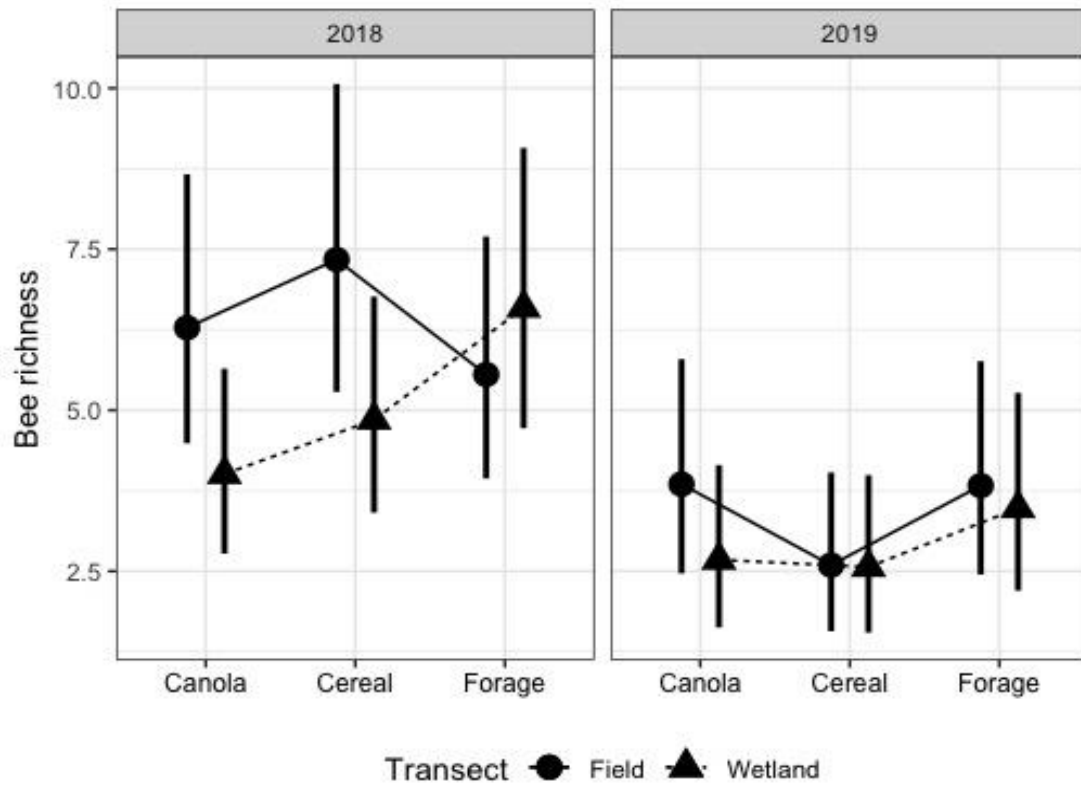


Figure 1.3. Relationship between bee richness (no. of genera) by crop type and transect location during the pre-seed period (May) in 2018 and 2019. Points denote model estimated means and bars indicate standard error.

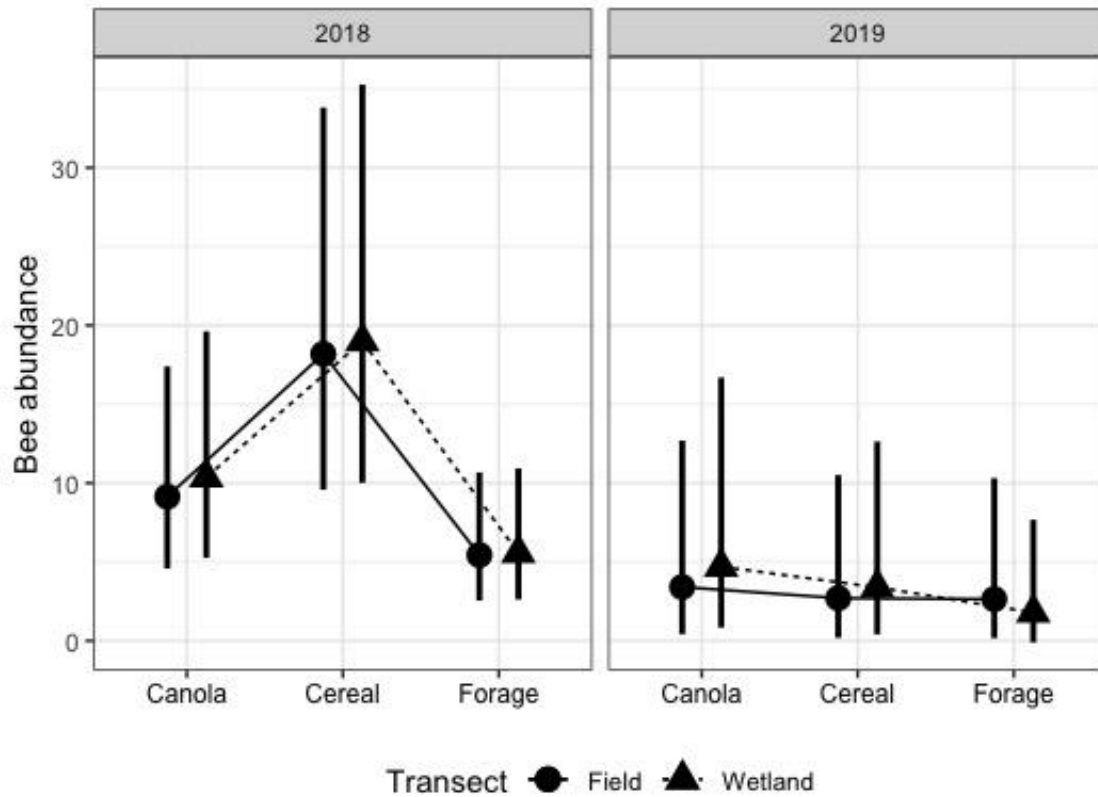


Figure 1.4. Relationship between bee abundance (no. of individuals) by crop type and transect location during the flowering period (July) in 2018 and 2019. Points denote model estimated means and bars indicate standard error.

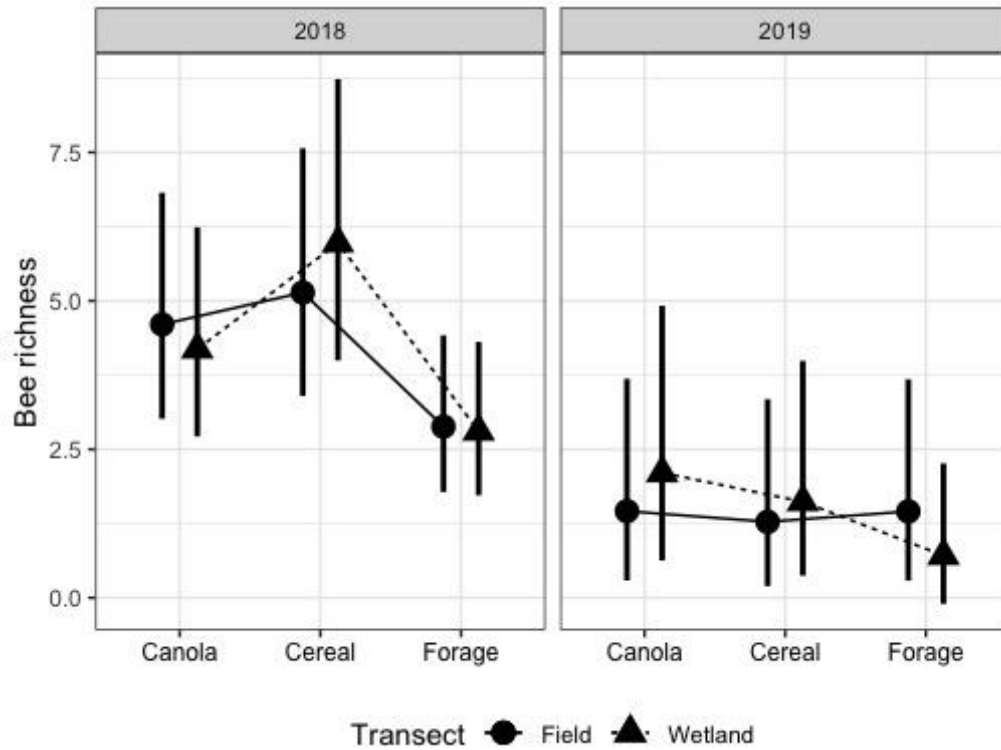


Figure 1.5. Relationship between bee richness (no. of genera) by crop type and transect location during the flowering period (July) in 2018 and 2019. Points denote model estimated means and bars indicate standard error.

PERMANOVA indicated that only 1.6 % of variation among bee communities was described by crop type during the pre-seed period, while 35% was explained by year. During the flowering period 9% of variation was explained by crop type, while only 1.8% of the variation was explained by year. These results are visually represented by PCoA plots, where years are distinctly clustered (Figure 1.6 and 1.7). Forage sites were clustered between years, while canola and cereal crops were not.

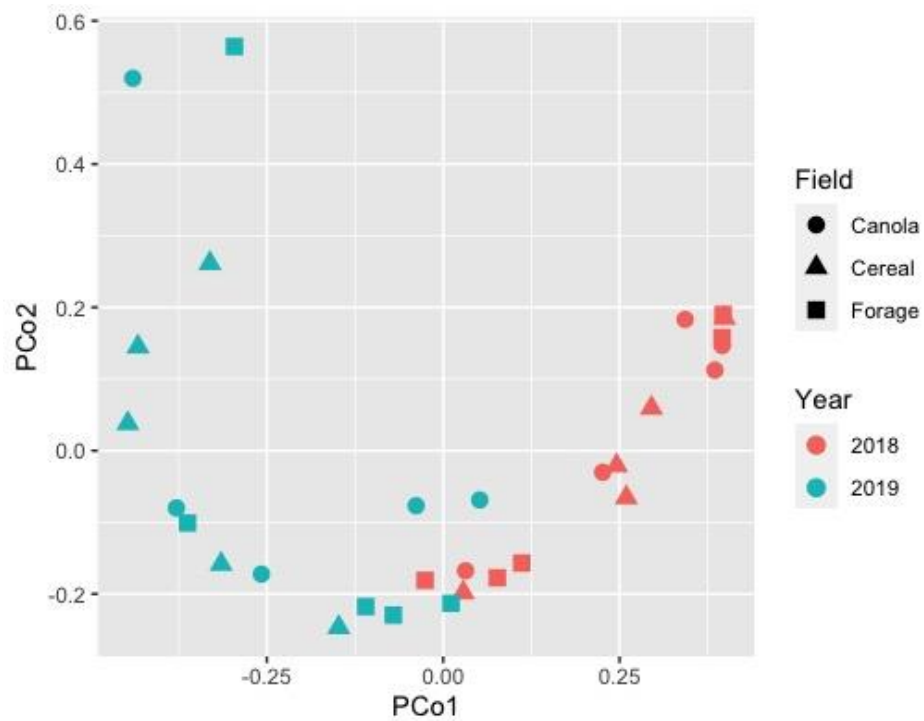


Figure 1.6. Principal component analysis (PCoA) ordination plot for bee communities in each crop type during the pre-seed period (May) in 2018 and 2019. PCoA analysis is based on Bray-Curtis distances.

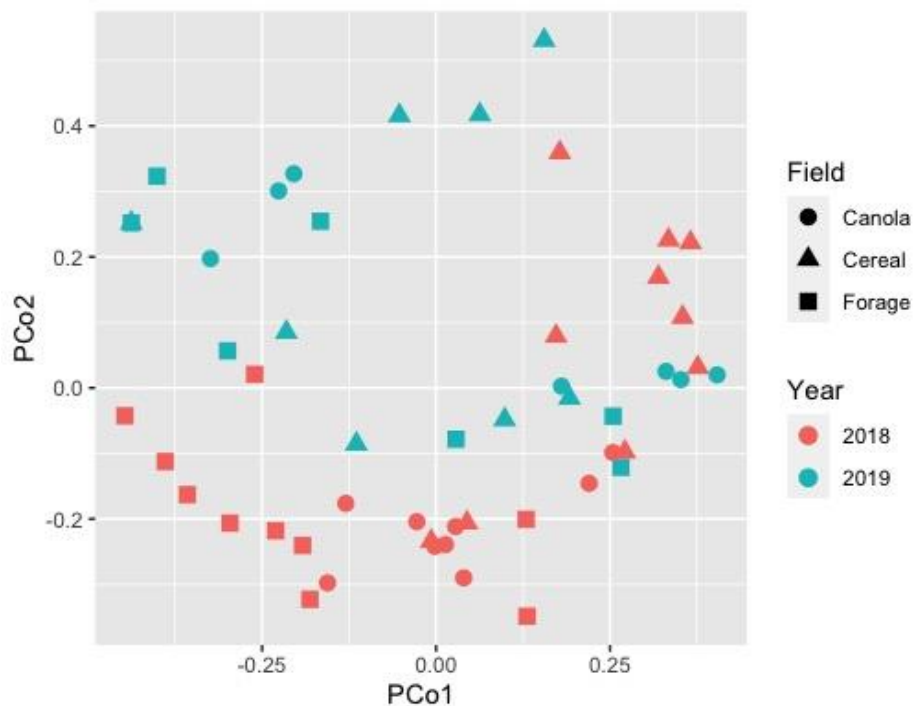


Figure 1.7. Principal component analysis (PCoA) ordination plot for bee communities in each crop type during the flowering period (July) in 2018 and 2019. PCoA analysis is based on Bray-Curtis distances.

3.3.3 Effects of Wetland and Field Edge Habitat on Bee Abundance and Community Structure

Based on the results of LMMs, transect (wetland or field edge) had no significant impact on the abundance or richness of bees collected during the pre-seed period and therefore the community composition was not tested in PERMANOVA (Tables 1.5, 1.6 and 1.7). During the flowering period, the abundance, richness and community composition of bees were not found to be significantly affected by transect location (Tables 1.5, 1.6 and 1.7). Trap position as an individual factor affected bee abundance and richness, although it did not significantly affect community composition (Table 1.5, 1.6 and 1.7). The interaction between transect and position did not impact the abundance and richness of bees, yet it impacted community composition (Table 1.5, 1.6 and 1.7). The raw abundance and richness of wetland transects was generally higher (Appendix 4). Year was also found to be a significant factor in the overall abundance, richness and community composition of bees, and abundance was higher in 2018 than in 2019 (Table 1.2, 1.5, 1.6 and 1.7).

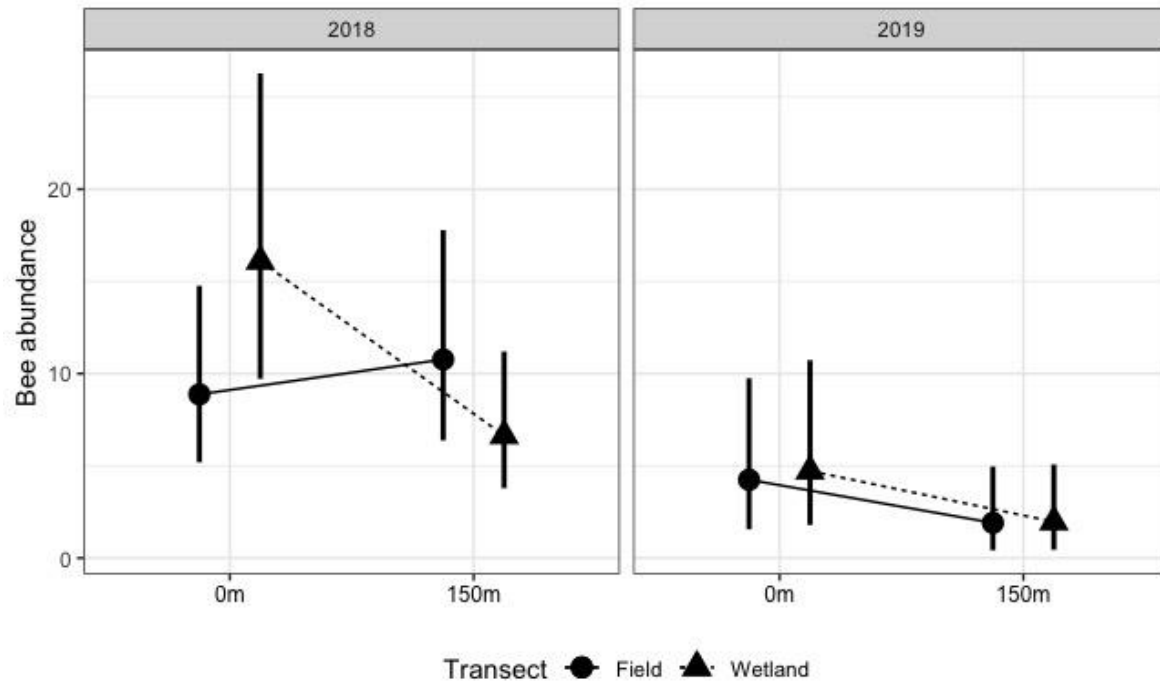


Figure 1.8. Relationship between abundance of bee genera by trap position of each transect during the flowering period (July) in 2018 and 2019. Points denote model estimated means and bars indicate standard error.

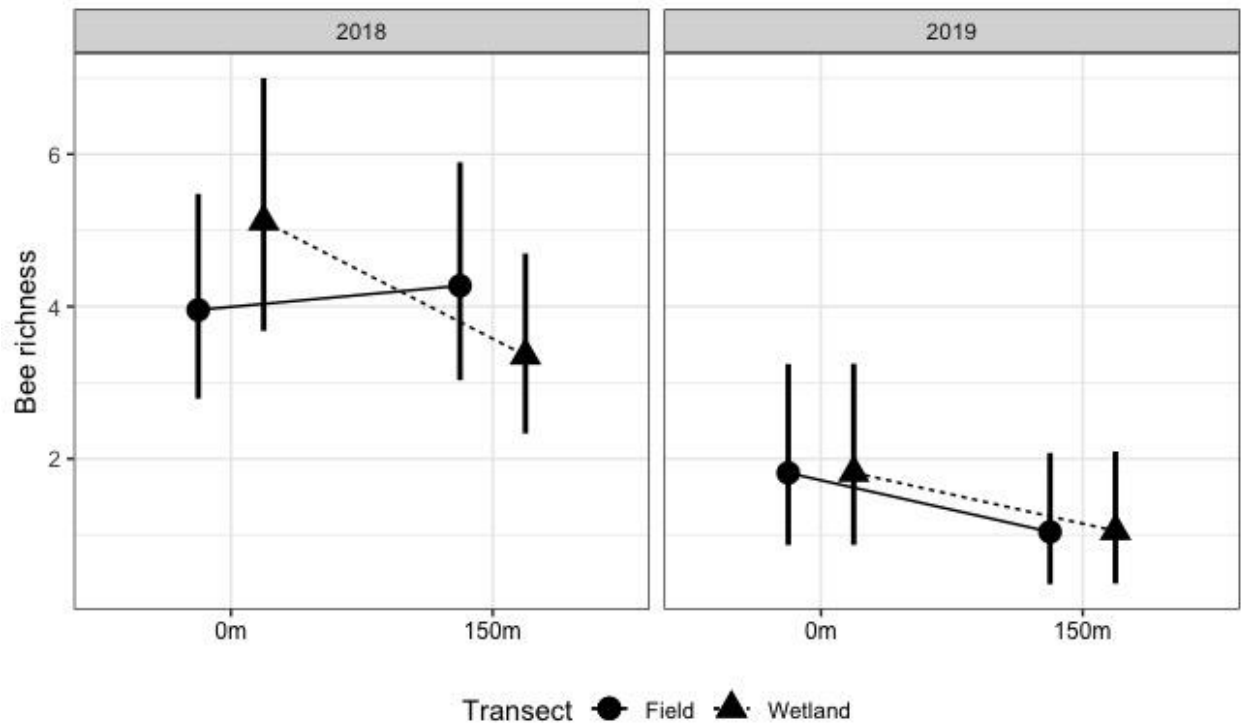


Figure 1.9. Relationship between richness of bee genera by trap position of each transect during the flowering period (July) in 2018 and 2019. Points denote model estimated means and bars indicate standard error.

3.3.4 Four-Way Interaction Between Crop Type, Transect, Position and Year

LMMs and PERMANOVA indicated a significant interaction between crop type, transect, year and position as they pertain to abundance and community composition (Table 1.5 and Table 1.7, Figure 1.6 and Figure 1.7). Although, this same interaction was not found to significantly impact richness (Table 1.6). Figure 1.10 provides a graphical representation of the four-way interaction and the effects on bee abundance. Bee abundance was higher in 2018 than in 2019 and was significantly different between crop types in 2018, yet these differences were not significant in 2019 (Table 1.2, Table 1.3 and Table 1.4). Cereal crops were found to be the most significant driver of differences in bee abundance during the 2018 field season (Figure 1.10). The same was true regarding differences in bee abundance between transects, with differences between the field and wetland being more apparent in 2018 than in 2019. In 2018, the 0m traps located within the wetland transects of the cereal crops had a significantly higher abundance of bees than those of other crop types, as well as the field transect.

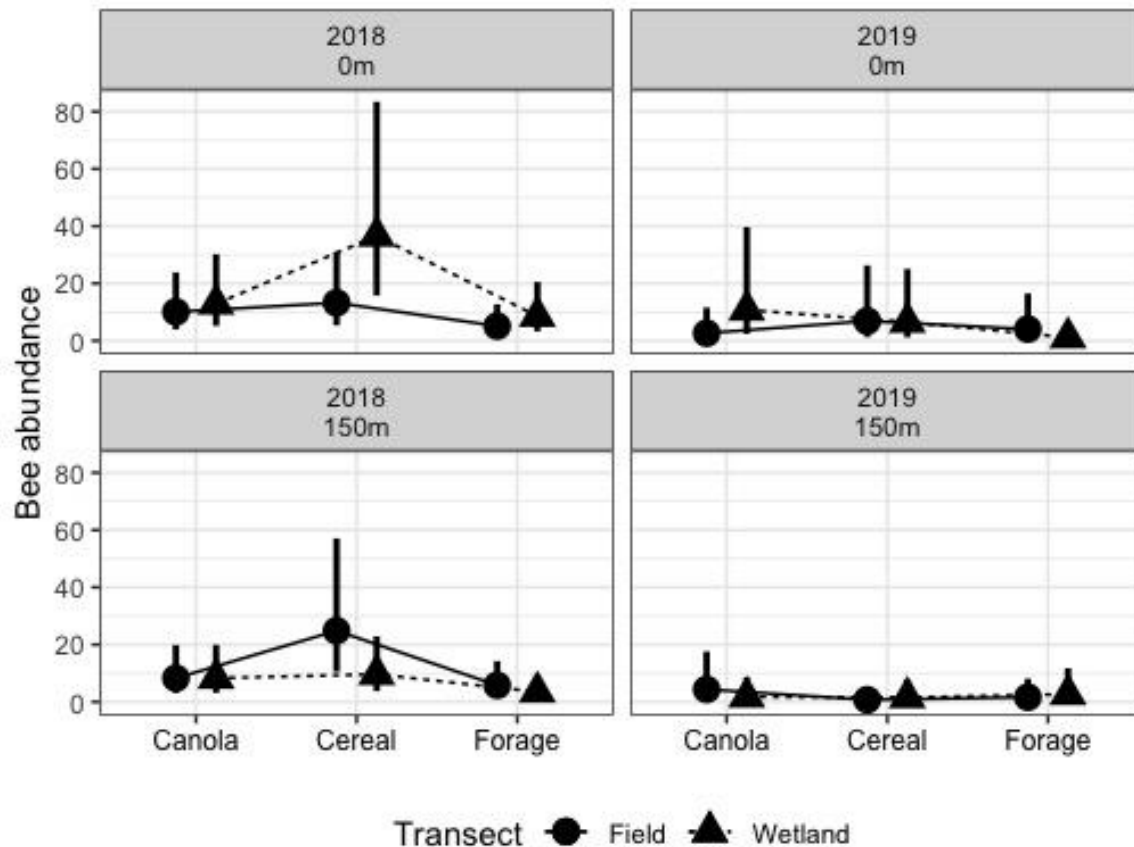


Figure 1.10. Relationship between bee abundance (no. of individuals) by crop type, transect location and trap position during the flowering period (July) in 2018 and 2019. Points denote model estimated means and bars indicate standard error.

3.4 Discussion

The results of this study reveal that a diverse assemblage of native bee genera exist within the agroecosystems of the Prairie Pothole Region of Saskatchewan. As with similar studies, these results enhance the assumption that semi-natural sites and the edge habitat of wetlands may provide important food and nesting resources for native bees (Begosh et al. 2020; Cranmer et al. 2012; Griffin et al. 2017; Shaw et al. 2020; Vickruck et al. 2019). Differences in bee abundance, richness and community structure between crop types were not significant during the pre-seed period. This lack of difference may be due to the absence of flowering crops and a low abundance of flowering native plants in May. Bees collected in these samples may be present in traps due to the absence of flowers in the area at this time, because the traps are the only thing in the field that resembles a food source. During the flowering period however, bees have a larger selection of food sources,

and this is likely why the abundance of bees collected was much higher in the pre-seed period than in the flowering period. Additionally, results from the flowering period indicated significant differences in abundance and community composition between crop types. Differences during the flowering period are likely attributed to bee preference for floral diversity and access to bare ground for nesting (Kline and Joshi 2020; Martinez-Bauer et al. 2021; Potts et al. 2005).

3.4.1 Impacts of Crop Type on Bee Communities

Combined data for 2018 and 2019 indicated that bee abundance was highest overall in semi-natural reseeded forage sites, although richness was not (Table 1.2, 1.3 and 1.4). These sites had higher observed floral richness, abundance and coverage of bare ground, all of which are covariates known to have a direct positive effect on bee abundance and richness (Hopwood, 2008; Griffin et al. 2017; Potts et al. 2005). Many of the native bee genera collected in this study were ground nesting bees, predominantly *Bombus* spp., *Lasioglossum* spp. and *Andrena* spp., that require adequate access to bare ground for nesting. The availability and quality of nesting resources within an ecosystem is known to impact the structure of bee communities (Potts et al. 2003; Winsa et al. 2017). Habitat disturbances associated with agronomic practices, such as tilling and mowing, influence these factors and is also known to change the structure of bee communities (Harmon-Threatt and Hendrix 2015; Odonaka and Rehan 2019; Tscharntke et al. 2005; Williams et al. 2010; Winfree et al. 2009). Forage sites had more undisturbed bare ground and were not hayed or mowed during this study which likely influenced the capacity to which bees could nest at these sites (Cranmer et al. 2012; Kim et al. 2006). Landscape heterogeneity and a lack of disturbance to nesting sites across both years also likely allowed bees to remain in a patch from one year to the next without requiring relocation.

The abundance of bees collected from canola fields was lower than in forage sites, although richness was the same in 2018 and higher in 2019. These results are similar to those of O'Brien et al. (2018) showing that canola fields foster diverse genera of bees and support extensive foraging activity of both honeybees and wild bees. Mass flowering crops, such as canola, provide an abundant food source over a short flowering period and may provide bees with an important supplementary food source (Galpern et al. 2017; Le Feon et al. 2013; Shaw et al. 2020; Vickruck et al. 2019). The small open flowers of canola are easily accessible to the solitary ground nesting bees such as *Lasioglossum* spp. that formed a high percentage of the bees collected, which could

be an integral food source as habitat loss becomes increasingly prevalent (Westphal et al. 2003). Bees may visit canola fields to collect floral resources, although it does not meet the needs of many specialists and generalists that require mixed floral resources for sufficient nutrition (Holzschuh et al. 2011; O'Brien et al. 2018; Williams et al. 2015). Due to the temporary window of flowering crops, bees still require floral resources pre- and post-flowering (Forrest et al. 2015; Mallinger et al. 2016; Martins et al. 2018). Therefore, florally diverse habitat adjacent to canola crops that also provides nesting resources can enhance pollination services through spill-over effect (Benjamin et al. 2014; Bommarco et al. 2012; O'Brien et al. 2018). The positive impact of semi-natural habitat on species richness and abundance of pollinators in an array of crops has been demonstrated by numerous studies, and prevalently in oil-seed rape (Shaw et al. 2020)

Similar to the findings of Vickruck et al. (2019) bee abundance was lowest in cereal crops which was expected as they do not use these crops as a food source, although richness of bee genera was found to be marginally higher. Some bee genera collected in this study are rare in this landscape and differences in richness may simply be due to a lack of these genera being sampled in all crop types.

3.4.2 Impacts of Edge Habitat on Bee Communities

Abundance, richness and community composition of bees was not significantly different between transect locations. Although, abundance and richness of bees was positively impacted by the presence of marginal habitat at field and wetland edges. Interestingly, transect location and trap position had no effect on community composition, yet their interaction seems to be an important factor. As with Vickruck et al. (2019), traps positioned within the marginal habitat located at field and wetland edges had a higher abundance and diversity on average than those located within the field (Appendix 4). Wetland and field edges had a higher observed diversity of floral resources than the large monocultured fields they surround which primarily contained the seeded crop, and these edges also provided undisturbed nesting habitat for native bees versus crop fields which are subject to various agronomic practices.

Data suggests that bees collected in this study are using habitat margins as a resource for nesting, it is also possible that bees are travelling from other patches to forage in this marginal habitat. Many bee genera collected were small central place foragers that search for food within 150m-600m radius from their nest (Cresswell et al. 2000; Heneberg et al. 2018), therefore bees

nesting within the margins of wetland habitat are likely visiting crop fields nearby providing increased pollination services. Aside from bare ground, wetland habitat also provides nesting resources for cavity nesting bees such as mason and leaf-cutter bees in the form of pithy stems and hollow reeds that are not found elsewhere in the landscape further highlighting their ecological value and a need to conserve them (Williams et al. 2010). Habitat loss continues to negatively impact bee abundance and richness and natural habitat patches scattered throughout fragmented agricultural landscapes may function as buffers against further bee population declines (Griffin et al. 2021; Kim et al. 2006; Kremen et al. 2004).

3.4.3 Differences Among Years

Interestingly, bee abundance and richness were significantly impacted by the collection year and were higher in the 2018 field season. The impact of year on bee abundance is most likely due to temperature and precipitation differences that impact native bee life history traits (Appendix 5). Average precipitation was higher in 2019, but average temperature was lower with fewer days above the temperature threshold in which bees can forage. It seems that the number of “bee days”, or days in which the temperature stayed between 12 and 22 degrees, may have been the strongest determinant of bee abundance in the area. The optimal flight and foraging temperature for most bees is between 12 and 25 degrees (Kenna et al. 2021). Bumble bees (*Bombus* spp.) are capable of foraging at low temperatures, as low as 5 degrees Celsius, under relatively wet conditions (Couvillon et al. 2010; Grixti et al. 2009). Honeybees generally do not forage at temperatures lower than 12 degrees (Thorp 1996), and the ambient temperature requirements of many smaller native bees are not well known.

Little is known about the general moisture requirements and desiccation tolerances of bees, although some studies have examined the tolerances of other orders of insects. A study conducted by Burdine and McCluney (2019) found that the desiccation and thermal tolerances appear to differ between bee species, with some being more susceptible to changes than others. The results of this study support a need for further research regarding temperature and moisture requirements of native bees especially as global climates continue to shift and temporal changes in bee communities over multi-annual spans remain poorly studied.

Bee communities exhibited lower abundance in cereal and canola fields between years. Differences in bee community structure and abundance among years were less extreme in the re-seeded forage sites, this is likely due to the consistent food sources available in this crop type. Although nutrient quality may have been affected by temperature and precipitation in the 2019 field season the availability of floral resources remained consistent (Al-Ghzawi et al. 2009; Phillips et al. 2018). Differences in temperature and moisture among years may have also impacted flower phenology of canola impacting the number of actual “bee days” during its flowering period. Crop rotation from one year to the next is commonplace in Saskatchewan, and the crop from one year may have also impacted the diversity and abundance of bees collected in the subsequent year (Andersson et al. 2014; Le Feon et al. 2013; Vickruck et al. 2019). Bees will provision their nests prior to overwintering and genera from the previous year will emerge in the spring affecting community composition in the next (Vickruck et al. 2019).

3.4.4 Effects of the Interaction Between Crop Type, Transect, Position and Year

There were significant four-way interactions between crop type, transect, year and position with respect to both abundance and community composition of native bees, although the same interaction was not found for the richness of genera present. Differences in bee abundance between 2018 and 2019 may be explained by differences in temperature and precipitation, which also likely impacted the abundance and density of floral resource (Burdine and McCluney 2019; Kenna et al. 2021; Grixti et al. 2009). As there were fewer bees collected overall in 2019, it is likely that this resulted in a more even distribution of abundance within sites, as well as across the landscape. Therefore, significant differences between crop types and transects were less apparent than in 2018. The density of plants and pollinators in a given area may change foraging behaviour to one that adapts to a necessity for resource partitioning depending on availability (Akter et al. 2017; Lazaro and Totland 2010). The same was true regarding differences in bee abundance between transects, with differences between the field and wetland being more apparent in 2018 than in 2019. Additionally in 2019, vegetation at wetland edges of some sites had been completely tilled at the beginning of the sample season and this may exacerbate those trends related to water and precipitation. Specifically, tillage may have decreased the abundance and composition of floral resources and may have also disturbed the nests of some ground nesting bee genera (Williams et al. 2010).

Cereals appear to be the most significant driver of differences in bee abundance between crop types during the 2018 field season. In 2018, the 0m traps located within the wetland transects of the cereal crops had a higher abundance of bees than those of other crop types. A similar pattern was observed with bees collected from the 150m traps located within the field transect. These results seem counterintuitive as bees do not forage on cereal crops. The patterns observed in cereal crops may be a result of bees that emerged from nests that had been established in the previous year (Vickruck et al. 2019). Crop rotation is commonly performed annually in Saskatchewan and sites with cereal crops in 2018 were seeded with canola the previous year (Smith et al. 2017). Sites seeded with canola are attractive to bees and provide adequate floral resources thereby providing a source population in subsequent years (Westphal et al. 2003, Shaw et al. 2020).

The four-way interaction between crop type, transect, position and year is complicated. The overall abundance of bees was higher in 2018 than 2019, this difference may be driving the effects observed at the 0m wetland transects of cereal fields in 2018. There is a myriad of possible explanations as to why this complex interaction significantly impacts native bee abundance and community composition. Environmental conditions in 2018 were representative of normal yearly temperature and precipitation requirements of native bees present in this area and floral resources were abundant. Additional data collected over a longer study period is needed to establish clear patterns in the relationship between these four factors. A more concise understanding of these interactions will contribute to more integrative management of future cropland use.

3.5 Conclusion

Data revealed that there are significant differences in the impact of crop type on the abundance, richness and community composition of bees in the agroecosystems located in the Prairie Pothole region of Saskatchewan. These results are consistent with numerous studies that have demonstrated the importance of semi-natural and restored grassland ecosystems in supporting native bee communities in agriculture-intensive landscapes.

Results from this study show that wetland remnants and florally diverse field margins, as well as areas of semi-natural re-seeded pasture play an important role in supporting native pollinator communities in highly cultivated landscapes. These areas appear to support a high

diversity of native bees and should be conserved as they provide integral nesting and dietary resources. Although the presence of wetland habitat was not found to be significant, natural edge habitat surrounding wetlands and agricultural crops clearly supports a higher abundance and richness of native bees, providing suitable food sources and habitat refuge. The preservation and restoration of semi-natural areas in the form of re-seeded forage and natural habitat edges within agroecosystems plays a pivotal role in securing native pollinator communities and the pollination services they provide.

4. General Conclusions

Native bee diversity and abundance remains threatened by the pressures of pesticide use, disease, habitat loss and potentially climate change (Griffin et al. 2021; Kerr et al. 2015; Williams et al. 2010; Winfree et al. 2009). Agricultural intensification and current farming practices continue to contribute to large scale habitat loss and fragmentation and are still among the top contributing factors in global bee decline (Galpern et al. 2017; Kremen et al. 2007). However, very few comprehensive surveys of native bee communities have been conducted and current databases lack sufficient data to monitor the intensity of these declines. Wetland loss and degradation is also persistent in these landscapes, their conservation, and in turn the habitat they provide, may be key in preserving the diversity and abundance of bees and other native pollinators (Vickruck et al. 2019; Verhoeven et al. 2010).

To investigate the effects of crop type and edge habitat on native bee populations and community assemblages, I sampled bees from fifteen sites in the Prairie Pothole Region of Saskatchewan. I hypothesized that native bee communities would differ among crop types and would also differ between field and wetland margins. My findings revealed that native bee abundance and community structures differ most significantly between crop types. Semi-natural re-seeded forage sites supported the highest abundance of native bees across both years when combined compared to crop sites such as canola and cereal. These differences are likely due to a higher availability of floral and nesting resources in the forage sites (Gathmann and Tscharntke 2002; Knight et al. 2009; Winsa et al. 2017). Community differences between field and wetland margins were not found to be significant, although they supported a higher diversity and abundance of bees when compared to in-field traps. Semi-natural edge habitat surrounding agricultural fields, much like the re-seeded forage sites, provides increased nesting and floral resources that are important for native bee survival (Purvis et al. 2019, Vickruck et al. 2019). The results of this study, as with many preceding it, support the concept that bees benefit from semi-natural habitat in highly cultivated and fragmented landscapes. Supplementary results of this study also highlight the possible effects of temperature and moisture requirements of bees and their importance as climate

change persists. Further research investigating these variables would also be beneficial towards future native bee conservation efforts.

Insect pollinator conservation can be enhanced by promoting native forb and floral communities in the form of semi-natural re-seeded forage. The conservation and re-seeding of significant sections of semi-natural flowering vegetation are a key component in securing native bee populations. The continuation of practices that mediate the decline of native pollinators and also re-establish their populations may be fundamental for the future of global food security. Land planning and management that increases suitable habitat for native bees and other pollinators aids in securing the pollination services they provide for both native plants and agricultural crops and is economically and ecologically beneficial. Bees are the most important pollinators of many crops, therefore, preserving habitat that provides key resources has benefits not only for biodiversity but also for farmers growing crops such as canola that require or benefit from animal pollination. A diversity of pollinators may also be important in maintain adequate crop pollination as climate change intensifies. This information will aid in the formation of future management strategies of crop land that supports the conservation of native bee and pollinator habitat in the form of semi-natural or unmanaged habitat.

This study was the first to survey the bee genera of the Prairie Pothole Region in Saskatchewan and should serve as a gauge for future monitoring of the native bees in this area. We still know very little about the conservation status of many native bee genera and very few species keys and monitoring databases exist in Western Canada and the United States. Increased research and monitoring are crucial to fill remaining knowledge gaps and aid in the protection and preservation of these important pollinators. Monitoring programs must be established to ensure sustainable and healthy native pollinator populations. There is still a need to better understand how to conserve native bee populations and promote sustainable agricultural practices and pollination services. The conservation of wetlands and other natural edge habitat in agroecosystems may play a pivotal role in preserving and re-establishing populations of native bees that have declined and continue to decline due to anthropogenic disturbances. Further protection of wetland habitat must continue in on a worldwide scale to secure crucial biodiversity in the Prairie Pothole Region.

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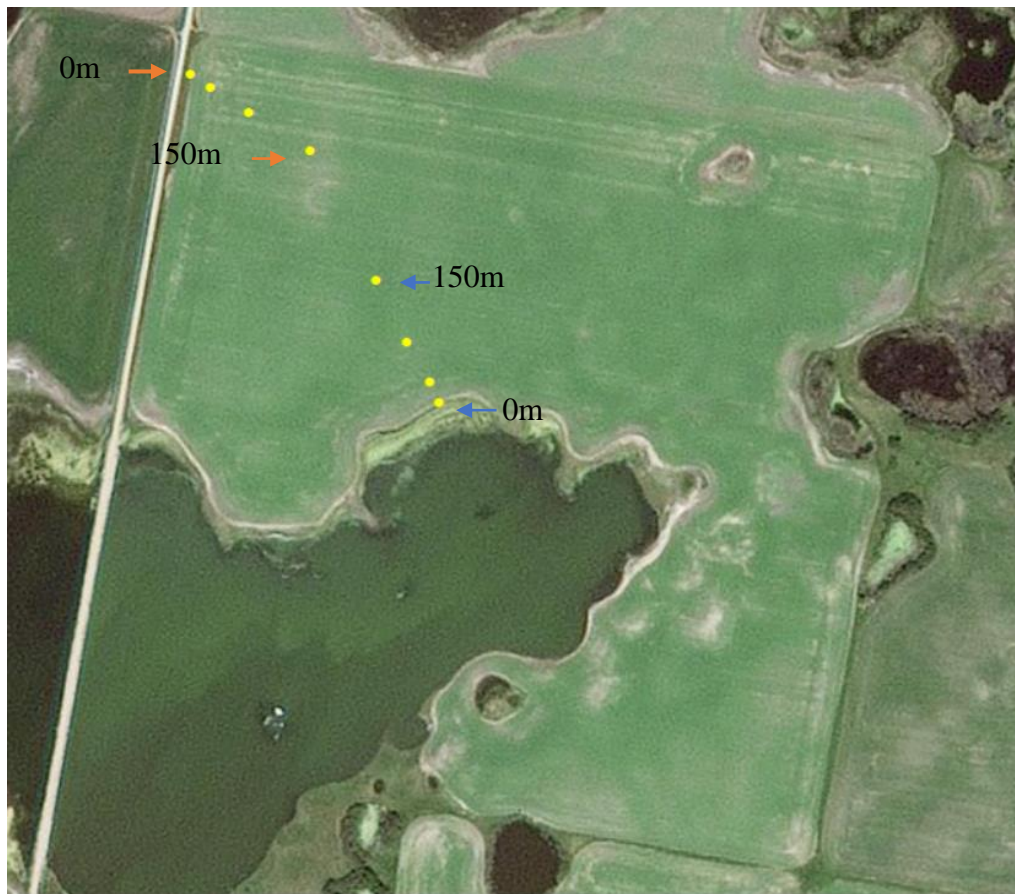
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6. Appendices

Appendix 1. Pan and vane trap set up. Blue/yellow vane traps (left) secured to polls and adjusted to the height of vegetation. Blue, yellow and white pan traps (right) placed in custom 3D printed holders and secured to poles at height of vegetation. Sticky cards (left) and pitfall traps (middle) were collected for use in a separate study.



Appendix 2. A site map representing the layout of transects with positions at 0m, 25m (2018), 75m, and 150m. Orange arrows represent 0m and 150m trap positions at a field edge, and blue arrows represent 0m and 150m traps positions at a wetland edge. Image courtesy of Jim Devries.



Appendix 3. Custom 3D printed pan trap holders with blue, yellow and white UV painted bowls. Pan holders were adjusted to plant height during each sample period using duct tape to secure them to the pole.



Appendix 4. Abundance and average richness of bees collected from margins (0m) and within the field (150m) from canola, cereal and forage during the growing seasons of 2018 and 2019.

	Transect	Position	Abundance	Average Richness
Canola - 2018	Wetland	0m	70	5
	Field		50	5
	Total		120	
	Wetland	150m	44	4
	Field		54	4
	Total		98	
Canola - 2019	Wetland	0m	134	5
	Field		32	2
	Total		166	
	Wetland	150m	29	2
	Field		54	7
	Total		83	
Forage - 2018	Wetland	0m	50	4
	Field		36	3
	Total		86	
	Wetland	150m	35	3
	Field		33	4
	Total		68	
Forage - 2019	Wetland	0m	42	7
	Field		68	3
	Total		110	
	Wetland	150m	51	2
	Field		23	2
	Total		74	
Cereal - 2018	Wetland	0m	229	7
	Field		75	5
			304	
	Wetland	150m	50	5
	Field		199	6
	Total		249	
Cereal - 2019	Wetland	0m	43	9

	Field	66	3
	Total	109	
	Wetland 150m	15	2
	Field	15	1
	Total	30	

Appendix 5. Summary table of average precipitation, average temperature, number of days with precipitation, number of “bee days” *, and number of days above average bee day threshold for the sampling period of May-September in 2018 and 2019.

Year	Month	Average Precipitation (mm)	Average Temperature (°C)	No. Days with Precipitation	No. Bee Days	No. days above threshold
2018	May	0.78	5.9	3	30	7
2018	June	1.26	10.4	6	30	8
2018	July	0.46	9.5	7	26	8
2018	Aug	0.55	9.3	8	31	10
2018	Sep	1.28	1.5	14	18	0
	Total				136	33
2019	May	0.35	1.9	7	22	3
2019	June	4.02	9.0	14	30	2
2019	July	3.15	10.7	14	31	2
2019	Aug	1.24	8.6	8	31	3
2019	Sep	0.84	5.3	9	25	1
	Total				139	11

*Bee days are defined as days in which the temperature was suitable for bee flight and foraging, between 5° and 26° Celsius. Threshold is defined as days where the maximum temperature was above 26 degrees Celcius.

Weather data. No climate data from 2018 and 2019 was available for a weather station situated between Peterson and Humboldt, Saskatchewan. Climate data were obtained from the Environment Canada database for the Pilger weather station (52°25'00.000" N, 109°00'00.000" W)(https://climate.weather.gc.ca/climate_data). The Pilger station is approximately 30km from the study sites. The Pilger station is the closest station with complete weather data for the study period. Number of bee days were calculated using the mean daily temperature (°C) and are days where the average temperature was ideal for bee flight, between 6 and 26 degrees Celsius.

Appendix 6. A list of all genera by family collected in samples from 2018 and 2019 near Humboldt, Saskatchewan.

Family	Genus
Apidae	<i>Apis</i> *
Halictidae	<i>Agapostemon</i>
Andrenidae	<i>Andrena</i>
Megachilidae	<i>Anthidium</i>
Apidae	<i>Anthophora</i>
Apidae	<i>Bombus</i>
Megachilidae	<i>Coelioxys</i>
Colletidae	<i>Colletes</i>
Halictidae	<i>Dufourea</i>
Apidae	<i>Eucera</i>
Halictidae	<i>Halictus</i>
Megachilidae	<i>Heriades</i>
Megachilidae	<i>Hoplitis</i>
Colletidae	<i>Hylaeus</i>
Halictidae	<i>Lasioglossum</i>
Megachilidae	<i>Megachile</i>
Apidae	<i>Melecta</i>
Apidae	<i>Melissodes</i>
Apidae	<i>Nomada</i>
Megachilidae	<i>Osmia</i>
Andrenidae	<i>Protandrena</i>
Halictidae	<i>Sphecodes</i>

*Apis refers to *Apis mellifera* as this was the only bee identified to species