TEMPORAL AND LANDSCAPE INFLUENCES ON THE BEE COMMUNITY ASSEMBLAGE OF THE MCMASTER RESEARCH AND CONSERVATION CORRIDOR

TEMPORAL AND LANDSCAPE INFLUENCES ON THE BEE COMMUNITY ASSEMBLAGE OF THE MCMASTER RESEARCH AND CONSERVATION CORRIDOR

By NOAH M. STEGMAN, B.Sc.

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements

for the Degree Master of Science

McMaster University

McMaster University MASTER OF SCIENCE (2022) Hamilton, Ontario (Biology)

TITLE: Temporal and Landscape Influences on the Bee Community Assemblage of the McMaster Research and Conservation Corridor

AUTHOR: Noah M. Stegman, B.Sc. (McMaster University)

SUPERVISOR: Professor S. A. Dudley

NUMBER OF PAGES: xvi, 123

ABSTRACT

In recent years the issues surrounding pollinator conservation and pollinator decline has been brought to the forefront of both the public and government. Declines are multifaceted and pollinator conservation and restoration tends to focus on open ecosystems, such as prairie and meadow habitats, where there exists a large body of research on the benefits of restoring such habitats for pollinators. However, this does not address the other ecosystems that pollinators can be found in and what critical role those habitats may play in the lifecycles of those species. I surveyed the bee and wasp community present in the Dundas Valley Region of Hamilton in southern Ontario, Canada across 5 distinct habitat types; open fields, forest edges, forests, forested groundwater fed springs, and wetlands. The abundance and richness of floral resources within these habitats and what role this might play at different times of the year was also surveyed. 10 focal species, belonging to 6 genera were chosen as a subset of the population to test for habitat use and movement on the landscape. I found that all habitat types were utilized by bees and wasps to varying degrees, depending on species, time of year, and resource availability. Males and females of the same species did not necessarily utilize the same habitats at the same time of year and there was clear evidence of population movement between these areas and habitat preference. Showing the clear need for a "big picture" approach to pollinator conservation and a need to move away from the standard restoration practice of simply creating open meadows and prairies. This does not address the diverse and heterogeneous habitat requirements needed over the course of their life cycles. Conservation efforts should focus on diversifying the types of habitats being restored on the landscape and recognizing the importance of existing remnant natural features that may add to the heterogeneity of the landscape and to the benefit of pollinator communities.

ACKNOWLEDGEMENTS

I would like to begin by thanking my supervisor, Dr. Susan Dudley, for providing me with this opportunity and for all of her support through the past few years that have seen their fair share of unique challenges. Thanks to my committee member Dr. Jurek Kolasa for all of his feedback and insight throughout this process and for keeping my research topic focussed and attainable.

Thank you to the members of the Dudley lab who have helped me with project design and for inspiring me to pick up this pollinator project. Thanks to Mara McHaffie, Sebastian Irazuzta, and Stefan Weber, for their insight into the research world of bees and plants. This project would not have been possible without over 100 undergraduate volunteers and over 1000 volunteer hours spent processing, sorting, pinning, labelling, and identifying almost 25,000 bees and wasps.

I would also like to thank Lisa Carmody with the City of Hamilton for allowing me to collect samples on City parklands and for providing me with potential candidate sites. Additionally, I would like to thank Mark Stewart, Scott Bennett, and Richard Watson from the McMaster Innovation Park for providing me access to the area for one of my sampling sites. Although the City of Hamilton and McMaster Innovation Park sites were not used in the analyses within this thesis, the data and samples collected remain available for further research.

I would like to give a special thanks to my partner Martha for her tremendous support these past few years and for her unoficially being appointed to the role of my field assistant during all of the covid restrictions of 2020. I would not have had the successful field season without assistance in the field. Finally, I would like to thank my parents and brothers, Jonah and

Kyle, for always supporting me and showing an interest in my work, despite my deeply involved and lengthy explanations. They have always encouraged me to follow my own path and supported my passion learning all I can about our environment and the animals that call it home. This work is dedicated to my grandparents Sidney and Hindy and to the loving memory of my grandparents Barbara and William, and my great grandparents Raye and Sol. They have always been there for me, and I would not be where I am today without their guidance, love, and support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ANOVA = Analysis of Variance

BDMU = McMaster University Insect Collection

FQI = Floristic Quality Index

GAM = Generalized Additive Model

MACBio = Dudley Lab Entomological Collection

MFNP = Ne:toh ho gyo’tgo:t egahado:do’k - Maam-pii naksin m’tigwaaki pane - McMaster Forest Nature Preserve

MNRF = Ontario Ministry of Natural Resources and Forestry

RBG = Royal Botanical Gardens

DECLARATION OF ACADEMIC ACHIEVEMENT

I, Noah Stegman, declare this thesis to be my own work. I am the sole author of this document. No part of this work has been published or submitted for publication or for a higher degree at another institution. To the best of my knowledge, the content of this document does not infringe on anyone’s copyright. My supervisor, Dr. Susan Dudley, and the other member of my supervisory committee, Dr. Jurek Kolasa, have provided guidance and support at all stages of this project. I completed all of the research work.

INTRODUCTION

Background

Pollinators and pollination are critically important to life on Earth. If plant-pollinator interactions are broken it could have devastating effects on the natural environment, world economy, and human health (Vanbergen & Insect Pollinators Initiative, 2013; Potts et al., 2016; Hristov et al., 2020). Potential threats to these interaction networks have surfaced in recent years and the plight of bee decline is a hot topic issue amongst the public and local governments. What the general public fail to realise are the intricacies at play within our pollinator communities and what is required to keep them strong and healthy. The majority of bee and wasp species in Ontario are ground nesting; these species dig burrows into the ground or take over an existing cavity. Bee and wasp species in Ontario are mostly solitary, although some do form social congregations. Exceptions to the solitary rule are the eusocial wasps and bees (*Apis sp., Bombus sp., Dolichovespula sp., Polistes sp., and Vespula sp.*) (Hallett, 2001; Cope et al., 2019; Kratzer, 2022). The vast majority of these bee and wasp species go unnoticed by the general public due to their small size. The wasps that do get noticed, mainly the large eusocial wasps, are maligned by the public. Whereas the bees that get noticed, mainly the honey bees (*Apis mellifera*) and the bumble bees (*Bombus sp.*), receive much admiration. Wasps unjustly get a bad reputation and honey bees receive more praise then they deserve. These thoughts will often influence land management practices, as local governments and land managers work to support public opinion. The “save the bee” campaigns and “bee city” designations (Bee City Canada, 2022) are positive steps in pollinator conservation, but without proper guidance can lead to unintentional consequences or less impact (Brown & Paxton, 2009; Hall & Martins, 2020).

Bee and wasp diversity changes on the landscape, *i.e.*, a geographic region or area made up of connected habitats or land features (Turner et al. 2001; Turner, 2005), depend on the quality of the habitat and any pressures on it or the insect community. High quality habitats that are speciose in vegetation are known to support a larger and more diverse insect community (Papanikolaou et al., 2017; Kratschmer et al., 2019; Felderhoff et al., 2022). Additionally, intact and remnant natural areas can have more diversity than restoration sites in the area (Polley et al., 2007; Tonietto et al., 2017). The higher diversity can be due to a number of factors including migration time or the presence of "hold out species" on the landscape, where a diverse community persists, but at very low population levels (Cane, 2001; Williams & Winfree, 2013). Often leading to issues with genetic diversity, genetic drift, and population viability (Goulson et al., 2008; Freiria et al., 2012; Frantine-Silva et al., 2021). Therefore it is important to have good survey records for a given area prior to any restoration efforts or to any development of remaining chunks of natural lands in already degraded areas. Restoration and conservation of pollinators like bees and wasps needs to be driven by the conditions on the landscape to be successful (Cranmer et al., 2012; Bennett & Isaacs, 2014; Connelly et al., 2015; Tonietto & Larkin, 2017; McHaffie, 2020; Weber, 2021). However, more research is needed to determine how to best judge a landscape for pollinator success.

Male and Female Ecology of Bees

Male and female bees share a variety of similarities and also many differences in terms of biology, ecology, and life history (Roswell et al., 2019; Urban-Mead et al., 2022). These traits range from diet, energy demands, and lifespans to sexual dimorphisms, and emergence windows. Male bees are typically foraging for nutrition from floral nectar sources. When visiting flowers, males do not actively collect pollen (Ne'eman et al., 2006; Roswell et al., 2019). Males have been recorded consuming pollen, but the degree to how often this occurs is unclear (Taniguchi 1956; Käpylä 1978; Schäffler & Dötterl 2011; Urban-Mead et al., 2022). Female bees on the other hand visit flowers to feed off the nectar source and to actively collect pollen to provision their nests (Ne'eman et al., 2006; Cane, 2016; Roswell et al., 2019). Due to the needs of females to provision a nest(s) and lay eggs, a larger caloric demand is required (Roswell et al., 2019). Females will spend more time at a given flower and travel as short a distance as possible to conserve and collect more resources. The added time foraging at a flower is to both to feed longer on nectar sources and to collect ample pollen resources for nest provisioning (Cane, 2016; Roswell et al., 2019). Males will often forage over greater distances compared to their female counterparts (Roswell et al., 2019). Pollination by males (passive pollination) thus have pollen transferred from a larger assemblage species across a larger geographic area and can lead to greater levels of genetic diversity in floral communities (Roswell et al., 2019; Urban-Mead et al., 2022). Males and females overall have been found to forage on different floral resources (Roswell et al., 2019). Sexual dimorphisms can be found in some groups of bees. With female bees often being larger than male bees (Shreeves & Field, 2008; Medina et al., 2016). These dimorphisms are likely derived from the need for females to collect pollen (Shreeves & Field, 2008; Medina et al., 2016). Cleptoparasitic bees however do not show the same levels of sexual dimorphism (Shreeves & Field, 2008).

Bees can have different lifecycles, either having univoltine (single cycle per year), bivoltine (two cycles per year), or multivoltine (more than two cycles per year) life histories (Onuferko, 2013; Holm, 2017). Most ground nesting bees have a univoltine lifecycle (Fawcett et al., 2019). The emergence of bees can occur at different times of the flight season (spring to autumn) depending on the species (Holm, 2017). Most bees in southern Ontario have a bivoltine or univoltine life cycle (Cordero, 2011; Richards et al., 2011; Onuferko, 2013; Holm, 2017). Male and female bees within a species will often have different emergence windows, with either males emerging first, protandrous, or females emerging first, protogynous (Batra, 1980; Sheffield et al., 2003; Holm, 2017; Fawcett et al., 2019). Males of univoltine insects are often known to emerge first in a protandrous cycle (Wiklund & Fagerström, 1977; Bulmer, 1983). Male and female bees will also have different lifespans once they emerge, however both sexes live for a single season and will die off at the end of the season (Holm, 2017). The next generation, or final generation for bivoltine/multivoltine bees, will overwinter as an egg, larvae, or adult depending on the species (Batra, 1980; Sheffield et al., 2003; Holm, 2017). Males will often be short lived, with their only purpose being to reproduce. Females will spend their flight seasons provisioning nests and are longer lived (Holm, 2017). The sex ratios of male to female bees can fluctuate year to year in univoltine bees (or season in bivoltine/multivoltine bees) based off the previous years resource availability. In areas and years of high floral resource availability sex ratios are often equal, whereas when floral resources are low more males are produced due to males requiring less pollen provisions (Kim, 1999; Martins et al., 1999; Peterson et al., 2006).

Current Impacts on Bee Communities

Pollinators, including bees, are under a variety of threats from the environment and from people. These threats range from climate change and habitat loss, to pesticide use, to competition and the spread of invasive species (Goulson et al., 2015; Koh et al., 2015; Kline & Joshi, 2020; Soroye et al., 2020). The issues are complex and do not all have clearly defined solutions. Climate change and its associated environmental impacts are far reaching (Gonza´lez-Varo et al., 2013; Haokip et al., 2020; Fisogni et al., 2022). The rate of change requires species to adapt quickly or risk extinction (Soroye et al., 2020). Small insects like bees are extremely susceptible to these climactic changes (Parmesan et al., 1999; Brown & Paxton, 2009). These changes can alter the niches that these pollinators utilize through a change in temperature, weather, vegetation community, or a variety of other possible factors (Brown & Paxton, 2009; Pyke et al., 2016; Soroye et al., 2020).

The impacts of habitat loss through the removal of natural areas, either for development, agriculture, or recreation lead to decreases in bee abundance and diversity (Goulson et al., 2015; Koh et al., 2015; Kline & Joshi, 2020). Additional pressures around these developments, such as the use of pesticides in agriculture and horticulture exacerbates these effects. Pesticides are one of the largest contributors to current pollinator declines (Brown & Paxton, 2009; Brittain et al., 2010; Goulson et al., 2015; Hladik et al., 2016; Nemésio et al., 2016; Kleczkowski et al., 2017; Kline & Joshi, 2020). Balancing the needs of the agricultural sector with that of the environment is an ongoing issue, without any clear solution.

Introduced bees, whether brought in accidentally or purposefully for agricultural pollination, have had a number of unintended consequences on both the environment and native bees (Colla, 2022). The most common and well known species of introduced bee is the European honey bee (*Apis mellifera*). It has been introduced around the world for agricultural pollination and honey production. Honey bees are eusocial, hive-forming bees that can reach colony sizes of greater than 100, 000 individuals (Cane & Tepedino, 2016). These large colonies require large amounts of resources to sustain them (Cane & Tepedino, 2016). In areas with high honey bee density, native bee density decreases. Since most native bees are solitary and relatively small compared to that of a honey bee, they cannot compete with the honey bee numbers and aggressiveness (Schaffer et al., 1983; Gross, 2001; Thomson, 2004; Hatfield et al., 2018; Russo et al., 2021; Page & Williams, 2022). The numerous worker bees from the hives can chase other bees away from floral patches and exhaust its pollen and nectar supplies. A single honey bee colony has been shown to have significant impacts on the surrounding bee community (Goulson, 2003; Cane & Tepedino, 2016; Bommarco et al., 2021). Honey bees are not the only introduced species that is cause for concern. *Osmia taurus* is a spreading introduced bee in North America. It is known to aggressively outcompete native *Osmia spp.* for floral resources and nesting sites (MacIvor et al., 2022). Other introduced bees with known competitiveness with native bees include *Osmia cornifrons, Anthidium oblongatum, Anthidium manicatum*, and *Megachile rotundata* (Goulson, 2003; LeCroy et al., 2020; Russo et al., 2021). Introduced bees also have the ability to spread introduced diseases into native bee populations (Colla et al., 2006; LeCroy et al., 2020; Russo et al., 2021; Colla, 2022).

Current Restoration Practices

Restoration and conservation of pollinator habitat is being brought to the forefront of conservation efforts in recent years. The literature suggests major conservation methods for urban settings are pollinator gardens and for landscape settings meadow and tallgrass prairie restorations (Moncada, 2003; Hopwood, 2008; Rutgers-Kelly & Richards, 2013; Tonietto & Larkin, 2017; Majewska & Altizer, 2018; Baldock, 2019; Sexton & Emery, 2020; Turo et al., 2020). Pollinator gardens involve the planting of pollinator friendly plants in a garden patch (often meadow species) or a rain garden (wetland and wet meadow plants). These are often small in size, and the diversity of the plant community is highly variable depending on construction. Success of these gardens can also be correlated with maintenance and flower selection. (Corbet et al., 2001; Johnson et al., 2017; Horstmann, 2021). The most common route for land managers is to create meadow or tallgrass prairie habitat on their managed lands for pollinators. These habitats are believed to provide the best suited habitat for pollinators and their conservation and restoration on the landscape (Hopwood, 2008; Winfree, 2010). Although meadows and prairies do provide high quality pollinator habitat, there are many other types of ecosystems that are not typically considered or addressed in the conservation planning process. Lesser studied and surveyed habitats such as wetland marshes, swamps, and forests could provide additional refuge to pollinators. More research is needed on the impacts of these habitats to determine their significance. Current restoration practices may be missing key pieces required for successful overall restoration efforts by not considering additional habitats.

Landscape Complexity and Bee Communities

Studies have shown that bee diversity is often tied to the diversity of the habitat surrounding a given population (Bukovinszky et al., 2017; Earaerts et al., 2022). This is true for natural systems and human impacted/derived systems, such as agricultural fields or hydro corridors (Otieno et al., 2015; Carrie et al., 2017; Galpern et al., 2021). When diversity from landscapes is removed through habitat fragmentation and increased edge effects pollinator communities suffer and bee diversity decreases (Olynyk et al., 2021). Bumble bees (*Bombus sp.*) are particularly susceptible to losses in landscape complexity and can result in negative effect to life history traits (Persson et al., 2015). Regional approaches to community studies and the need to value the potentially greater impacts of landscape over the smaller scale impacts of individual sites is of critical importance (Steffan-Dewenter, 2002). However, few studies of this scale have been completed for bee communities (Cane, 2001; Steffan-Dewenter, 2002; Otieno et al., 2015; Coutinho et al., 2018). Restoration efforts that focus on single site scales, without considering the broader landscape, have had mixed success (Scheper et al., 2015). A greater diversity of habitats on the landscape leads to greater resource availability and diversity in both floral resources and nesting resources (Benton et al. 2003; Miljanic et al., 2019). The impacts of present landscape heterogeneity on a bee community are driven by the connectivity of individual site habitat quality to the landscape. High quality habitats must be present on the landscape for heterogeneity to have the greatest impact (Ballare et al., 2019). Increasing the amount of natural cover on the landscape will in turn benefit the community of bees present in the area (Scheper, 2015; Bukovinszky et al., 2017). These restorations must connect individual site enhancements with the broader landscape to work effectively (Bukovinszky et al., 2017). Restorations should look to increase landscape heterogeneity, over enhancing common features on the landscape (Ballare et al., 2019; Miljanic et al., 2019).

Forgotten Pollinators

Bees get most of the public's attention when it comes to pollination and beneficial insects. Wasps are often maligned and treated as pests and nuisances. Wasps can also be excellent pollinators and will visit flowers for nectar and pollen resources. Most wasps are predatory in nature. They parasitize insects to provision their nests with and raise their young. Pollination in most wasp groups is accidental (Committee on the Status of Pollinators in North America, 2007; Brock et al., 2021; Kratzer, 2022). The effectiveness of pollination by wasps can be determined by the hairiness of the species, as well as its size and how often it visits flowers. Wasps with more hair, such as *Vespula sp.*, are better at pollinating due to pollen grains getting stuck in their hair. The largest and one of the primary groups of pollinating wasps is the Aculeate wasps, which includes the families Ampulicidae, Bethylidae, Chrysididae, Crabronidae, Dryinidae, Mutillidae, Pompilidae, Scoliidae, Sphecidae, Thynnidae, Tiphiidae, and Vespidae (this group also includes ants (Formicidae) and bees (Anthophila)) (Brock et al., 2021). These wasps are generalist pollinators. Hundreds of plant-pollinator interactions have been recorded in wasps (Brock et al., 2021). The importance of this pollination on the environment varies, but in certain environments it can be incredibly significant. In some instances, wasps were found to be of equal or even greater pollination benefit than bees in both natural and agricultural environments (Aluri, Reddi & Das, 1998; Hallett et al., 2017). Overall, the maligned wasp deserves recognition as an important pollinator, not a pest. Additional research and public awareness is needed to encourage studies on this topic.

Ontario Bee Communities

Numerous studies have assessed the bee communities of Ontario and what species are present across the province (Fye, 1972; MacKay & Knerer, 1979; Grixti & Packer, 2006; Colla & Dumesh, 2010; Richards et al., 2011; Pindar, 2013; Rutgers-Kelly & Richards, 2013; Onuferko et al., 2015; City of Toronto, 2016; Fredenburg, 2020). The Ontario Ministry of Natural Resources and Forestry (MNRF) keeps a list of all confirmed bee species in the province and their assigned conservation (S) rank (Natural Heritage Information Centre, 2022). From these records, and many others, over 400 species of bee belonging to 6 different families have been identified in Ontario. Even with extensive pollinator research and surveys completed in Ontario data gaps and under surveyed areas persist. One such area is the City of Hamilton, covering the historic areas of Dundas, Ancaster, Flamborough, Stoney Creek, Glanbrook, Hamilton, and the County of Wentworth.

Hamilton Bee Communities

The bee community in Hamilton, like many regions of Ontario, have had few studies completed on them. Occasional collections and species records have been collected by researchers or citizen scientists (GBIF, 2022), but few large scale survey projects have been conducted. The only surveys that were identified were a study on Royal Botanical Gardens land by Andrachuk (2014), a 2015-2018 study by MOECP (2020), looking at bumble bees (*Bombus sp.*) at select sites in Hamilton, and a study by Irazuzta (n.d.), looking at the impacts of prairie restoration on bees in the Dundas Valley. Present data should be treated cautiously and does not necessarily represent the entire geographic region of the City of Hamilton. Research in such a high biodiversity area could be enhanced through additional survey work in other localities and habitats. Without proper data on what species are present and where they occur, conservation programs and land managers cannot effectively protect this vulnerable group of insects.

Thesis Objectives

The objectives of my research were to determine how landscape complexity interacts with bee and wasp populations and how do these population change seasonally and by sex in their habitat use. The purpose of this was to determine if the landscape use and life history of the pollinator communities align with current restoration practices. Differing results would indicate a need to adapt the current practices related to pollinator conservation and restoration. By looking at phenology of the same taxa in different habitat, by sex, I will have a more dynamic view of bees in the landscape and how they interact with it. Many studies have established how landscape complexity is important, but few have looked at why it is important for specific taxa. Additionally, I hoped to contribute to the pollinator research of the Hamilton area and to improve the knowledge of what species are present. Five habitat types, fields, forest edges, forests, forested springs, and wetlands, were selected to survey the vegetation, wasp, and bee communities to assess spatial and temporal variation in populations of of bee species, and bee and wasp genera. The following questions were proposed:

1) How do floral resources change on the landscape and is this tied to temporal or habitat variables?

2) Do wasp communities follow similar patterns to bee communities?
3) Do the 10 focal species use the surveyed habitat types differently and does this show any preferences or specializations?
4) Do male and female bees utilize the same habitats and at the same time?
5) Is there suggested movement of bee populations on the landscape and is this tied to temporal patterns?

METHODS

Study sites

Fourteen sites were selected to survey bee and wasp populations within the Dundas Valley in Hamilton, Ontario in 2020 (Figure 1). All of these sites were located either on the campus of McMaster University (6 sites) or at the Ne:toh ho gyo’tgo:t egahado:do’k - Maam-pii naksin m’tigwaaki pane - McMaster Forest Nature Preserve (MFNP) (8 sites). An additional six sites were surveyed in 2021, but were not included in the final analysis due to time constraints. I selected four major habitat types were selected to survey: forests (3 sites), fields/meadows (3 sites), marshes/wetlands (3 sites), and forest edges (3 sites). Forested groundwater fed springs (2 sites) were an additional habitat type that was surveyed as a minor habitat type. A third site for this habitat type could not be found within the research area. The locations of the survey sites were selected based on the availability and ease of access of habitats found within lands owned by McMaster University. Individual sites were at least 0.5 hectares and at least 200 metres apart (Figures 2 & 3). The two major localities, McMaster University and MFNP were located approximately 1.5 kilometres apart (Figure 4) and both are within the McMaster Research and Conservation Corridor. I endeavored to select replicate sites of the same habitat to be similar to each other but as far apart as possible to reduce potential movement of bees and wasps between replicate sites. All lands are found within the Carolinian zone, ecoregion 7E-3.

MFNP is a 46.5 hectare nature preserve owned by McMaster University. It is located in the Dundas Valley at 1105 Lower Lions Club Road, Hamilton, ON. The property was historically forested table and ravine lands, with some wetland features present. The table lands were cleared and converted to agricultural fields in the early 1800's and farming continued on the property until 1954 when the land was sold to a developer. McMaster University acquired the lands in 1964 and 1969 and has retained them ever since. Restoration work conducted in 2014 removed approximately four hectares of European Buckthorn (*Rhamnus cathartica*) and replaced it with native tallgrass prairie species. MFNP is currently comprised of a mosaic of different ecosites, including tallgrass prairie, old field, wet meadow, palustrine marshes and swamps adjacent to creeks, creeks, ravine lands, table lands, shrub thickets, new growth deciduous and mixed forests, and old growth mixed forests. This diversity of ecosites made it a prime location for this study.

McMaster University's main campus is comprised of 102.6 hectares located in Hamilton, Ontario. This includes the central campus area (67.8 hectares) located at 1280 Main Street West, the west campus area (40 hectares) located at 4 Cootes Drive, and additional adjacent properties (3.8 hectares). McMaster University purchased land in this location in 1928 from the City of Hamilton and developers and officially opened its doors in 1930. Lands surveyed for this project were acquired by McMaster University from the Royal Botanical Gardens (RBG) in 1963 (North Campus and part of West Campus) and the City of Hamilton in 1964 (part of West Campus). Natural areas of North Campus include deciduous forests bordered by the developed campus and athletic fields, as well as the lands of Cootes Paradise, a biodiversity 'hotspot' for Canada.

Natural areas of West Campus include deciduous forests, deciduous swamps, forested springs, wet meadows, old fields, creeks, created prairie, conifer plantation forests, and an abandoned rail corridor. West Campus has little overall presently developed land, save for many large continuous parking lots, 3 baseball diamonds, and a few buildings. The area is bordered by housing development to the west and south, Cootes Drive to the north and east, a narrow natural corridor to the southwest and northwest (following upstream of Ancaster and Spencer creeks), Cootes Paradise to the North, and McMaster's Central Campus to the east beyond Cootes Drive. Despite numerous habitat pressures, this area provides a natural connectivity corridor between the urban areas of the historical Town of Dundas and the City of Hamilton.

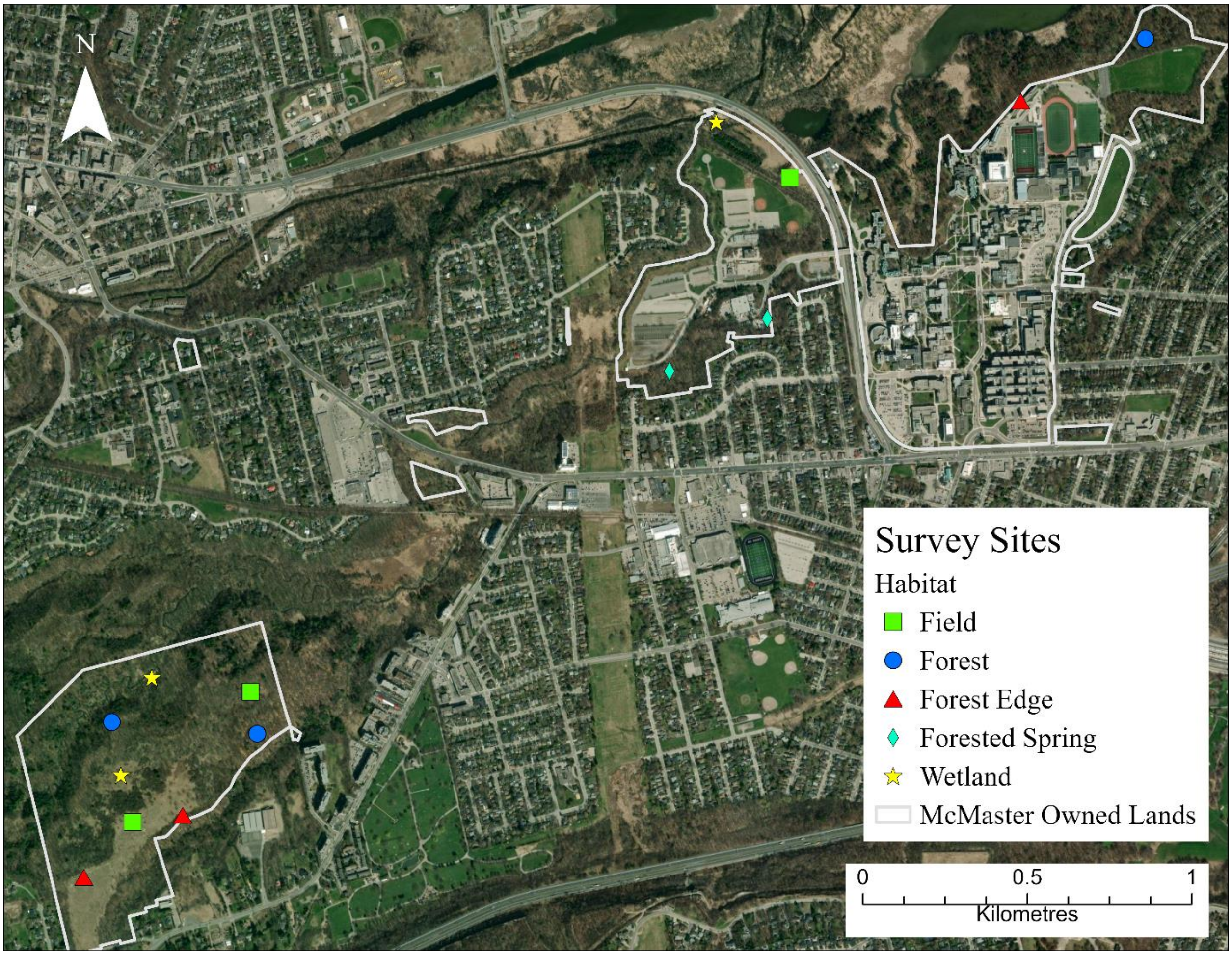

Figure 1: Locations of 14 survey sites across McMaster University's campus and MFNP. Imagery obtained from Esri, Maxar and Earthstar Geographics.

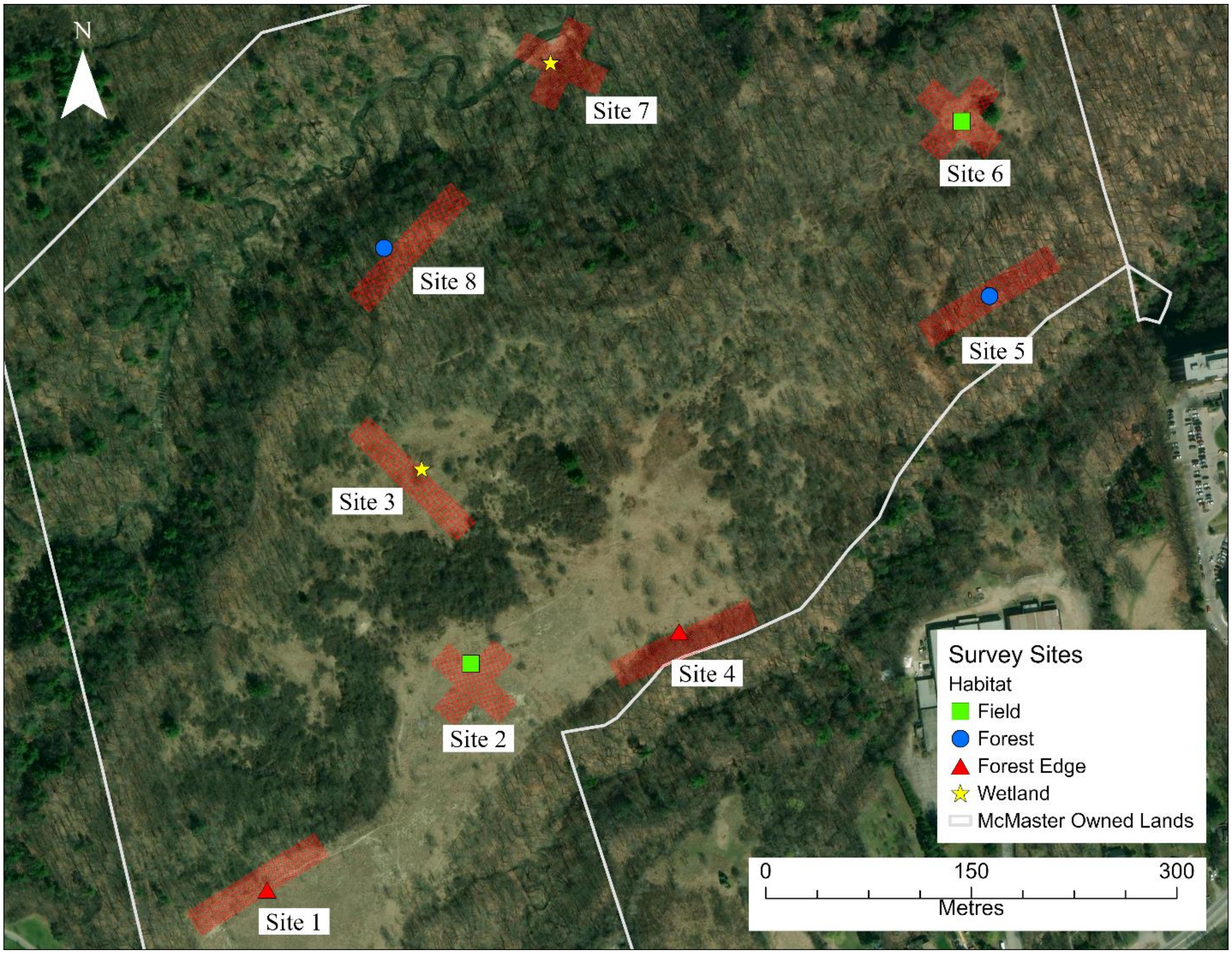

Figure 2: Location of sites 1-8 at MFNP. Red shading indicates the site boundaries used for vegetation, floral, and insect surveys. Imagery obtained from Esri, Maxar and Earthstar Geographics.

Figure 3: Location of sites 9-14 at McMaster University’s campus. Red shading indicates the site boundaries used for vegetation, floral, and insect surveys. Imagery obtained from Esri, Maxar and Earthstar Geographics.

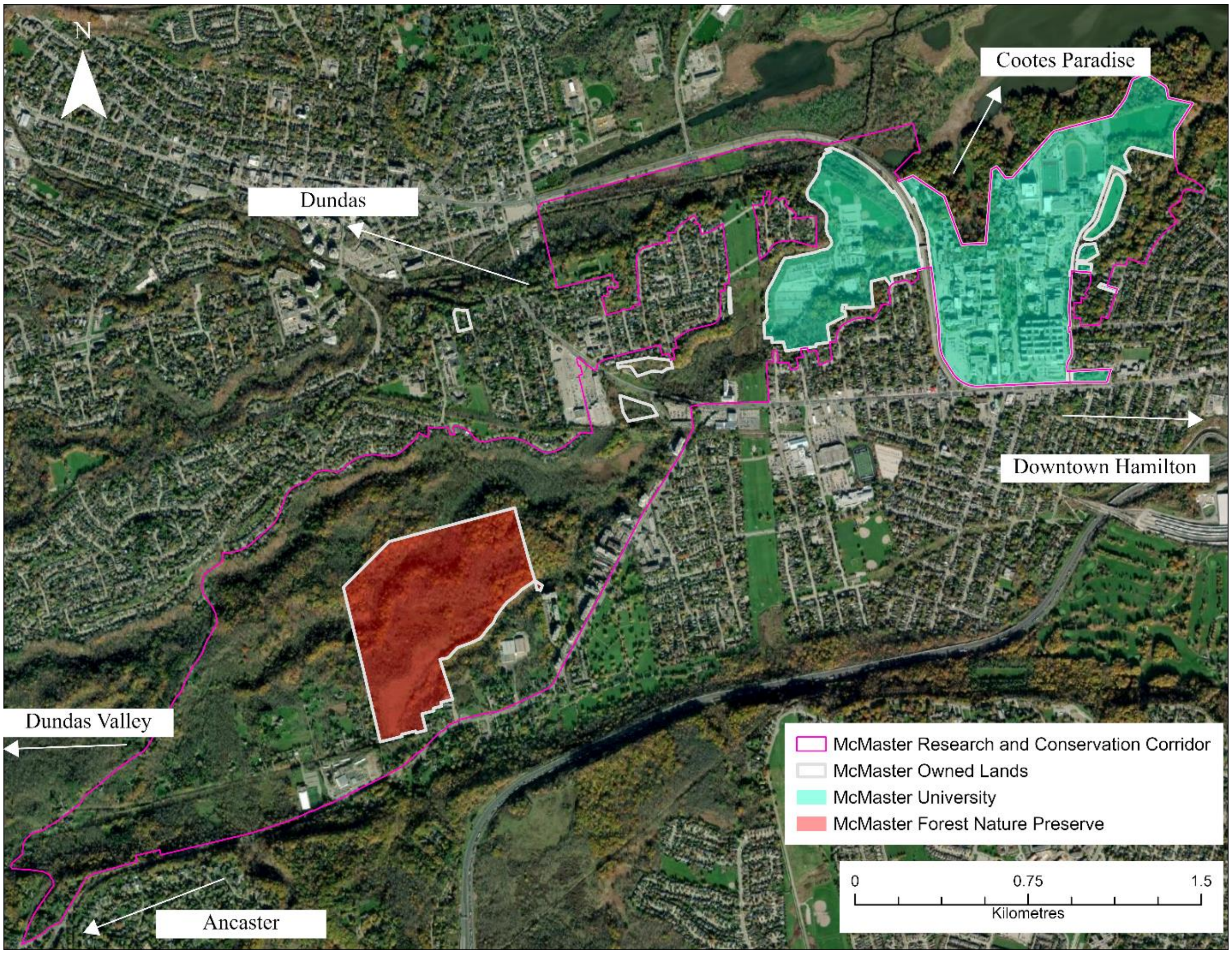

Figure 4: McMaster Research and Conservation Corridor showing the location of McMaster University's campus and MFNP. Imagery obtained from Esri, Maxar and Earthstar Geographics.

Insect Collections

Bees and wasps were surveyed weekly using a combination of pan traps and vane traps at each of the fourteen survey sites. These two types of traps were used to maximize the sampling effort and increase the potential of catching a wider assemblage of species (McCravy, 2018; Portman et al., 2020; Prendergast, 2020; Tronstad et al., 2021). Surveying occurred from the week of March 23 to the week of November 23, 2020 for a total of 35 weeks. Sampling days were split by locality, with McMaster University and MFNP sites being surveyed on different days within the same week. This was due to the lack of resources and time to survey all sites on the same day. Every effort was made to sample both localities on consecutive days to limit the potential for major fluctuations in weather and temperature. Whenever possible, sites were surveyed on days with optimal weather conditions, when temperatures were above 10-15°C, sunny, and sustained wind speeds less than 20-30km/h. Temperature at time of set up, collection, and daytime maximum, as well as weather, maximum daytime windspeed, and average windspeed during set up and collection were recorded on each sampling date.

Pan traps used consisted of 3.25 oz New Horizons Supported Services Inc. 'Bee Bowls' (New Horizons Supported Services Inc., n.d.) painted in fluorescent yellow, white, or blue. Vane traps used consisted of 64 oz Springstar blue or yellow vane traps (SpringStar, 2020). 30 pan traps (10 blue, 10 yellow, 10 white) and 4 vane traps (2 blue and 2 yellow) were set out at each site every week. Pan traps were filled approximately ¾ of the way and vane traps approximately ⅓ of the way with a mixture of water and unscented dish soap (approximately 10 drops of Nature Clean® fragrance free dish soap per litre of water). Pan traps were placed approximately 3 metres apart along either a single straight transect, a single arced transect, or across two diagonal transects forming an 'X' shape (NSERC-CANPOLIN, 2009; Droege, S., 2015). Different placements were necessary depending on the unique geographic constraints of individual sites. Pan trap colour was kept in a consecutive pattern of blue-white-yellow. Vane traps were evenly spaced across the straight transect (approximately 30 metres apart), or for 'X' shaped sites, placed at each end of the transects. Transect length was approximately 90 metres for straight/arced transects and two approximately 45 metre crossed transects for the 'X' shaped sites. Transects were placed in the centre of each site to limit any edge effects. Pan traps were placed on flat ground with vegetation stamped down around each pan trap to avoid any obstruction. Vane traps were hung from tree branches or on plastic posts approximately 1 metre off the ground. Traps were set between 7:30am and 12:00pm, left out for approximately 7-8 hours, and subsequently collected between 3:00pm and 8:00pm. Set up and collection times varied depending on daylight hours and optimal conditions. All invertebrates caught were placed in 50mL Falcon™ centrifuge tubes and filled with 70% ethanol. Vane trap and pan trap samples were kept separate for each site.

Insect Processing

Collected insects were processed in a laboratory setting. This involved straining collected insects of ethanol and sorting out the Hymenopterans (less Formicidae). Hymenopterans were rinsed with tap water for 1 minute in order to remove ethanol from hairs. Non-hymenopteran bycatch was stored for future study. Sorted Hymenopterans were subsequently dried and pinned using established entomological protocols. Pinned specimens were then labelled with a unique database code as part of the Dudley Lab Entomological Collection (MACBio) database. All specimens were subsequently deposited and maintained within the McMaster University Insect Collection (BDMU).

Insect Identifications

Due to the time constraints of this project, not all specimens collected were identified to the species level. Wasps were primarily identified to the family level using Goulet and Huber (1993), although some groups (especially those within the family Vespidae) were able to be further identified (Bradley, 1917; Heinrich, 1960; Heinrich, 1961a; Heinrich, 1961b; Parker, 1962; Wharton et al., 1997; Bohart & Kimsey, 1979; Buck et al., 2008; Ascher & Pickering, 2020). Bees were primarily identified to the genus level using Packer et al. (2007). Ten focal bee species belonging to six genera (Table 1) were chosen to identify to species due to their ease of identification and relative abundance. Bees were identified using a variety of sources (Rehan & Sheffield, 2011; Portman et al., 2022). These species were the 10 most abundant amongst identified species. However, these 10 species may not represent the actual most abundant species as some abundant genera, such as *Lasioglossum* and *Andrena*, not being identified. A variety of other sources were consulted when further identifying other groups of bees (Laverty & Harder, 1988; Romankova, 2003; Buck et al., 2005; Romankova, 2007; Gibbs, 2010; Sheffield et al., 2011; Dumesh & Sheffield, 2012; Williams, 2014; Onuferko, 2017; Arduser, 2019; Ascher & Pickering, 2020; Gardner & Gibbs, 2021).

Table 1: List of 10 focal bee species selected for identification and further analysis

Family	Genus	Subgenus	Species	Authority	S Rank	Nesting
Apidae	*Apis*	*Apis*	*mellifera*	Linnaeus, 1758	SE	Hive Box
Apidae	*Ceratina*	*Zadontomerus*	*calcarata*	Robertson, 1900	S5	Stem-carpenter
Apidae	*Ceratina*	*Zadontomerus*	*dupla*	Say, 1837	S5	Stem-carpenter
Apidae	*Ceratina*	*Zadontomerus*	*mikmaqi*	Rehan and Sheffield, 2011	S5	Stem-carpenter
Apidae	*Ceratina*	*Zadontomerus*	*strenua*	Smith, 1879	S3S4	Stem-carpenter
Halictidae	*Agapostemon*	*Agapostemon*	*virescens*	Fabricius, 1775	S5	Ground
Halictidae	*Augochlora*	*Augochlora*	*pura*	Say, 1837	S5	Wood-cavity excavator
Halictidae	*Augochlorella*	*aurata group*	*aurata*	Smith, 1853	S5	Ground
Halictidae	*Halictus*	*Seladonia*	*confusus*	Smith, 1853	S5	Ground
Halictidae	*Halictus*	*Odontalictus*	*ligatus*	Say, 1837	S5	Ground

Vegetation and Floral Surveys

All 14 sites were surveyed for plant abundance and diversity to assess similarities and differences across sites and habitats. The vegetation community of each site was surveyed once between June 16 and August 1st. In each site, I randomly sampled 25 1-metre square quadrats (1 metre x 1 metre). Sites were defined with a 10-metre buffer around the transects used for insect collections, stratified by subareas within each site. The strata of each site were divided roughly every 22 metres across the site, with quadrats being selected within the strata using a random number generator. This resulted in a 110 metre by 20 metre rectangular grid for sites with a straight transect. I quantified vegetation cover using the Daubenmire (1959) cover class method, which estimates cover between <1%, 1-5%, 6-25%, 26-50%, 51-75%, 76-95% and >96% cover (Brown & Bugg 2001). All vegetation layers were scored additively by species, including groundcover, shrub layer, and canopy layer. The percentage of bare ground and any open water were also recorded. Total coverage was allowed to exceed 100% due to overlapping vegetation. Vegetation was identified in field and where this was not possible voucher specimens were collected for each unique species. Plants were identified using a variety of print and digital sources (Newcomb, 1989; Royer & Dickinson, 1999; Hallowell, 2001; Harris & Harris, 2001; Voss & Reznicek, 2012; Farrar, 2017; Native Plant Trust, 2022). Once all quadrats had been surveyed, I walked through the site and noted any additional species not found within the quadrats.

Floral surveys were conducted across all fourteen sites every week for the 35 weeks of insect sampling. Surveys recorded the species of flowering plants present at each site and their abundance. Floral abundance was scored by counting the number of individual flowering stems/plants present across the site to a maximum of 1000+ individuals. All species were scored equally, irrespective to size, plant type (forb vs. grass vs. shrub vs. tree), or number of flowering heads. A 10 minute walkthrough of the site was conducted to estimate the floral resources present. All flowering plants were recorded, including trees, shrubs, vines, forbs, grasses, and sedges. Grasses and sedges may be viewed as an atypical source of pollen, but many studies have shown that bees will utilize the resources that are present on the landscape, including grasses when they are flush with pollen (Terrell & Batra, 1984; Rivernider et al., 2017; Hall et al., 2021;

Siede et al., 2021; Wilson et al., 2021; Pound et al., 2022). Canopy trees were recorded when visible. Floral estimates in the spring may be underscored due to difficulty in viewing the canopy.

Calculations and Summations

Total bee and wasp abundance was calculated for each site and for each habitat type. Weekly counts were obtained by taxa (bees and wasps) for richness and abundance, with wasps being identified further to family and bees to genus. The 10 focal bee species selected were assessed for species abundance. These abundance and richness values were obtained by summing the total catches of all vane traps and pan traps for each site. Other factors such as number of cleptoparasitic bees and wasps, number of male vs female bees and wasps, and the number of bees/wasps with parasites on them were also recorded and summed for each site.

To calculate vegetation abundance and richness across all 14 sites the cover classes were assigned a value based on the midpoint of the class (0-1% = **0.5%**, 1-5% = **3%**, 5-25% = **15%**, 25-50% = **37.5%**, 50-75% = **62.5%**, 75-95% = **85%**, 95-100% = **97.5%**) (Daubenmire 1959; Brown & Bugg 2001). The total abundance/coverage and richness were further defined as native and non-native species. The coverage and richness across all 25 quadrats were summed for each site to create an average site vegetation coverage and richness. Species recorded as part of site walkthroughs (not present in quadrats) were included in the total site species richness and coverage. They were assigned a coverage rank of 0.5%, indicating they are present but in low abundance. Total vegetation coverage and individual native species coverages were used in the calculation of a floristic quality index (FQI) for each site.

FQI was calculated using $FQI = [\ \sum(Cover_i \times CC_i) / \sum(\text{Total Cover})\ ] \times 10$ (USGS, n.d.), a modified version of Swink & Wilhelm (1979), original equation. This modified equation takes into account the abundance of an individual species compared to the total vegetation abundance, whereas Swink & Wilhelm (1979), only looks at the presence of an individual species, not its abundance. $Cover_i$ is the summed cover of an individual species across all 25 quadrats, CC_i is the coefficient of conservatism of a given species as set by the Ontario Ministry of Natural Resources and Forestry's (MNRF) Natural Heritage Information Centre (NHIC, 2022), total cover is the total summed cover of all vegetation at a given site. Non-native species cover scores a zero in this calculation, but it is used in the calculation of total cover. Any species that could not be identified was excluded from these calculations.

Floral surveys were summed by week for total weekly floral resources across the McMaster Research and Conservation Corridor by habitat type, and by site. Total floral resources were further divided into native floral resources and non-native floral resources. A weekly approach was chosen to view seasonal variation in greater detail.

Statistical Analyses

Statistical analyses for this project were all conducted in R version 4.2.1 (R Core Team, 2022). Floristic Quality Index (FQI) calculations were completed in Microsoft Excel.

Vegetation survey data was used to determine the similarity and differences across different sites and habitats. To identify differences between sites I created hierarchical clustering dendrograms and calculated a weighted diversity index of Floristic Quality (FQI). Using the vegdist() function with the Bray-Curtis dissimilarity method, the distance between each of the 14 sites was determined, as it related to vegetation quadrat similarities in the R package "dendextend" (Galili, 2015). The hclust() function was then used with the "complete" method to group the sites into six distinct clusters. A dendrogram and cluster plot were then made to visualize the data. To better visualize these clusters, the fviz_cluster (Kassambara & Mundt, 2020) function was used with the "factoextra" package (). FQI values and the average for each site were plotted using the geom_boxplot() function in R package "ggplot2" (Wickham, 2016).

Floral resource abundance, flowering floral richness, wasp abundance, and bee abundance were visualized through stacked area plots. Linear and GAM models were used to look for significant differences in the communities and habitats over time. Using the geom_area() function in R package "ggplot2" (Wickham, 2016) stacked area plots were created for native/introduced floral abundance, native/introduced floral richness, total wasp abundance and total bee abundance. Summed totals of site values for each of the 5 habitat types were used for these plots. A linear model of the log abundance of bees and wasps compared with habitat and sex were conducted using the lm() function. The base model used was lm(log(Abundance+1)~Species*Habitat*Sex)). Habitat was made a factor. The function emmeans(lm, ~Species:Habitat) was then plotted. An analysis of variance (ANOVA) with a type III sums of squares was completed to test for the significance of these interactions using the R package "car" (Fox & Weisberg, 2019). Additionally, GAM models were created for each target bee species (one model for each sex), for floral abundance (defined as native and introduced), for floral richness (defined as native and introduced), and for wasp abundance (for the top 7 families). In all models the dependent variable was the number of individuals in a given week, taxa, sex and habitat, summed over replicate sites. The independent variables were habitat (factor), sex (factor), species (factor), week(continuous variable), and their interactions. The interaction model gam(y ~ Habitat + s(Week, by=Habitat) function was used to create these models using the R package "mgcv" (Wood, 2011). The main effects model (gam(y ~ Habitat + s(Week))) was compared with the interaction model using the AIC() function to ensure that the interaction model improved model performance. The GAM models were further modified to ensure that they were "wiggly" enough (ensuring that the model fits the data well) using the k.check() function. All GAM models were assigned a k value (the number of basis functions used to create the smooth function) of 30 according to this test. Final models were then plotted using ggplot().

RESULTS

Site Vegetation Composition and Similarities

Clear differences in the vegetation communities of the five target habitats were observed (Fields, Forests, Forest Edges, Forested Springs, and Wetlands). In the cluster analysis of my 14 sites looking at vegetation quadrat surveys, 6 distinct site groupings were identified. Sites that were close geographically were not necessarily clustered more closely together. Additionally, sites from the same habitat types did not always cluster together (Figure 5 and Figure 6). The two Forested Spring sites (Site 13 and Site 14) had distinctly different vegetation communities, even though they were geographically close together and of the same habitat. In contrast, Site 2 (Field) and Sites 1 and 4 (Forest Edge) clustered together. These sites were geographically close and represented two different habitat types. At least two of the three habitat replicates clustered close together amongst the remaining 12 sites.

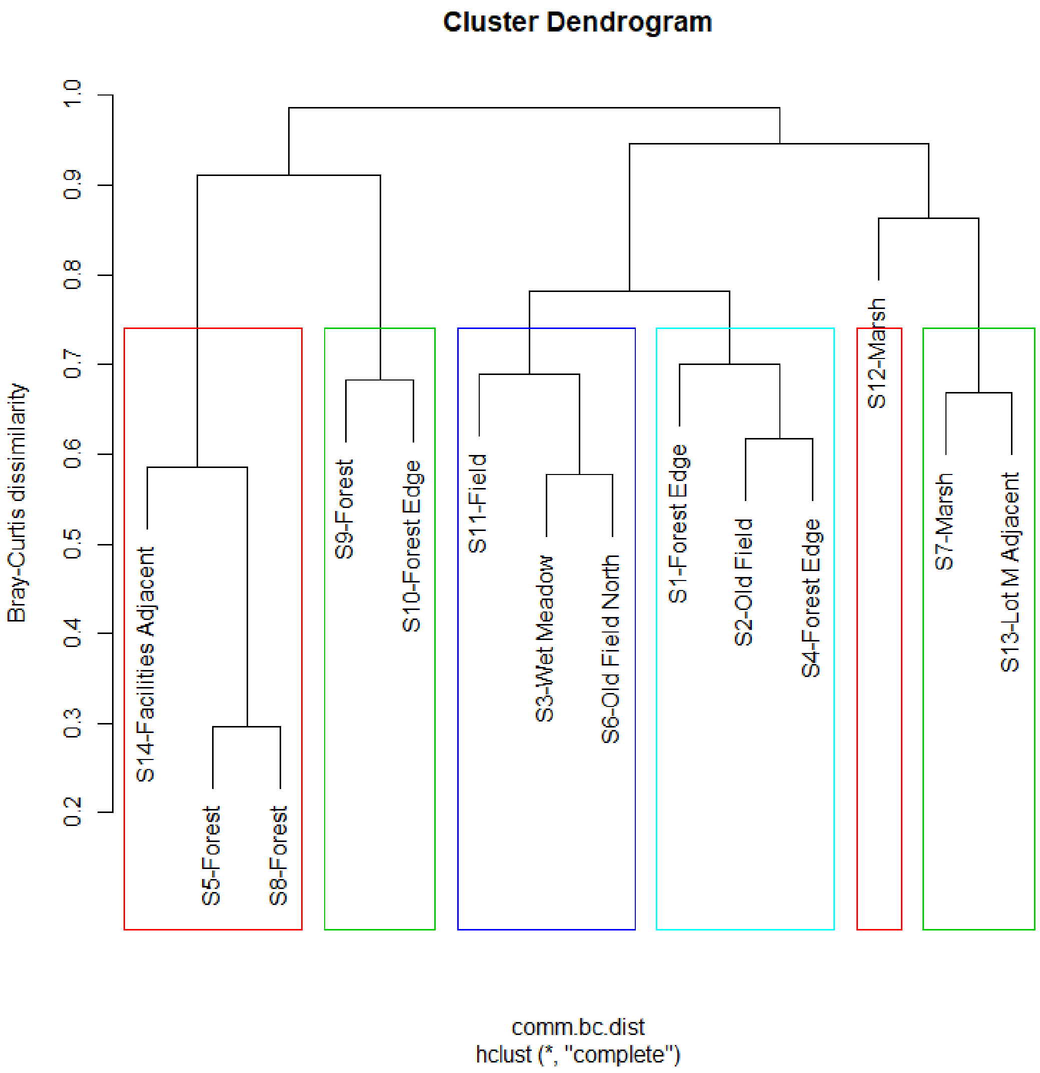

Figure 5: Clustering of 14 surveyed sites showing relatedness/similarity. Five habitat types were surveyed: Fields (S2, S6, and S11), Forest Edges (S1, S4, and S10), Forests (S5, S8, S9), Forested Springs (S13 and S14), and Wetlands (S3, S7, and S12). Sites were clustered using a Bray-Curtis dissimilarity matrix calculated using the Complete method and vegetation species abundance data. Data obtained from surveyed vegetation quadrats between June and August 2020.

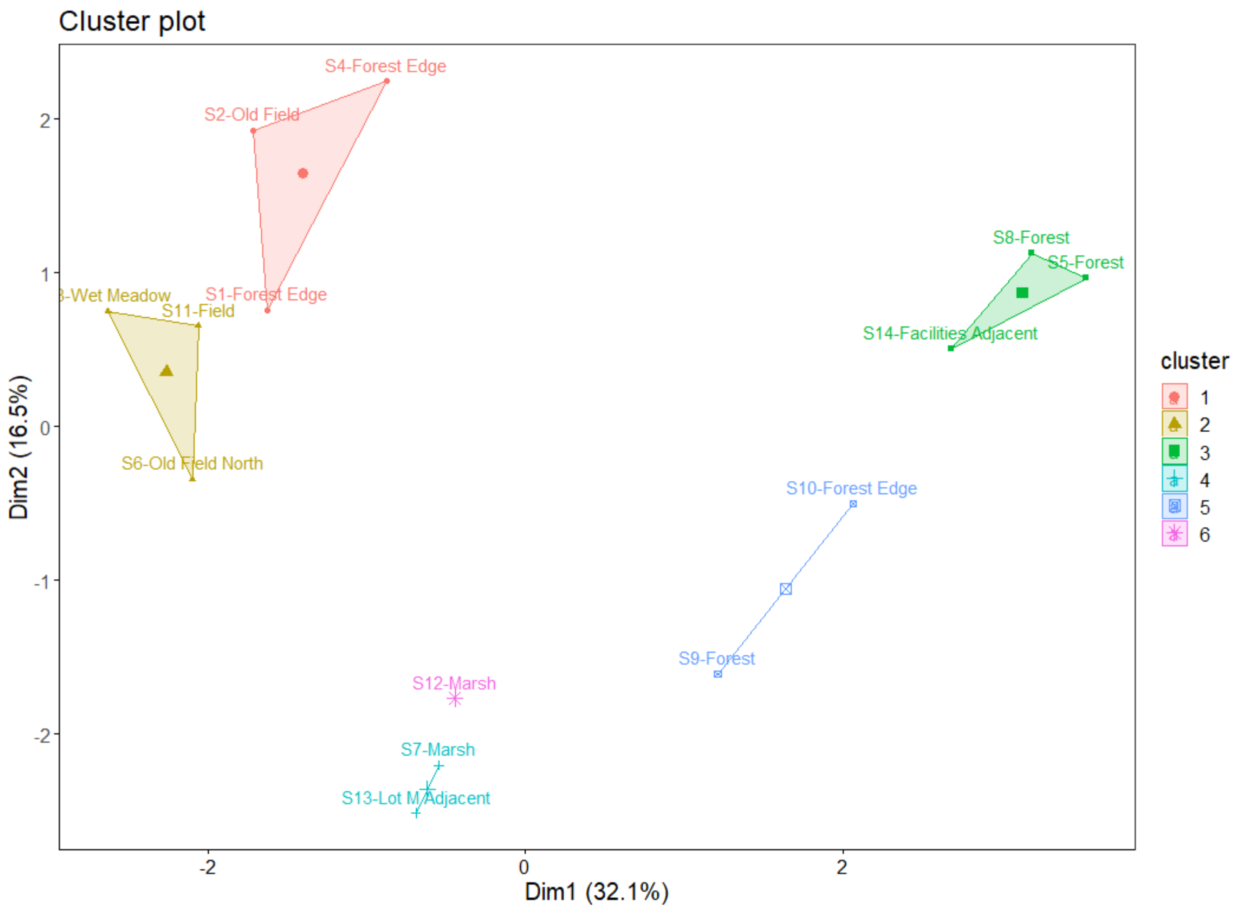

Figure 6: Visualized clustering of 14 surveyed sites showing relatedness/similarity. Five habitat types were surveyed: Fields (S2, S6, and S11), Forest Edges (S1, S4, and S10), Forests (S5, S8, S9), Forested Springs (S13 and S14), and Wetlands (S3, S7, and S12). Sites were clustered into subgroups using a Bray-Curtis dissimilarity matrix calculated using the vegetation species abundance data. Data obtained from surveyed vegetation quadrats between June and August 2020.

Habitat floristic quality and vegetation makeup varied greatly across all 14 sites. The 5 habitats differed in species richness (Figure 7). The Wetland sites were found to be the most speciose habitat (an average species richness of 120), followed by Forest Edge (105), Forested Spring (94), Field (89), and Forest (76). The 10 most abundant plant species for each site varied and were not consistent in %cover between related habitats (Tables 2-6). Floristic quality was not consistent across all habitat types (Figure 8 and Table 7). Forest sites 5 and 8 had similar scores, but site 9 was more than 10 points lower. Forest Edge sites were more consistent, being less than 10 points difference between them. The two Forested Spring sites varied by more than

10 points as well. Field sites 2 and 11 had similar floristic quality values, whereas site 6 was more than 10 points greater. Wetland sites had the greatest variation in floristic quality, with site 7 being the greatest (35.63), followed by site 3 (20.12) and site 12 (8.77). The average FQI scores for each habitat area as follows: Forests (39.02), Forested Springs (31.11), Forest Edges (26.62), Wetlands (21.51), and Fields (17.12).

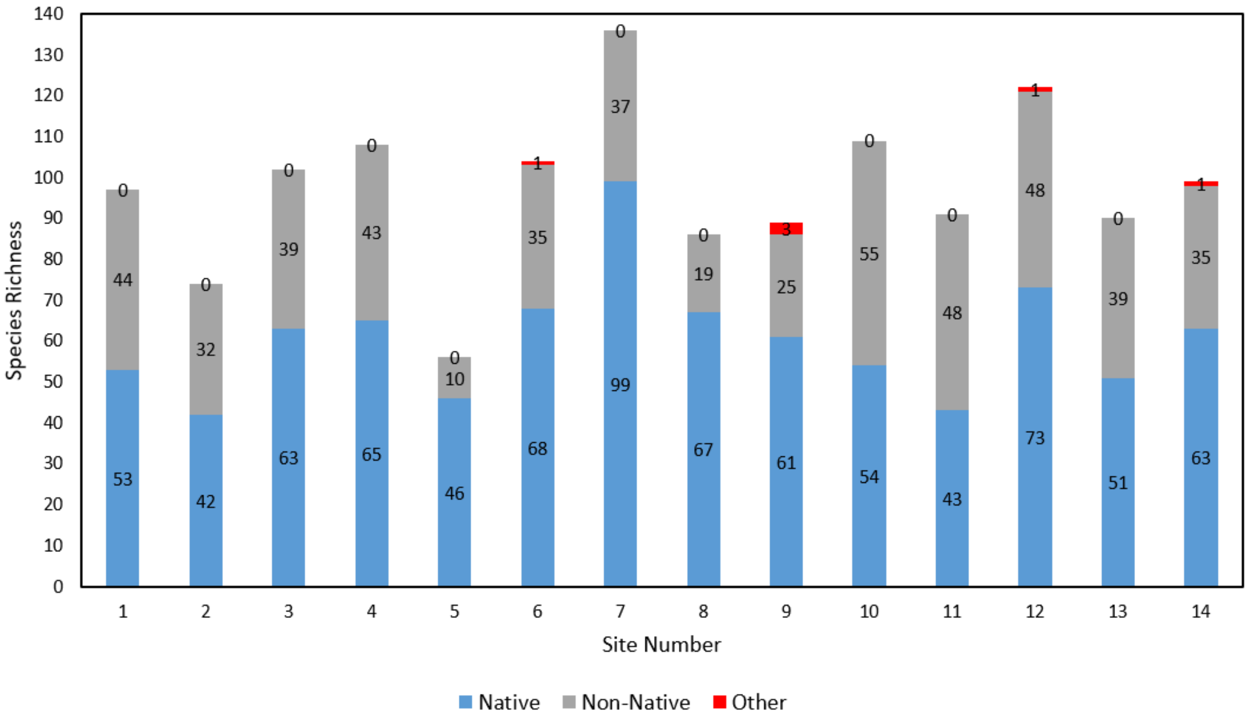

Figure 7: Total species richness across all surveyed sites. Data obtained from surveyed vegetation quadrats.

Table 2: The top ten most abundant species by percent cover for each Field site. CC = Coefficient of Conservation. CF = Coefficient of Wetness

Field														
Site 2					Site 6					Site 11				
Species	% Cover	S Rank	CC	CF	Species	% Cover	S Rank	CC	CF	Species	% Cover	S Rank	CC	CF
Lotus corniculatus	**21.72**	**SNA**		**3**	Rubus occidentalis	36.4	S5	2	5	**Lolium pratense**	**29.52**	**SNA**		**3**
Poa pratensis	**20.64**	**SNA**		**3**	**Poa pratensis**	**29.46**	**SNA**		**3**	Acer saccharinum	27.52	S5	5	-3
Carex granularis	12.12	S5	3	-3	Solidago altissima	15.58	S5	1	3	**Poa pratensis**	**20.66**	**SNA**		**3**
Rhamnus cathartica	**11.14**	**SNA**		**0**	Monarda fistulosa	15.44	S5	6	3	**Lolium arundinaceum**	**15.52**	**SNA**		**3**
Lolium arundinaceum	**8.34**	**SNA**		**3**	Juglans nigra	14.8	S4?	5	3	**Dactylis glomerata**	**14.22**	**SNA**		**3**
Agrostis gigantea	**7.32**	**SNA**		**-3**	Fraxinus americana	10.44	S4	4	3	Vitis riparia	10.82	S5	0	0
Fragaria virginiana	6.36	S5	2	3	Amphicarpaea bracteata	9.96	S5	4	0	Solidago altissima	10.04	S5	1	3
Cornus racemose	5.4	S5	2	0	**Rosa multiflora**	**9.82**	**SNA**		**3**	Juglans nigra	8.4	S4?	5	3
Acer x freemanii	4.24	SNA	6	-5	Rubus idaeus	9.1	S5	2	3	Moss	5.2			
Rosa multiflora	**3.26**	**SNA**		**3**	**Hesperis matronalis**	**4.62**	**SNA**		**3**	Phalaris arundinacea	5	S5	0	-3

Table 3: The top ten most abundant species by percent cover for each Forest Edge site. CC = Coefficient of Conservation. CF = Coefficient of Wetness

Forest Edge														
Site 1					Site 4					Site 10				
Species	% Cover	S Rank	CC	CF	Species	% Cover	S Rank	CC	CF	Species	% Cover	S rank	CC	CF
Crataegus sp.	30.9				*Ostrya virginiana*	32.28	S5	4	3	*Quercus rubra*	74.1	S5	6	3
Rhamnus cathartica	**23.82**	**SNA**		**0**	*Tilia americana*	23.64	S5	4	3	Bare Ground	30.54			
Juglans nigra	21	S4?	5	3	***Poa pratensis***	**21.54**	**SNA**		**3**	***Poa annua***	**23.32**	**SNA**		**3**
Calamagrostis canadensis	17.82	S5	4	-5	***Lolium arundinaceum***	**18.24**	**SNA**		**3**	***Rhamnus cathartica***	**22.64**	**SNA**		**0**
Moss	9.9				***Lotus corniculatus***	**17.32**	**SNA**		**3**	*Acer x freemanii*	19.5	SNA	6	-5
Dactylis glomerata	**8.96**	**SNA**		**3**	*Cornus racemosa*	16.6	S5	2	0	*Fraxinus americana*	18.18	S4	4	3
Lotus corniculatus	**8.46**	**SNA**		**3**	*Acer saccharum*	11.92	S5	4	3	***Alliaria petiolata***	**14.32**	**SNA**		**0**
Solidago altissima	8.22	S5	1	3	*Carpinus caroliniana*	11.7	S5	6	0	***Plantago Major***	**8.44**	**SNA**		**3**
Acer Saccharum	7.84	S5	4	3	*Carya cordiformis*	10.02	S5	6	0	*Prunus serotina*	7.8	S5	3	3
Bare Ground	7.12				*Quercus rubra*	9.54	S5	6	3	Moss	5.16			

Table 4: The top ten most abundant species by percent cover for each Forest site. CC = Coefficient of Conservation. CF = Coefficient of Wetness

Forest														
Site 5					Site 8					Site 9				
Species	% Cover	S Rank	CC	CF	Species	% Cover	S Rank	CC	CF	Species	% Cover	S Rank	CC	CF
Acer saccharum	93.6	S5	4	3	*Acer saccharum*	97.5	S5	4	3	***Alliaria petiolata***	**61.32**	**SNA**		**0**
Bare Ground	83.32				Bare Ground	65.42				*Prunus serotina*	39.44	S5	3	3
Fagus grandifolia	58.5	S4	6	3	*Fagus grandifolia*	14.32	S4	6	3	*Acer x freemanii*	27.8	SNA	6	-5
Quercus rubra	31.2	S5	6	3	*Quercus rubra*	11.7	S5	6	3	*Vitis aestivalis*	22.74	S4	7	3
Prunus serotina	13.36	S5	3	3	*Tilia americana*	11.7	S5	4	3	*Fraxinus americana*	22.32	S4	4	3
Quercus alba	7.8	S5	6	3	Moss	6.56				*Carya cordiformis*	21	S5	6	0
Carex pensylvanica	2.62	S5	5	5	*Ostrya virginiana*	4.26	S5	4	3	*Crataegus sp.*	10.9			
Fraxinus americana	2.28	S4	4	3	*Populus grandidentata*	3.9	S5	5	5	Bare Ground	10.3			
Lapsana communis	**1.34**	**SNA**		**3**	*Tsuga canadensis*	3.9	S5	7	3	*Parthenocissus quinquefolia*	6.12	S4?	6	3
Vitis riparia	0.48	S5	0	0	***Rhamnus cathartica***	**2.78**	**SNA**		**0**	*Galium aparine*	6.04	S5	4	3

Table 5: The top ten most abundant species by percent cover for each Forested Spring site. CC = Coefficient of Conservation. CF = Coefficient of Wetness

Forested Spring									
Site 13					Site 14				
Species	% Cover	S Rank	CC	CF	Species	% Cover	S Rank	CC	CF
Salix euxina	**39**	**SNA**		**0**	*Acer saccharum*	70.2	S5	4	3
Juglans nigra	31.2	S4?	5	3	*Prunus serotina*	39.36	S5	3	3
Fraxinus americana	30.2	S4	4	3	*Symplocarpus foetidus*	36.74	S5	7	-5
Acer negundo	27.54	S5	0	0	*Fraxinus pennsylvanica*	31.44	S4	3	-3
Hesperis matronalis	**13.6**	**SNA**		**3**	Bare Ground	26.34			
Glyceria striata	12.8	S5	3	-5	*Quercus rubra*	19.5	S5	6	3
Rubus occidentalis	11.74	S5	2	5	*Tilia americana*	18.22	S5	4	3
Toxicodendron radicans	10.74	S5	2	0	*Lindera benzoin*	16.2	S4	6	-3
Symplocarpus foetidus	10.1	S5	7	-5	*Juglans nigra*	11.7	S4?	5	3
Cardamine pensylvanica	8.9	S5	6	-3	***Rosa multiflora***	**10.18**	**SNA**		**3**

Table 6: The top ten most abundant species by percent cover for each Wetland site. CC = Coefficient of Conservation. CF = Coefficient of Wetness

Wetland														
Site 3					Site 7					Site 12				
Species	% Cover	S Rank	CC	CF	Species	% Cover	S Rank	CC	CF	Species	% Cover	S Rank	CC	CF
Poa pratensis	**33.3**	**SNA**		**3**	*Juglans nigra*	46.8	S4?	5	3	***Glyceria maxima***	**50.64**	**SNA**		**-5**
Juglans nigra	27.42	S4?	5	3	*Amphicarpaea bracteata*	25.84	S5	4	0	***Salix euxina***	**14.2**	**SNA**		**0**
Cornus racemosa	21.56	S5	2	0	*Fraxinus americana*	21	S4	4	3	*Solidago altissima*	10.64	S5	1	3
Carex spicata	**16.74**	**SNA**		**3**	*Solidago patula*	15.74	S4	8	-5	Open Water	9.4			
Solidago altissima	16.46	S5	1	3	*Phalaris arundinacea*	12.12	S5	0	-3	*Acer negundo*	7.9	S5	0	0
Euthamia graminifolia	11.2	S5	2	0	***Iris pseudacorus***	**11.5**	**SNA**		**-5**	*Phalaris arundinacea*	6.1	S5	0	-3
Calamagrostis canadensis	6.06	S5	4	-5	***Alnus glutinosa***	**10.8**	**SNA**		**-3**	*Fraxinus americana*	5.5	S4	4	3
Poa palustris	5.5	S5	5	-3	***Rhamnus cathartica***	**7.8**	**SNA**		**0**	*Juglans nigra*	4.62	S4?	5	3
Parthenocissus vitacea	5.16	S5	4	3	*Acer saccharum*	7.8	S5	4	3	Bare Ground	4			
Fraxinus americana	4.98	S4	4	3	*Tsuga canadensis*	7.8	S5	7	3	***Bromus inermis***	**4**	**SNA**		**5**

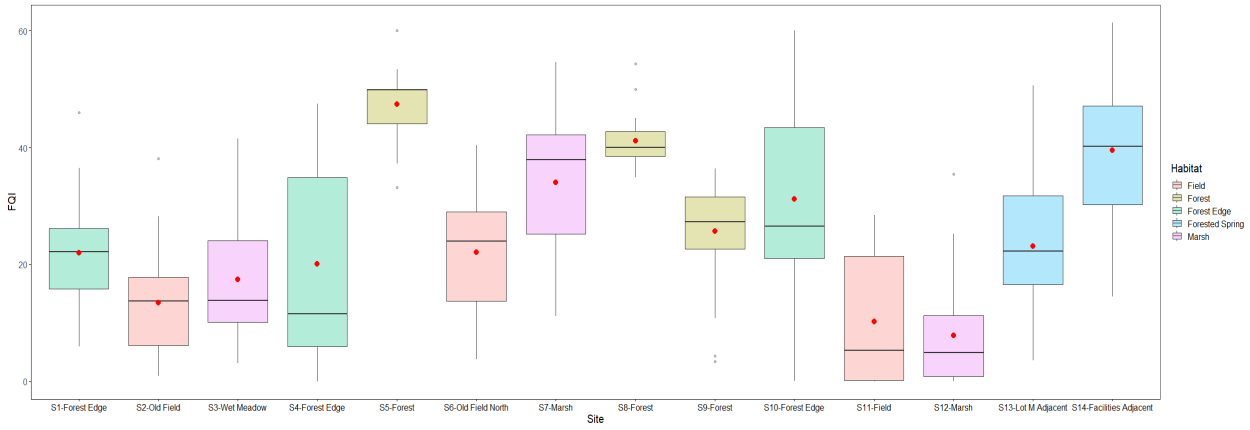

Figure 8: Boxplots of average FQI values across all sites. FQI ranges are across all 25 surveyed quadrats. Red dots indicate average FQI value.

Table 7: Analysis of variance for the differences among Habitats in FQI scores. F and p values are for type III sums of squares.

Parameters	Df	F value	
Intercept	1	98.328	***
Habitat	4	33.753	***
Residuals	359		

Changing Floral Resources

Floral resource availability varied between sites and habitat types over the course of the survey period. The most sustained floral resource availability was found to be in Wetlands and Forest Edge habitats (Figure 9), with all habitats having significantly different resource availabilities (Table 9). Two major peaks in resource availability were observed, one in early-summer (around week 15) and one in late-summer (around week 25). Resource abundance consisted of two peaks, the first and largest peak in early summer (around week 15) and a smaller peak around week 20 in mid-summer (Figure 10). Introduced floral abundance peaked in late spring/early summer (around week 13), with a second smaller peak in mid-summer (around week 19). Native floral abundance was found to have two peak seasons, one small peak in mid-summer (around week 18) and a large peak in late summer (around week 25). Overall, Wetlands had peak floral abundance in late spring and late summer, Forests had peak floral abundance in late spring and late fall, Fields had peak floral abundance in early summer and late summer, Forest Edges had peak floral abundance in early summer and late summer, and Forested Springs had peak floral abundance in late spring and late summer. Total floral resource availability across all habitats starts to increase in the spring and starts to drop mid summer, with resources starting to increase again towards the fall. This leads to bimodal distributions in the floral resources, with native and introduced species making up the majority of each peak independently (Figure 10 and Table 9).

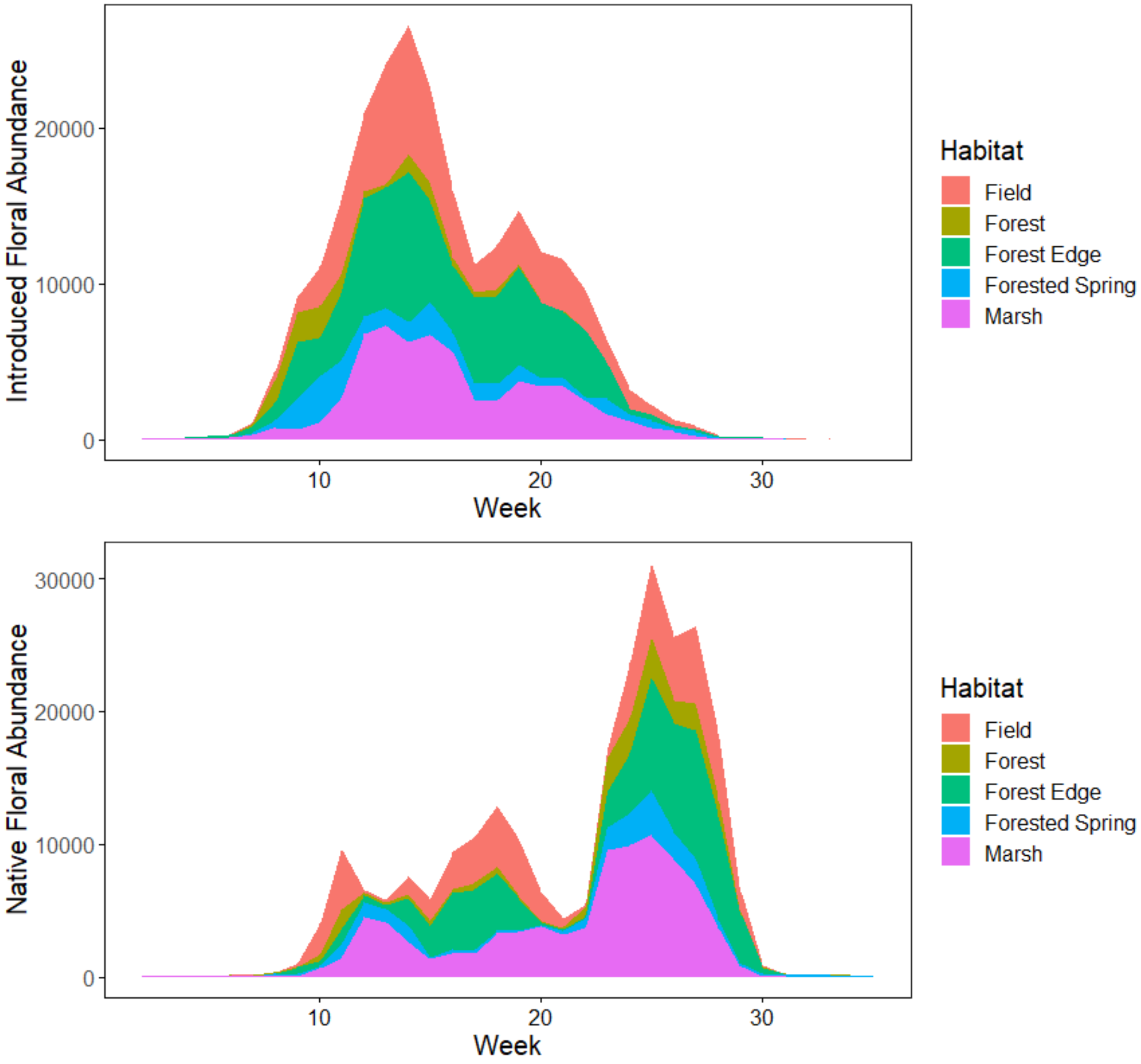

Figure 9: Floral abundance available across all habitats, for native and introduced species, recorded from the end of March (week 1) to the end of November (week 35).

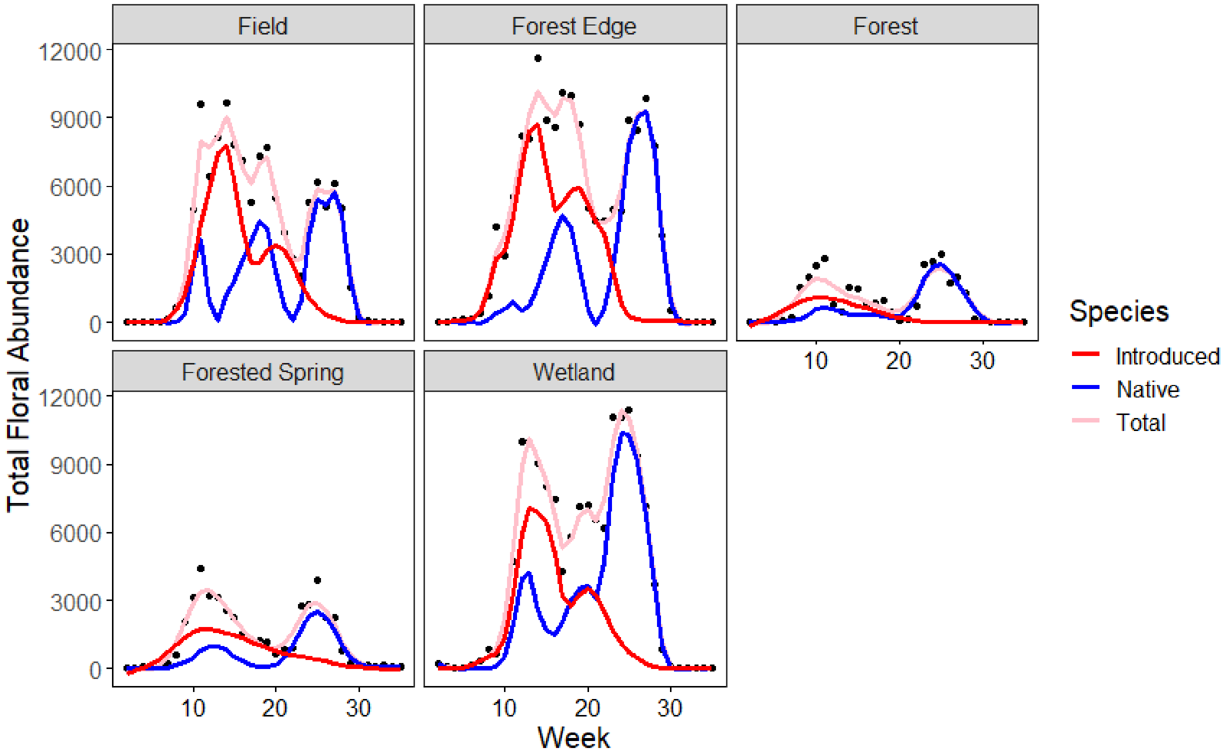

Figure 10: Floral abundance available across all habitats, recorded from the end of March (week 1) to the end of November (week 35). Black dots represent total floral resource abundance recorded each week.

Table 8: Akaike Information Criterion (AIC) test showing that the interactive model is a significant improvement over the main effects model for the three GAM models, Introduced Floral Abundance, Native Floral Abundance, and Total Floral Abundance. Main effects model: gam(Floral_Resource ~ Habitat +s(Week)). Interactive model: gam(Floral Resource ~ Habitat +s(Week, by= Habitat)).

Model	Total Abundance	Introduced Richness	Native Richness
Main Effects	3153.314	3000.595	3061.390
Interaction	2953.309	2796.266	2912.634

Table 9: GAM comparison of the abundance of floral resources recorded in the different habitat types over a 35 week period. This was divided into native resources, introduced resources, and total resources. A k value of 30 was selected to provide a better fit for the models. gam(Floral_Resource~Habitat+s(Week, by=Habitat, k=30), method= "REML")

	Introduced	Native	Total
Habitat	F value	F value	F value
Field	50.281***	29.205***	38.599***
Forest Edge	66.207***	67.643***	58.665***
Forest	5.569***	9.317***	5.359***
Forested Spring	9.891***	8.750***	9.988***
Wetland	46.021***	80.407***	64.265***
Habitat	148.700***	158.400***	241.000***

Floral richness of flowering plants followed a slightly different pattern than that of floral abundance. Introduced floral richness quickly peaked in late spring and then slowly tapered out until late autumn (Figure 11). Introduced species richness was greatest in Wetlands and Forest Edges, followed closely by Fields. Native floral richness had the opposite pattern to that of introduced species. Native floral richness of flowering plants slowly rose to a peak in early autumn and then quickly tapered out in late autumn (Figure 11). There was one small peak of native flowers in late spring. Wetlands had the greatest richness of floral species, followed by Forest Edges and Fields. Across all habitat types introduced species flowered before their native counterparts (Figure 12). Total flowering species richness for Fields followed a bimodal distribution, with peaks late spring (around week 12) and early autumn (around week 28). Total flowering species richness for Forests followed unimodal distribution with richness peaking in early summer (around week 18). Forest Edge floral richness also followed a bimodal distribution, with richness peaking in early summer (around week 15) and late summer (around week 25). Forested Springs followed a unimodal distribution, with total floral richness peaking in late spring (around week 12) and then leveling off until late summer (around week 25) before dropping back down. Wetland total floral richness continued to grow throughout the sampling season, reaching a peak in late summer (around week 25).

Floral resource abundance and flowering species richness did not appear to be correlated with total bee or wasp abundance for Forest Edge, Forested Spring, or Wetland habitats. Total bee and wasp abundances, however, were correlated with floral resource abundance and flowering species richness of Field and Forest habitats (Figure 13). Total bee abundance was directly correlated with both the abundance of floral resources and their richness in Field habitats. This same pattern was not observed in wasp abundance. Total bee and wasp abundance was directly correlated with floral resource abundance, but not with floral richness.

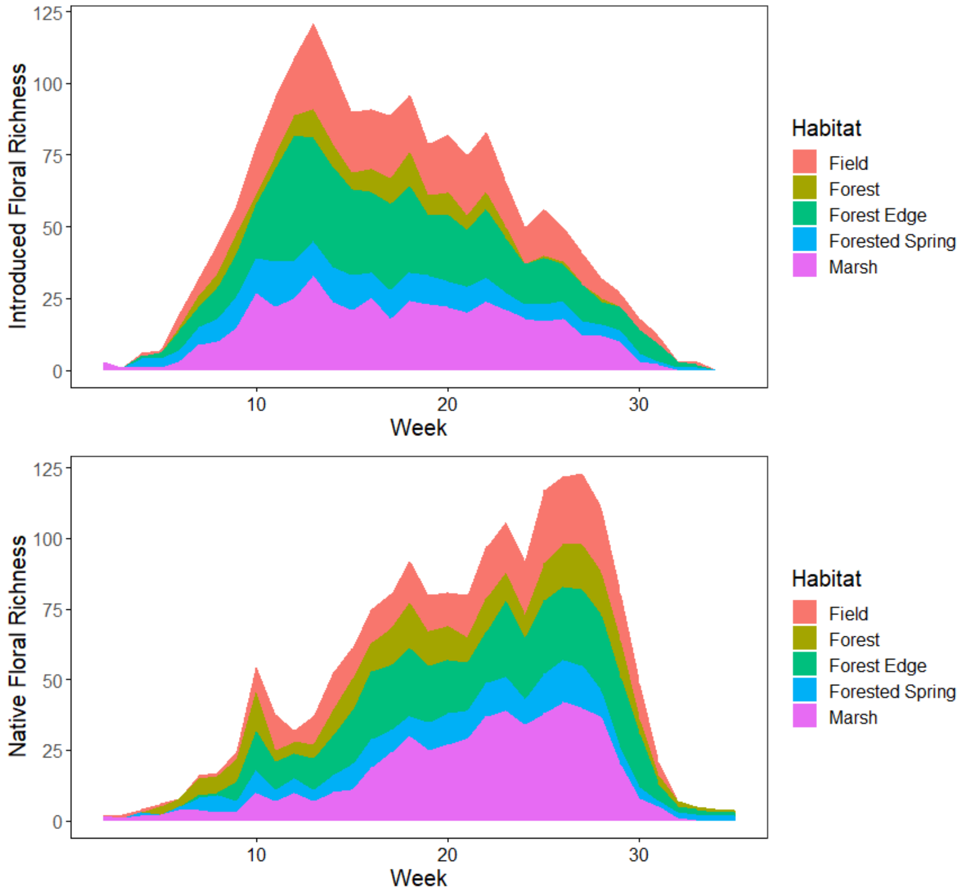

Figure 11: Floral richness of plants in flower recorded across all habitats, for native and introduced species, recorded from the end of March (week 1) to the end of November (week 35).

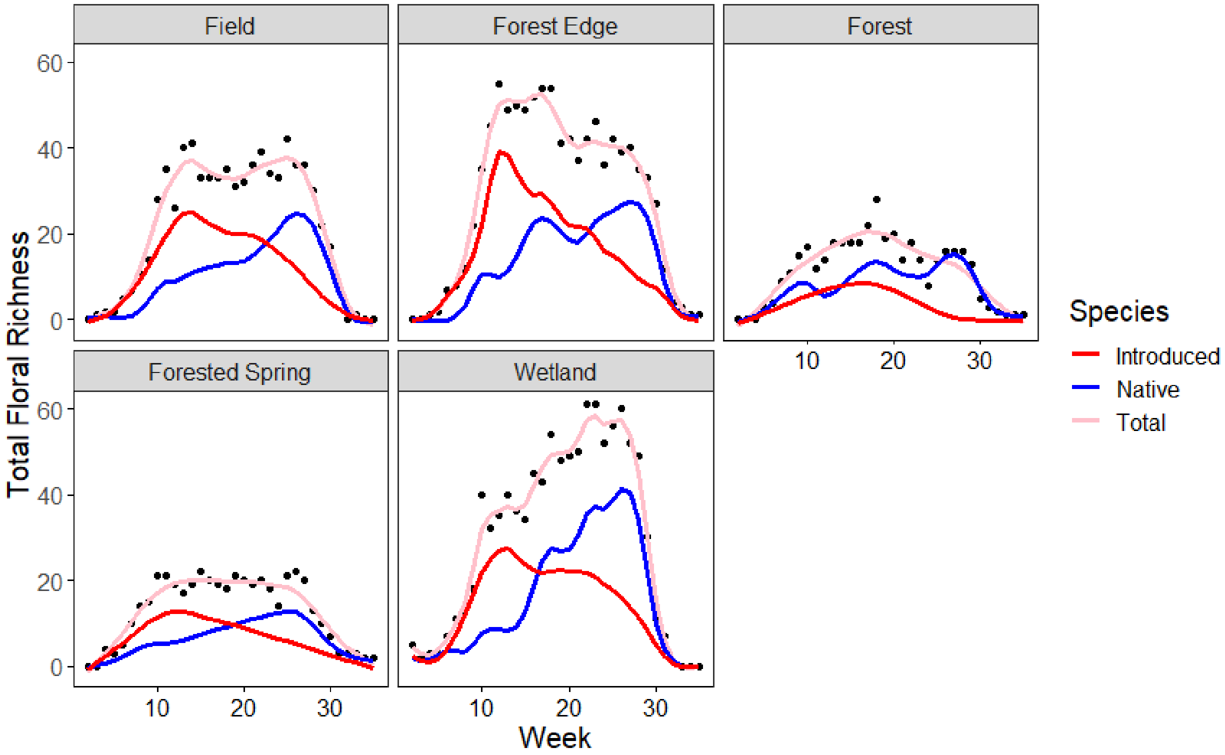

Figure 12: Floral richness of plants in flower recorded across all habitat, recorded from the end of March (week 1) to the end of November (week 35). Black dots represent total floral richness recorded each week.

Table 10: Akaike Information Criterion (AIC) test showing that the interactive model is a significant improvement over the main effects model for the three GAM models, Introduced Floral Richness, Native Floral Richness, and Total Floral Richness. Main effects model: gam(Floral_Richness ~ Habitat +s(Week)). Interactive model: gam(Floral Richness ~ Habitat +s(Week, by= Habitat)).

Model	Total Richness	Introduced Richness	Native Richness
Main Effects	1218.353	1016.024	1054.816
Interaction	952.260	790.356	836.749

Table 11: GAM comparison of the species richness of floral resources recorded in the different habitat types over a 35 week period. This was divided into native species, introduced species, and total species. A k value of 30 was selected to better fit the models. gam(Floral_Richness~Habitat+s(Week, by=Habitat, k=30), method= "REML")

Habitat	Introduced F value	Native F value	Total F value
Field	64.800***	42.760***	62.060***
Forest Edge	74.840***	52.310***	85.480***
Forest	16.580***	15.540***	25.080***
Forested Spring	25.010***	17.190***	26.490***
Wetland	66.310***	95.100***	91.820***
Habitat	250.100***	140.800***	267.400***

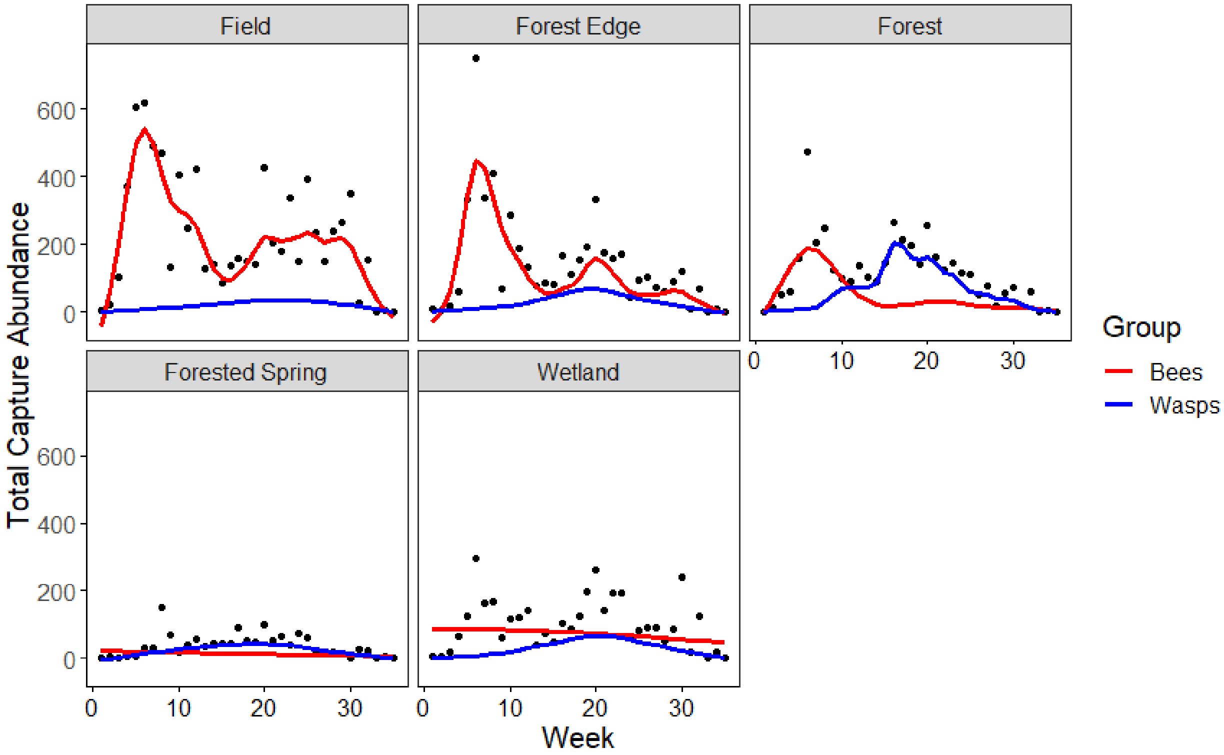

Figure 13: All Hymenoptera (less Formicidae) captured across all sites from the end of March (week 1) to the end of November (week 35). Black dots represent total number of bees and wasps caught each week.

Table 12: Akaike Information Criterion (AIC) test showing that the interactive model is a significant improvement over the main effects model for the two GAM models, Bee Abundance and Wasp Abundance. Main effects model: gam(Insect_Group ~ Habitat +s(Week)). Interactive model: gam(Insect_Group ~ Habitat +s(Week, by= Habitat)).

Model	Bee Abundance	Wasp Abundance
Main Effects	2073.601	1607.121
Interaction	2040.743	1455.622

Table 13: GAM comparison of the abundance of wasps and bees caught in the different habitat types over a 35 week period. A k value of 30 was selected to better fit the models. gam(Insect_Group~Habitat+s(Week, by=Habitat, k=30), method= "REML")

	Bees	Wasps
Habitat	F value	F value
Field	10.178***	7.511***
Forest Edge	7.311***	16.365***
Forest	3.455**	40.785***
Forested Spring	0.162	11.522***
Wetland	0.572	18.479***
Habitat	40.430***	87.890***

Wasp Community Assemblage

Wasp abundance followed a seasonal arc, with peak abundance occurring mid-summer (around week 20) (Figure 14). Wasps showed a clear preference towards forest sites (Figures 15-16 and Table 15). Forest Edges, Wetlands, and Forested Springs were used to a lesser extent. Wasps were least prevalent in Field sites and do not appear to use these areas overall in high abundance. All habitat types peaked in wasp abundance around the same time (week 20, mid-summer). The seven most abundant wasp families collected were Ichneumonidae, Braconidae, Diapriidae, Crabronidae, Pompilidae, Dryinidae, and Vespidae (in order of abundance, with Ichneumonidae being the most abundant family collected). Ichneumonidae were most prevalent in the Forest sites, followed by Forest Edges, Wetlands, and Forested Springs. They were mostly absent or collected in very low numbers in Field sites. Ichneumonidae peak abundance occurred mid-summer around week 20. Braconidae were most prevalent in the Forest sites, followed by Wetlands, Forested Springs, and Forest Edges. They were mostly absent or collected in very low numbers in Field sites. Braconidae peak abundance occurred early-summer around week 15. Diapriidae were mostly prevalent in the Forest sites and largely absent or collected in very low numbers in all other habitats. Diapriidae peak abundance occurred mid-summer around week 20. Crabronidae were most prevalent in the Forest Edge sites, followed by Forests, Wetlands, and Fields. They were mostly absent or collected in very low numbers in Forested Spring sites. Crabronidae peak abundance occurred mid-summer around week 20. Pompilidae were most prevalent in the Forest sites, followed by Forest Edges and Wetlands. They were mostly absent or collected in very low numbers from Forested Spring and Field sites. Pompilidae peak abundance occurred mid-summer around week 20. Dryinidae were most prevalent in the Forest sites. They were mostly absent or collected in very low numbers in Wetlands, Forested Springs, Fields, and Forest Edges. Dryinidae peak abundance occurred early-summer around week 15. Vespidae were most prevalent in the Field sites, followed by Wetlands and Forest Edges. They were mostly absent or collected in very low numbers in Forest and Forested Spring sites. Vespidae peak abundance occurred early-autumn around week 28. 37 Families were identified as part of this study (Appendix C).

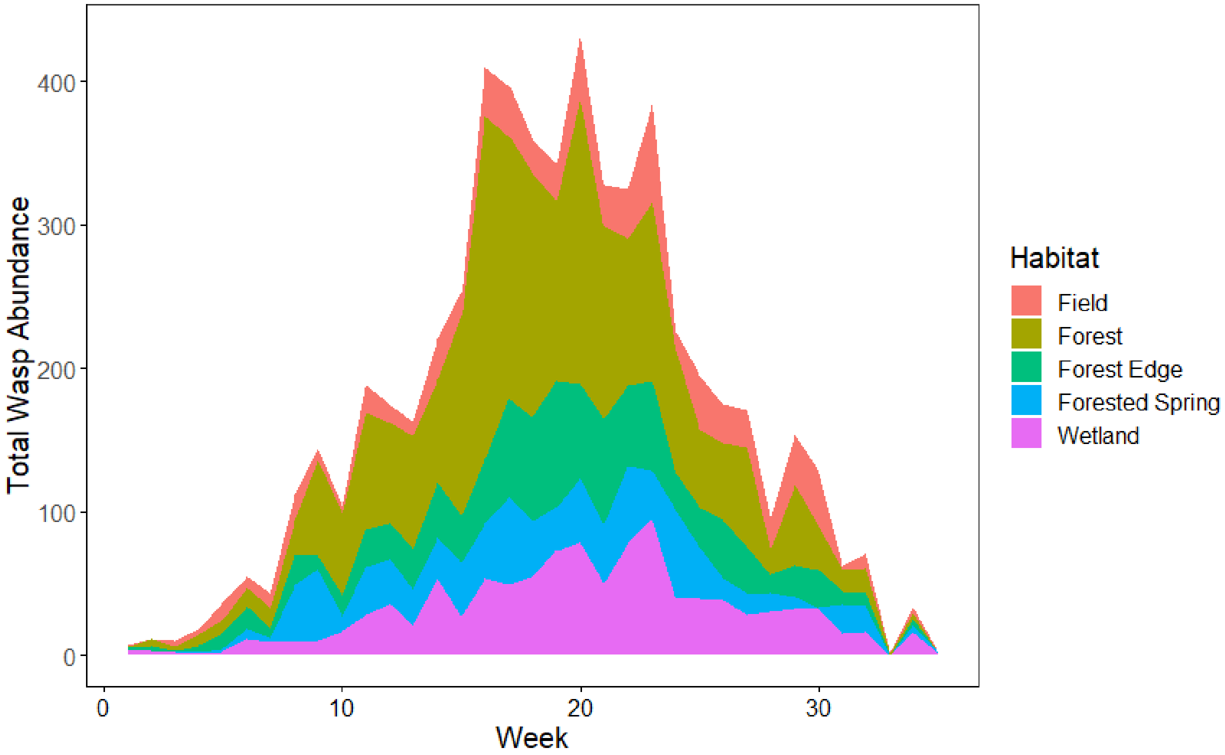

Figure 14: The abundance of wasps in each habitat type from the end of March (week 1) to the end of November (week 35).

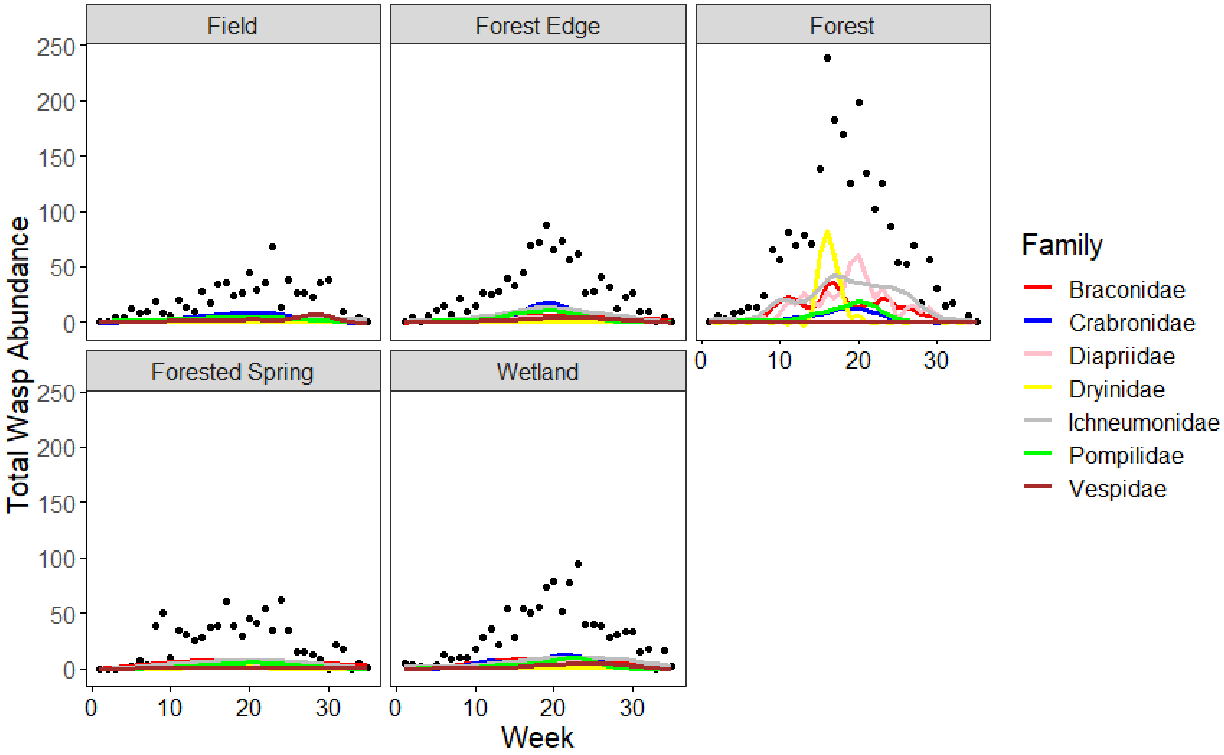

Figure 15: The breakdown of wasp abundance by habitat for the 7 most abundant families. End of March (week 1) to the end of November (week 35). Black dots represent total number of wasps across all families caught each week.

Table 14: Akaike Information Criterion (AIC) test showing that the interactive model is a significant improvement over the main effects model for the seven GAM models, Braconidae, Crabronidae, Diapriidae, Dryinidae, Ichneumonidae, Pompilidae, and Vespidae. Main effects model: gam(Family~Habitat ~ Habitat +s(Week)). Interactive model: gam(Family~Habitat ~ Habitat +s(Week, by= Habitat)).

Model	Braconidae	Crabronidae	Diapriidae	Dryinidae	Ichneumonidae	Pompilidae	Vespidae
Main Effects	1056.776	941.315	1172.997	1249.275	1150.428	918.705	699.848
Interaction	1001.214	931.124	1007.240	1048.982	1025.881	901.831	669.860

Table 15: GAM comparison of the abundance of wasps collected by family in different habitat types over a 35 week period. Only the 7 most abundant families were used for this analysis. A k value of 30 was selected to better fit the models. gam(Family~Habitat+s(Week, by=Habitat, k=30), method= "REML")

Habitat	Braconidae F value	Crabronidae F value	Diapriidae F value	Dryinidae F value	Ichneumonidae F value	Pompilidae t value	Vespidae F value
Field	1.535	7.306***	0.070	0.014	1.182	2.878*	5.037***
Forest	15.421***	7.681***	37.548***	279.339***	29.079***	8.576***	0.754
Forest Edge	4.396**	10.840***	3.129*	0.103	7.448***	12.474***	8.756***
Forested Spring	3.948**	5.268***	3.214*	5.994***	4.442**	4.537**	1.673
Wetland	9.031***	7.278***	5.862***	0.790	5.298***	5.318***	8.693
Habitat	41.410***	1.674	116.300***	187.200***	79.890***	4.472**	8.235***

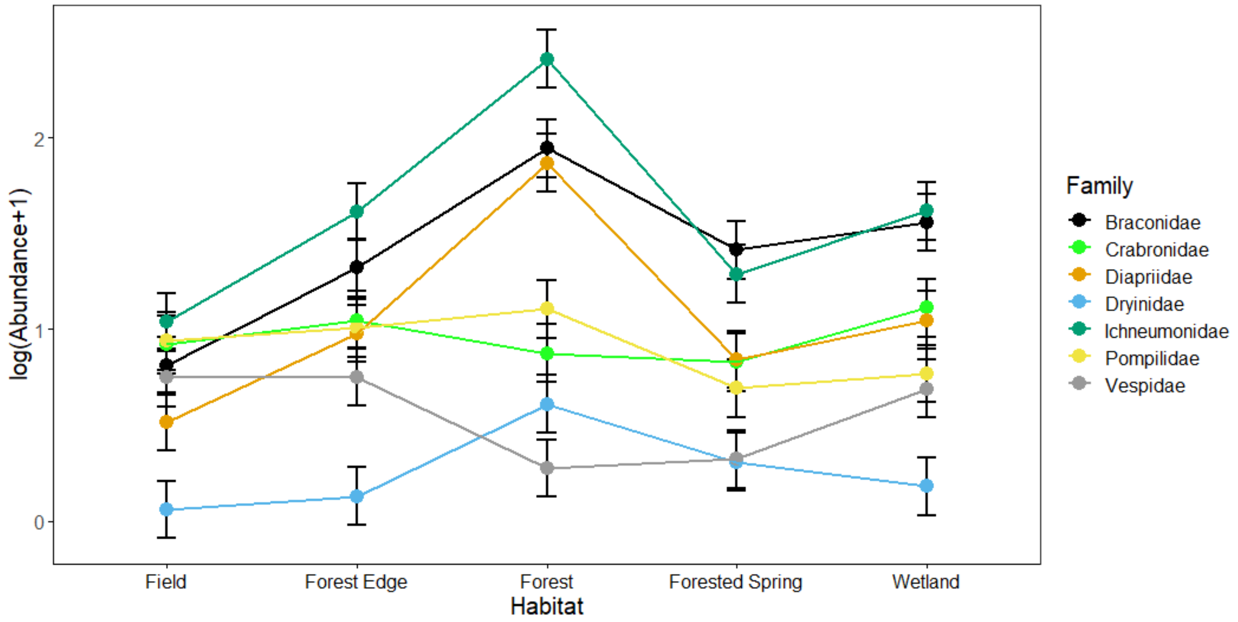

Figure 16: Linear model with log transformation of total captured wasp abundance over the 35 week collection period showing a significant habitat x family interaction

Table 16: Analysis of variance, looking at the effect habitat has on wasp abundance and the interaction between different families. Only the 7 most abundant families were used for this analysis. F and p values are for type III sums of squares and abundance values used in the linear model were log transformed.

Parameters	Df	F value	
Intercept	1	29.1066	***
Family	6	4.9872	***
Habitat	4	7.4688	***
Family:Habitat	24	3.6237	***
Residuals	1190		

Bee Community Assemblage

Bee abundance varied greatly between different habitat types and over the course of the 35 week sampling period. The observed changes in bee abundances were distinctly different between the males and females (Figure 17) These differences varied by habitat. Overall bees were most abundant in Field sites, followed by Forest Edges, Forests, Wetlands, and Forested Springs (where they were only present in very low numbers). Overall bee abundance was greatest in the mid-spring, but fluctuated greatly throughout the sampling season (Figure 18). Overall total male abundance peaked in mid-spring, whereas females were relatively consistent in their abundance throughout the season (Figure 17). However, this overall relationship in the bee community did not remain consistent by family (Figure 19 and 20). Andrenids peaked in abundance in the mid-spring in Fields, Forests, and Forest Edges. They then declined and were mostly absent (or remaining in low numbers) throughout the rest of the season. They were not overly abundant in Wetlands or Forested Springs. Apids were most abundant in mid-spring in Field and Forest Edge sites. They sustained a steady community within the Fields sites, but declined amongst the Forest Edge sites throughout the sampling season. They remained in low abundance across the Forest, Forested Spring, and Wetland sites. Colletids were most abundant in early-spring within Field sites and quickly declined by late spring. They sustained low numbers across the Field sites for the remainder of the survey period. They were largely absent (or in very low numbers) across all other habitat types. Halictids were most abundant in late-summer in Field sites, early-summer in Forest Edge sites, and mid-summer in Wetland Sites. They existed in low numbers across Forest and Forested Spring sites. Megachilids were most abundant in early to mid-spring across Field and Forest Edge sites. They sustained low numbers across Field sites until mid-summer. Megachilids were largely absent (or in very low numbers) across Forest, Wetland, and Forested Spring sites.

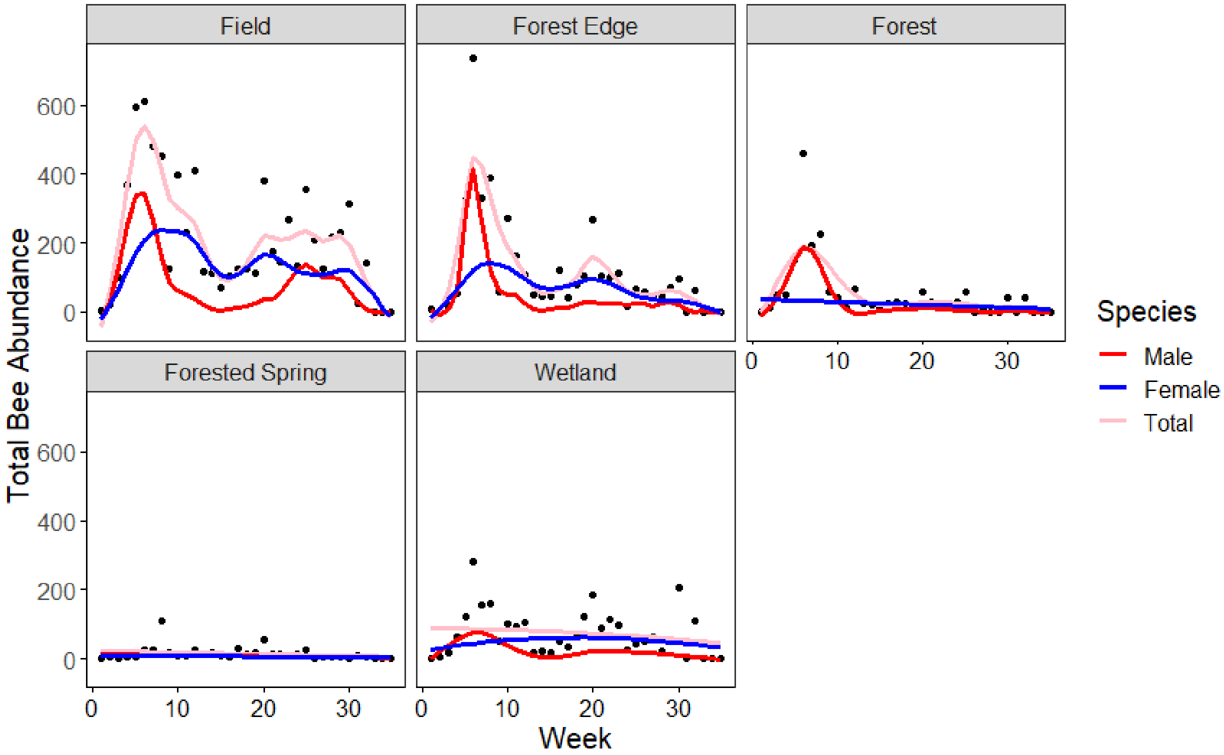

Figure 17: Total bee abundance recorded over time from late March (week 1) to late November (week 35), divided by sex. Black dots represent total number of bees caught each week.

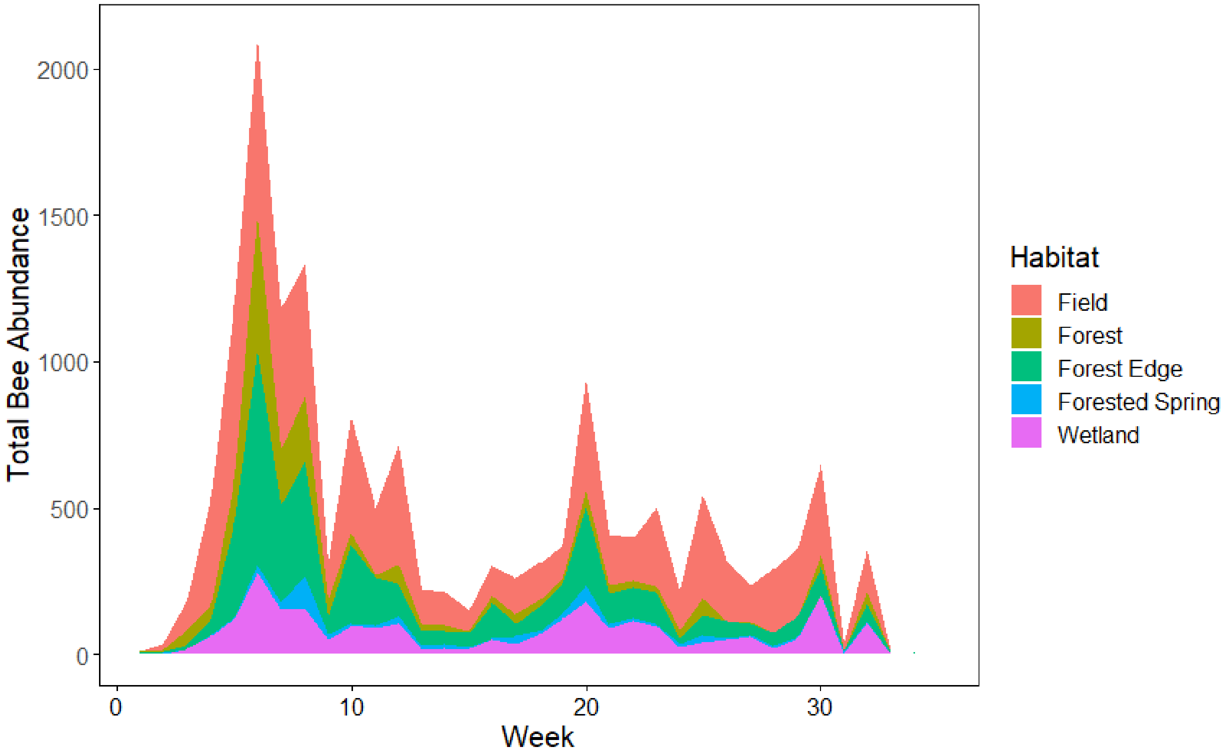

Figure 18: Total bee abundance by habitat type recorded over the sampling season, late March (week 1) to late November (week 35).

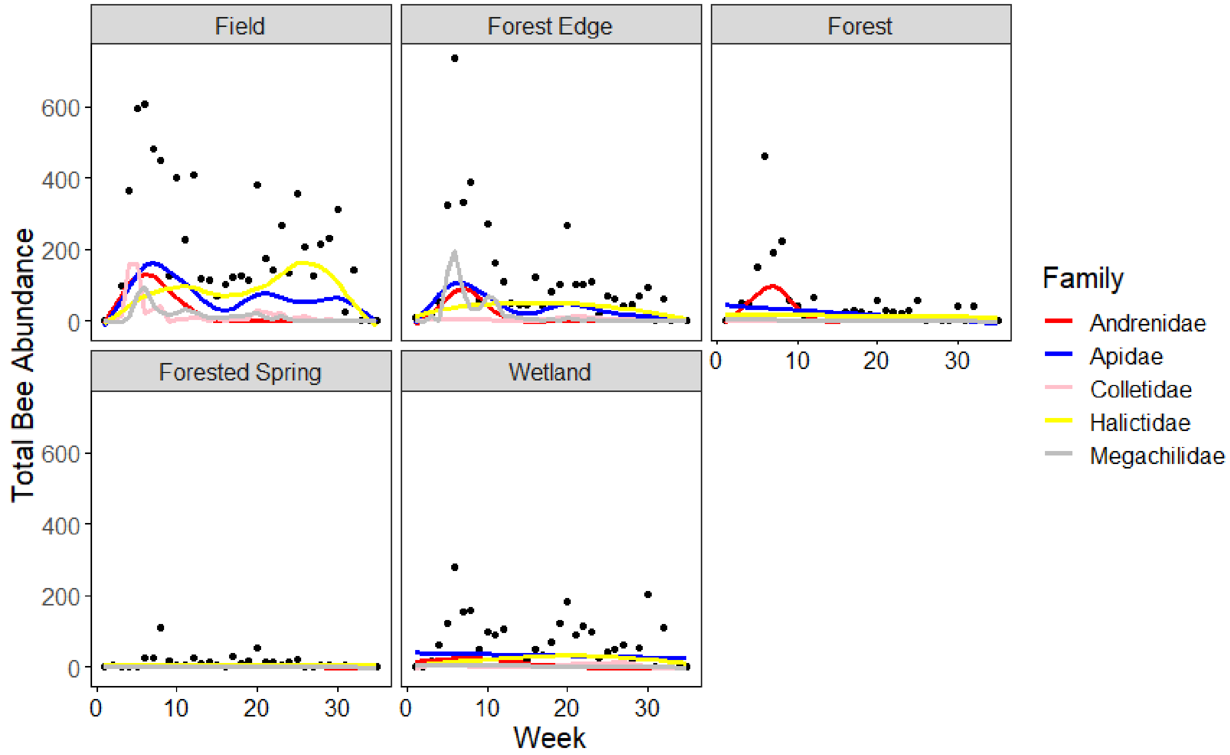

Figure 19: Bee abundance by family and habitat from late March (week 1) to late November (week 35). Black dots represent total number of bees caught each week.

Table 17: Akaike Information Criterion (AIC) test showing that the interactive model is a significant improvement over the main effects model for the five GAM models, Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae. Main effects model: gam(Family~Habitat ~ Habitat +s(Week)). Interactive model: gam(Family~Habitat ~ Habitat +s(Week, by= Habitat)).

Model	Andrenidae	Apidae	Colletidae	Halictidae	Megachilidae
Main Effects	1633.468	1844.643	1485.294	1709.989	1549.353
Interaction	1581.733	1855.942	1368.903	1654.668	1478.391

Table 18: GAM comparison of the abundance of bees collected by family in different habitat types over a 35 week period. A k value of 30 was selected to better fit the models. gam(Family~Habitat+s(Week, by=Habitat, k=30), method= "REML")

Habitat	Andrenidae F value	Apidae F value	Colletidae F value	Halictidae F value	Megachilidae F value
Field	15.651***	3.939***	103.519***	12.555***	16.379***
Forest Edge	7.052***	2.545*	3.620***	2.945*	58.181***
Forest	7.910***	3.712	0.074	0.094	2.614
Forested Spring	0.257	0.072	0.001	0.000	0.864
Wetland	2.677*	0.318	4.055***	1.902	5.412*
Habitat	7.586***	9.261***	113.200***	47.560***	70.100***

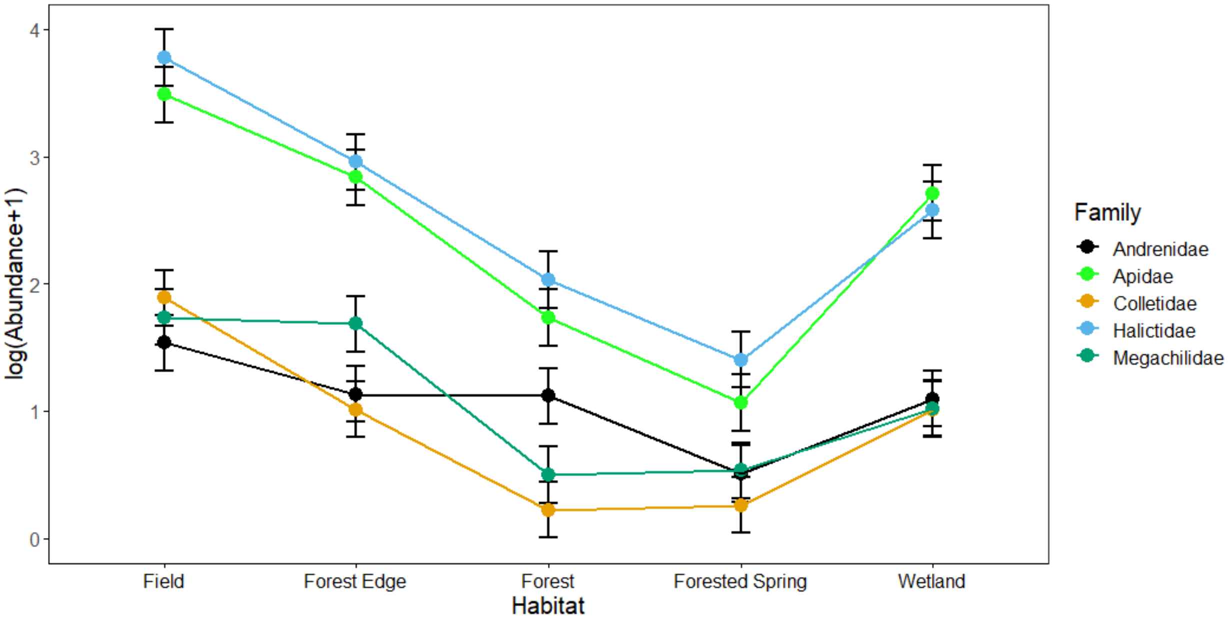

Figure 20: Linear model with log transformation of total captured bee abundance over the 35 week collection period showing a significant habitat x family interaction.

Table 19: Analysis of variance, looking at the effect habitat has on bee abundance and the interaction between different families. F and p values are for type III sums of squares and abundance values used in the linear model were log transformed.

Parameters	Df	F value	
Intercept	1	48.3984	***
Family	4	23.0506	***
Habitat	4	2.7747	*
Family:Habitat	16	2.0353	**
Residuals	850		

Table 20: GAM comparison of the abundance of bees collected by floral abundance over a 35 week period. A k value of 30 was selected to better fit the models. gam(Bee Abundance~Floral Abundance, k=30, method= "REML").

Parameters	Df	Bee Abundance F value
Floral Abundance	1	0.699
Habitat	4	9.195***
Floral Abundance:Habitat	4	0.299

The 10 focal species that were identified (Table 1) all had distinctive differences in their abundances across habitat types, by sex, and by week. These species belonged to two families (Apidae and Halictidae) and 6 genera (*Apis*, *Ceratina* and *Agapostemon*, *Augochlora*, *Augochlorella*, *Halictus*).

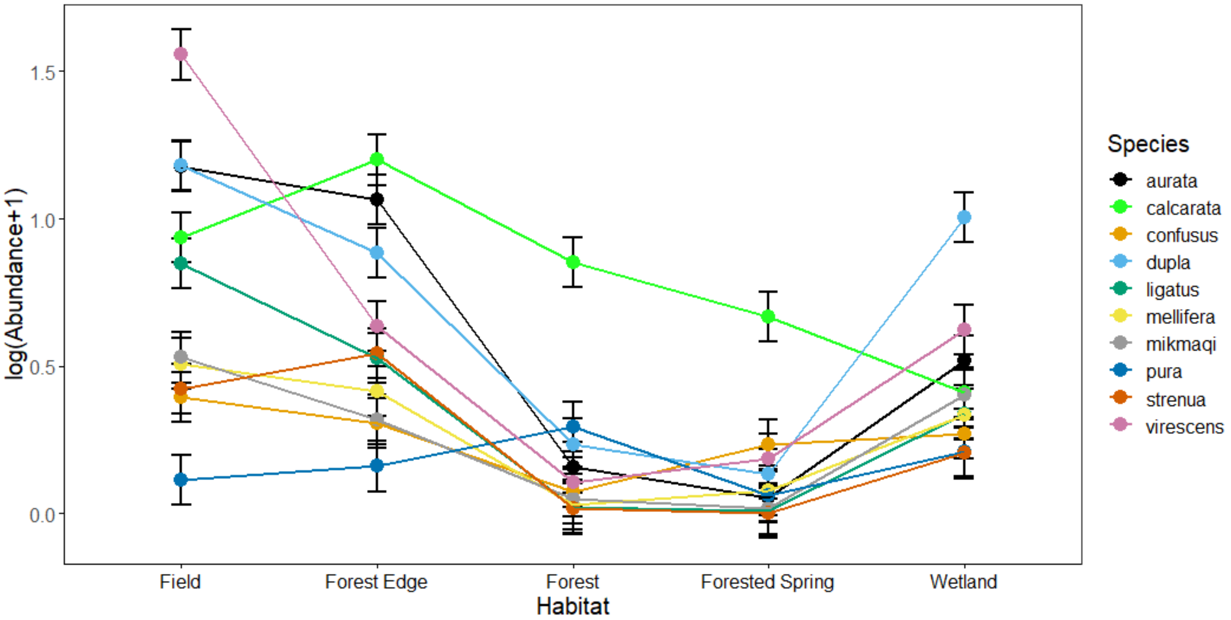

Figure 21: Linear model with log transformation of total captured bee abundance for the 10 focal species over the 35 week collection period showing the significant interaction between habitat and species. Species are *Augochlorella aurata*, *Ceratina calcarata*, *Halictus confusus*, *Ceratina dupla*, *Halictus ligatus*, *Apis mellifera*, *Ceratina mikmaqi*, *Augochlora pura*, *Ceratina strenua*, and *Agapostemon virescens*.

Table 21: Analysis of variance, looking at the effect habitat has on bee abundance and the interaction between different families. F and p values are for type III sums of squares and abundance values used in the linear model were log transformed.

Parameters	Df	F value	
Intercept	1	290.8512	***
Species	9	25.0787	***
Habitat	4	47.4727	***
Sex	1	105.4611	***
Species:Habitat	36	8.1847	***
Species:Sex	9	10.7935	***
Habitat:Sex	4	14.9245	***
Species:Habitat:Sex	36	3.5509	***
Residuals	3400		

Table 22: Count data for the 10 focal species by habitat and sex.

	Apis mellifera		*Ceratina calcarata*		*Ceratina dupla*		*Ceratina mikmaqi*		*Ceratina strenua*		*Agapostemon virescens*		*Augochlora pura*		*Augochlorella aurata*		*Halictus confusus*		*Halictus ligatus*	
Habitat	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Field	0	107	694	153	108	392	25	94	19	51	616	440	3	11	21	528	10	61	105	130
Forest Edge	0	70	41	477	139	151	8	46	38	77	72	74	9	12	49	266	6	9	38	59
Forest	0	3	84	184	32	38	3	4	0	2	3	11	15	34	3	21	1	39	0	2
Forested Spring	0	10	46	112	15	9	0	2	0	0	18	8	3	3	0	6	20	17	0	1
Wetland	0	58	48	87	172	253	6	84	12	20	70	59	15	13	9	102	7	39	21	36
Sex Total	**0**	**248**	**913**	**1013**	**466**	**843**	**42**	**230**	**69**	**150**	**779**	**592**	**45**	**73**	**82**	**923**	**44**	**165**	**164**	**228**
Grand Total	**248**		**1926**		**1309**		**272**		**219**		**1371**		**118**		**1005**		**209**		**392**	

Apis mellifera, more commonly known as the European Honey Bee, was found across all sites and habitats (except for Site 8, which was a forest site) (Appendix B). Only female individuals were captured during survey work. *Apis mellifera* showed a clear habitat preference towards fields, with this habitat type having the greatest sustained abundance (Figure 22 and Table 24). To a lesser degree Forest Edges and Wetlands were also utilized by this species. Forest and Forested Springs did not record significant presences of *Apis mellifera*. *Apis mellifera* went through three peak seasons, one in early-spring (around week 5), one in mid-summer (around week 20) and one in early autumn (around week 28). In the spring and summer *Apis mellifera* is primarily utilizing fields, in late-summer and autumn they additionally utilize forest edges and wetlands (while maintaining a strong preference for field habitats).

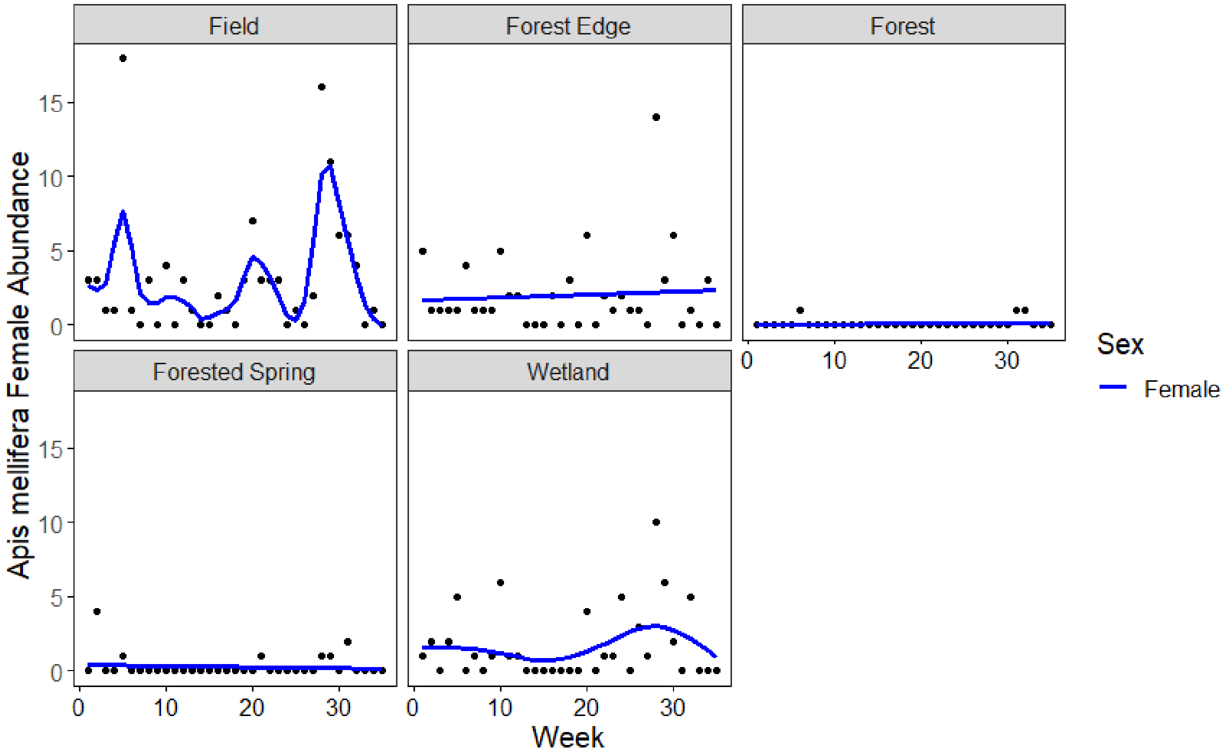

Figure 22: Abundance of the Eurasian Honey Bee (*Apis mellifera*) across all habitat types. Only females of this species were caught during this study. Black dots represent total number of *Apis mellifera* caught each week.

Ceratina calcarata, more commonly known as the Wide-legged Little Carpenter Bee, was found across every habitat and site surveyed (Appendix B). This species was collected in the greatest abundance out of the 10 target species. Abundance of *Ceratina calcarata* was divided by habitat and sex (Figure 23 and Table 24). Female *Ceratina calcarata* were found to prefer Forest Edge habitats and peaked in abundance in mid-summer (around week 20). Males on the other hand had a preference for Field habitats and peaked in late-summer (around week 25). All sites sustained populations of *Ceratina calcarata* throughout the survey season, but Forests, Forested Springs, and Wetlands were not widely utilized by this species. Overall, *Ceretina calcarata* exhibited a univoltine life cycle with a protogynous mid-summer emergence.

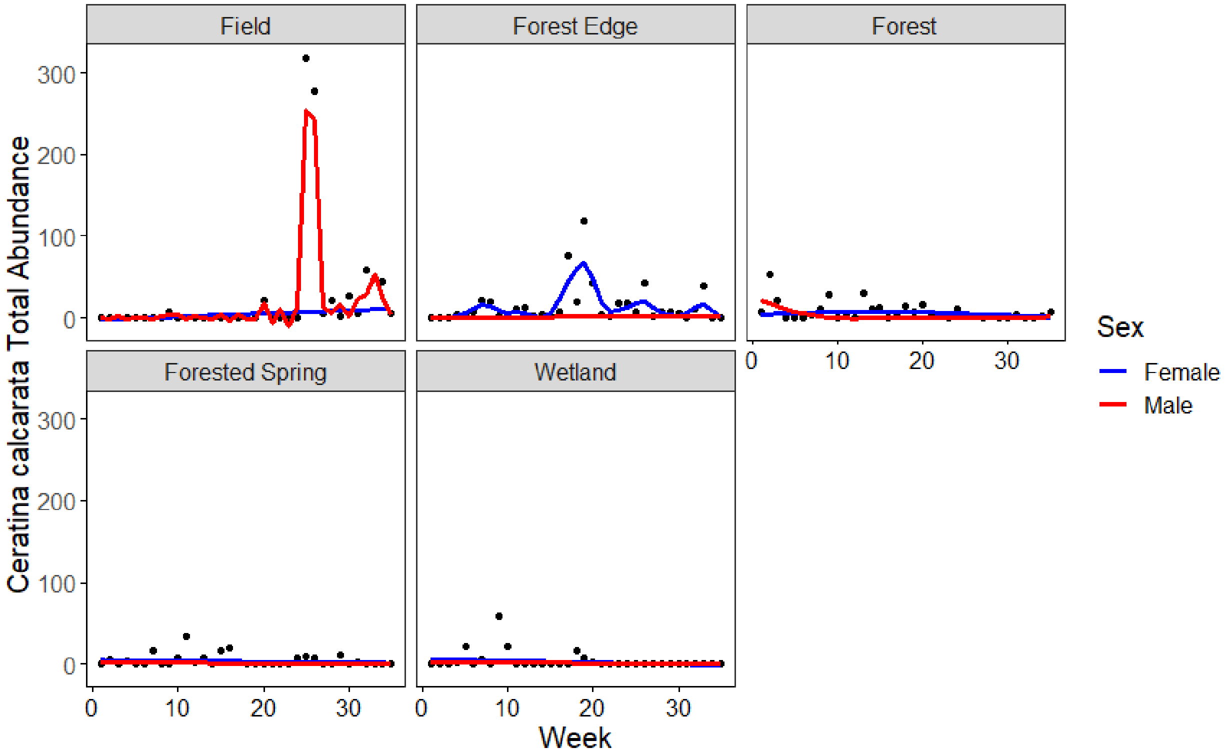

Figure 23: Abundance of the Wide-legged Little Carpenter Bee (*Ceratina calcarata*) across all habitat types and by sex. Black dots represent total number of *Ceratina calcarata* caught each week.

Ceratina dupla, more commonly known as the Common Eastern Little Carpenter Bee, was found across every habitat and site surveyed (Appendix B). This species was the 3rd most abundant species collected out of the 10 target species. Abundance of *Ceratina dupla* was divided by habitat and sex (Figure 24 and Table 24). Female *Ceratina dupla* were found to prefer Field and Wetland habitats and peaked in abundance in mid-autumn (around week 30). Males on the other hand preferred Field, Forest Edge, and Wetland habitats and peaked at the beginning of the survey period in early to mid-spring (around week 8). All sites sustained populations of *Ceratina dupla* throughout the survey season, but Forests and Forested Springs were not widely utilized by this species. Overall, *Ceretina dupla* exhibited a univoltine life cycle with a protandrous mid-spring emergence.

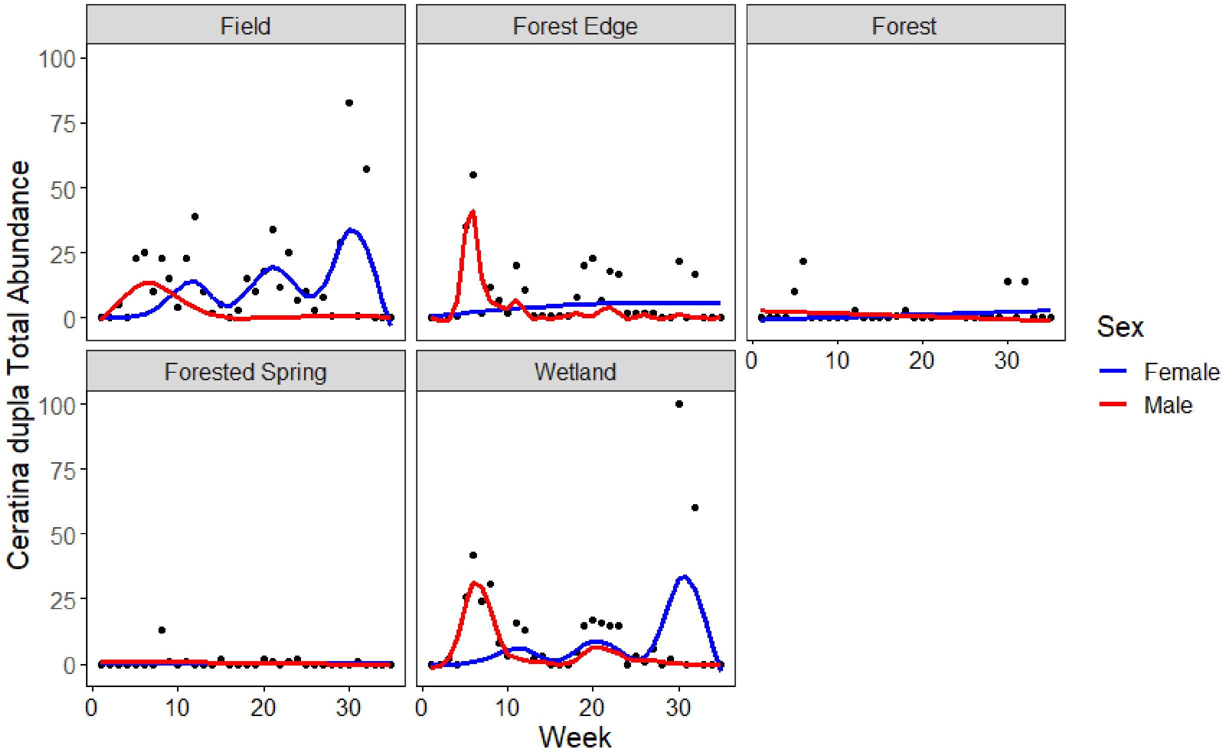

Figure 24: Abundance of the Common Eastern Little Carpenter Bee (*Ceratina dupla*) across all habitat types and by sex. Black dots represent total number of *Ceratina dupla* caught each week.

Ceratina mikmaqi, more commonly known as the Mikmaq Little Carpenter Bee, was found across every habitat and site surveyed, except for Site 9 (a forest habitat) and site 14 (a forested spring habitat) (Appendix B). This species was the 6th most abundant species collected out of the 10 target species. Abundance of *Ceratina mikmaqi* was divided by habitat and sex (Figure 25 and Table 24). Female *Ceratina mikmaqi* were found to prefer Field and Wetland habitats and peaked in abundance in mid-summer (around week 20). Forest edges were also utilized by females to a lesser extent. Smaller peaks in female abundance occurred in early-mid spring (around weeks 8-10) and mid-autumn (around week 30). Males on the other hand mainly preferred Field habitats and peaked at the beginning of the survey period in early to mid-spring (around week 8) and in late summer (around week 28). All sites with recorded population of *Ceratina mikmaqi* sustained these populations throughout the survey season, however Forests and Forested Springs were not widely utilized by this species. Overall, *Ceretina mikmaqi* exhibited a potentially bivoltine life cycle with a protandrous mid-spring and late summer emergence.

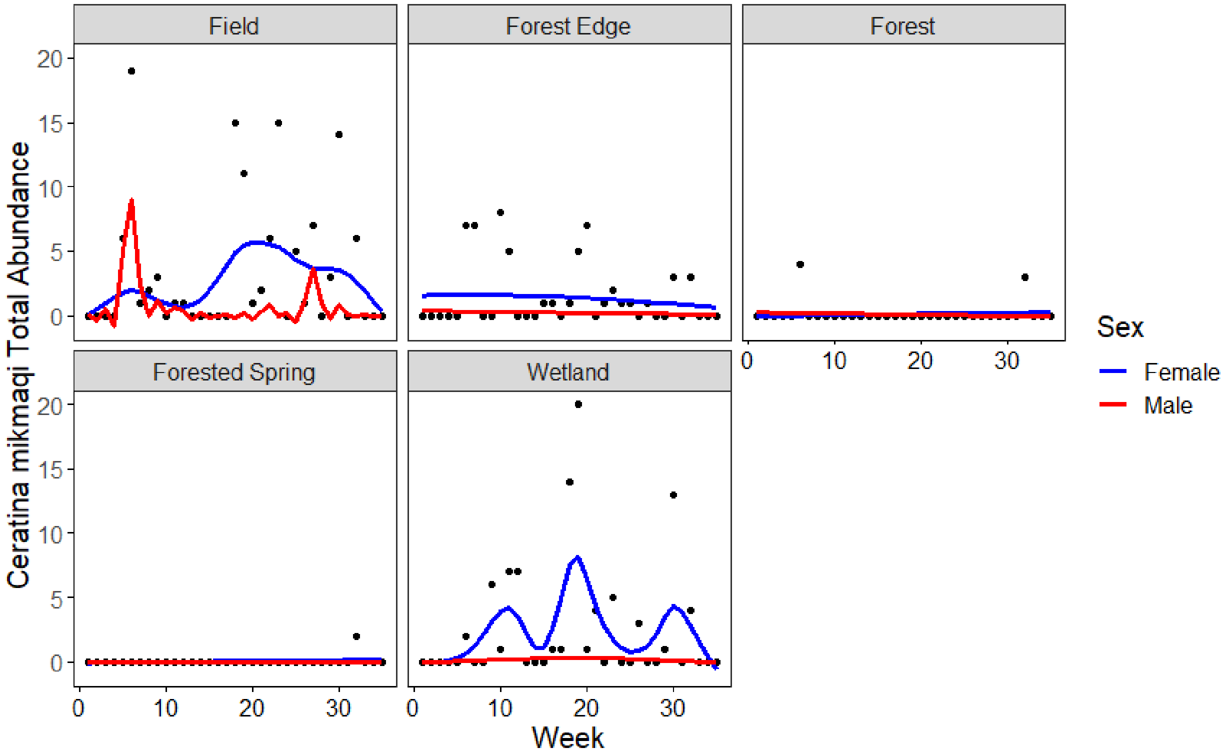

Figure 25: Abundance of the Mikmaq Little Carpenter Bee (*Ceratina mikmaqi*) across all habitat types and by sex. Black dots represent total number of *Ceratina mikmaqi* caught each week.

Ceratina strenua, more commonly known as the White-striped Little Carpenter Bee, was found across every habitat, except for Forested Springs, and most sites surveyed, except for Sites 5 and 9 (Appendix B). This species was the 8th most abundant species collected out of the 10 target species. Abundance of *Ceratina strenua* was divided by habitat and sex (Figure 26 and Table 24). Female *Ceratina strenua* were found to have a strong preference for Field and Forest Edge habitats and to a lesser extent Wetland Habitats. Their populations peaked in abundance in late-spring (around week 10) and mid-summer (around week 20). Males on the other hand preferred Forest Edge habitats and peaked around the same time as the females. All sites with recorded populations of *Ceratina strenua* sustained these populations throughout the survey season, except for Forests (that had very few recorded individuals) and Forested Springs (with no recorded individuals) which were not widely utilized by this species. Overall, *Ceretina strenua* exhibited a potentially bivoltine life cycle with a protandrous mid-spring and mid-summer emergence.

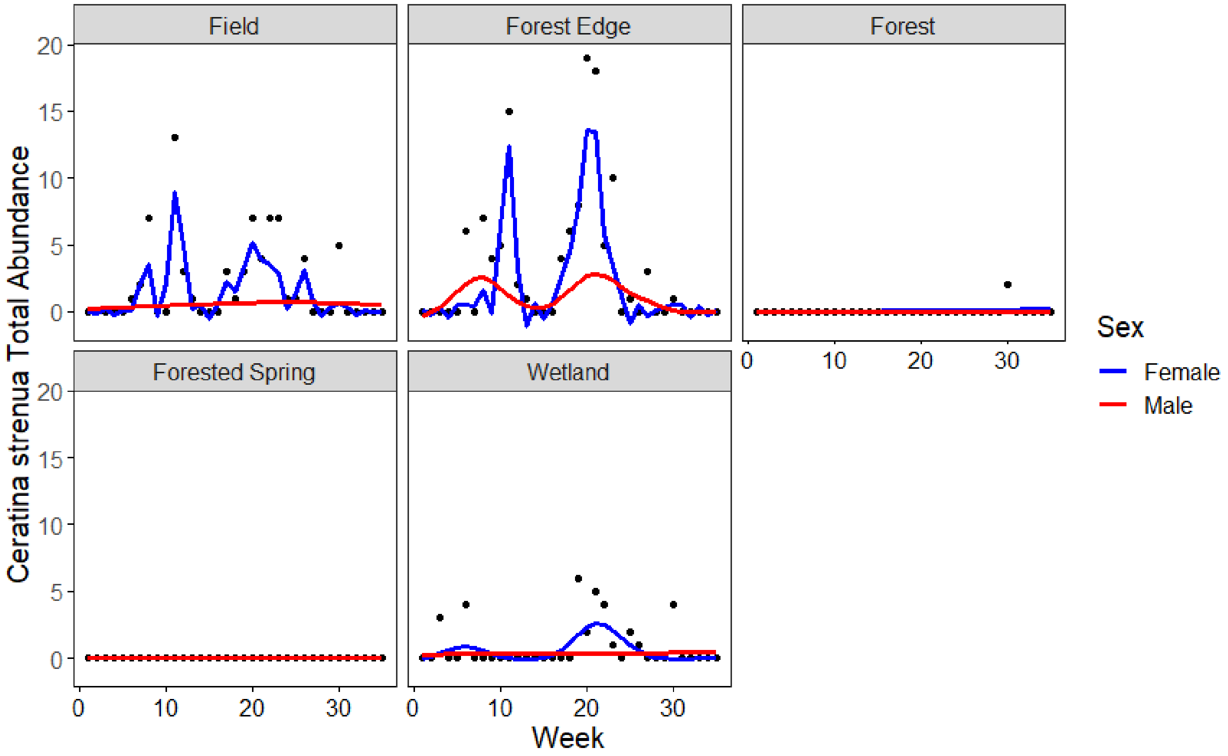

Figure 26: Abundance of the White-striped Little Carpenter Bee (*Ceratina strenua*) across all habitat types and by sex. Black dots represent total number of *Ceratina strenua* caught each week.

Agapostemon virescens, more commonly known as the Bicoloured Sweat Bee, was found across every habitat and site surveyed (Appendix B). This species was the 2nd most abundant species collected out of the 10 target species. Abundance of *Agapostemon virescens* was divided by habitat and sex (Figure 27 and Table 24). Female *Agapostemon virescens* were found to have a strong preference for Field habitats, with their populations peaking in late-spring (around week 12) and early-autumn (around week 28). Males on the other hand were found to have a strong preference for Field habitats and to a lesser extent Forest Edge and Wetland Habitats. Their populations peaked in abundance in late-summer (around week 25). All sites with recorded population of *Agapostemon virescens* sustained these populations throughout the survey season. Forest and Forested Spring sites were rarely used by *Agapostemon virescens* and Forest Edge and Wetland sites were not widely used, except for males in late-summer. Overall, *Agapostemon virescens* exhibited a univoltine life cycle with a protogynous early-summer emergence.

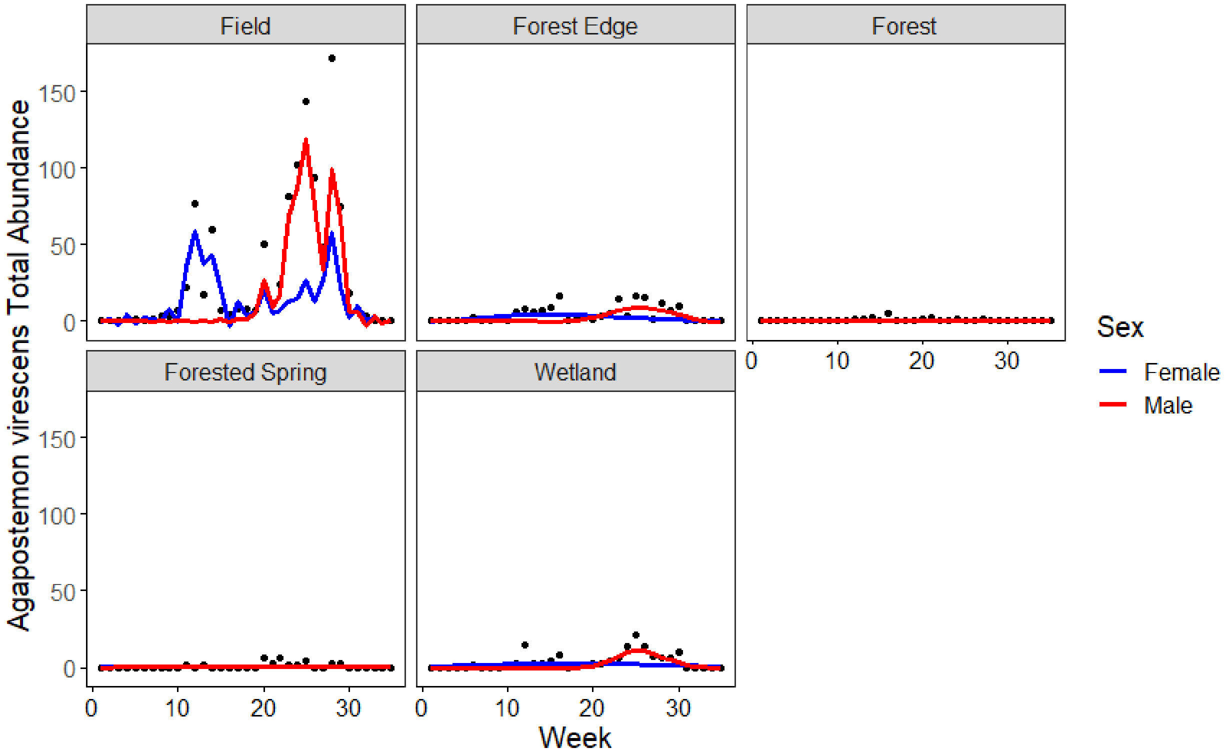

Figure 27: Abundance of the Bicoloured Sweat Bee (*Agapostemon virescens*) across all habitat types and by sex. Black dots represent total number of *Agapostemon virescens* caught each week.

Augochlora pura, more commonly known as the Pure Sweat Bee, was found across every habitat and site surveyed (Appendix B). This species was the 10th and least abundant species collected out of the 10 target species. Abundance of *Augochlora pura* was divided by habitat and sex (Figure 28 and Table 24). Female *Augochlora pura* were found to have a strong preference for Forest habitats, but were still observed utilizing Field, Forest Edge, and Wetland habitats to a lesser degree. Their populations peaked in abundance in early-spring (around week 5) and mid-autumn (around week 30). Males on the other hand had a strong preference for Forest habitats, and to a lesser extent (but still greater than the females) Forest Edges and Wetlands. Males peaked in mid-summer (around week 20). All sites with recorded population of *Augochlora pura* sustained these populations throughout the survey season, except for Forested Spring (that had very few recorded individuals). Fields and Forested Springs were not widely utilized by either sex and females additionally did not widely utilize forest edges. Overall, *Augochlora pura* exhibited a bivoltine life cycle with a protogynous early-spring and mid-autumn emergence.

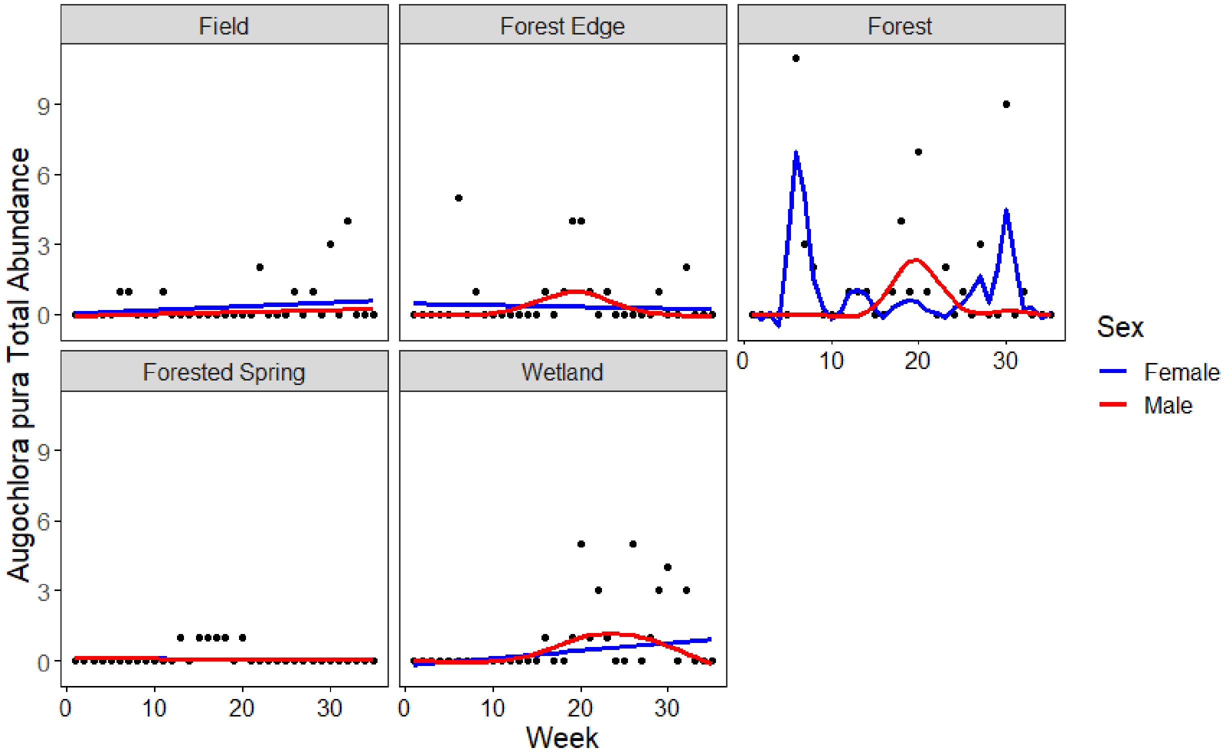

Figure 28: Abundance of the Pure Sweat Bee (*Augochlora pura*) across all habitat types and by sex. Black dots represent total number of *Augochlora pura* caught each week.

Augochlorella aurata, more commonly known as the Golden Sweat Bee, was found across every habitat and site surveyed (Appendix B). This species was the 4th most abundant species collected out of the 10 target species. Abundance of *Augochlorella aurata* was divided by habitat and sex (Figure 29 and Table 24). Female *Augochlorella aurata* were found to have a strong preference for Field and Forest Edge habitats and abundance peaked in mid-spring (around week 10) and late-summer (around week 25). Males on the other hand had a strong preference for Forest Edge habitats and abundance peaked in mid-summer (around week 20). All sites with recorded populations of *Augochlorella aurata* sustained these populations throughout the survey season. Forests, Forested Springs, and Wetlands were not widely utilized by either sex. Overall, *Augochlorella aurata* exhibited a bivoltine life cycle with a protogynous mid-spring and late summer emergence.

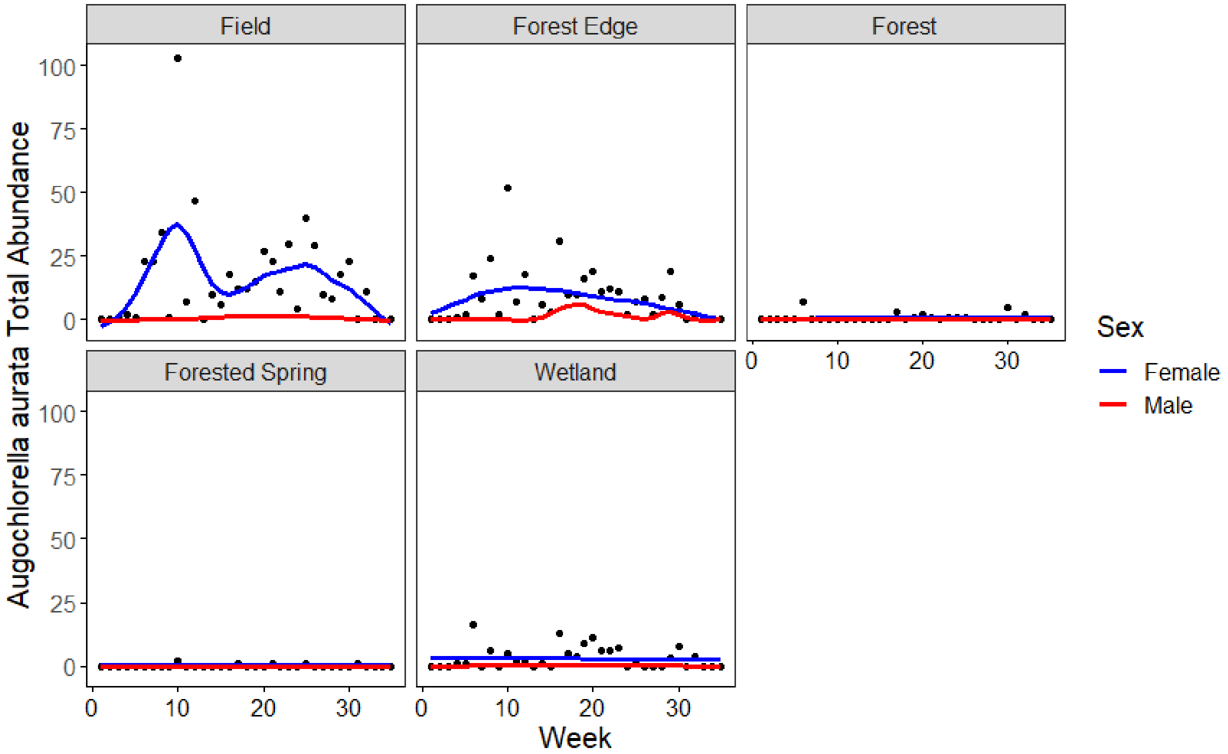

Figure 29: Abundance of the Golden Sweat Bee (*Augochlorella aurata*) across all habitat types and by sex. Black dots represent total number of *Augochlorella aurata* caught each week.

Halictus confusus, more commonly known as the Confused Sweat Bee, was found across every habitat and site surveyed (Appendix B). This species was the 9th most abundant species collected out of the 10 target species. Abundance of *Halictus confusus* was divided by habitat and sex (Figure 30 and Table 24). Female *Halictus confusus* were found to have a strong preference for Field, Wetland, and Forest Edge habitats and abundance peaked in mid-summer (around week 20). Males on the other hand had a strong preference for Forested Spring habitats and abundance also peaked in mid-summer (around week 20). Low male populations persisted throughout the collection season in Field, Forest Edge, and Wetland habitats. All sites with recorded populations of *Halictus confusus* sustained these populations throughout the survey season. Forests were not widely utilized by either sex. Overall, *Halictus confusus* exhibited a bivoltine life cycle with a protogynous mid-spring emergence and a protandrous mid-summer emergence.

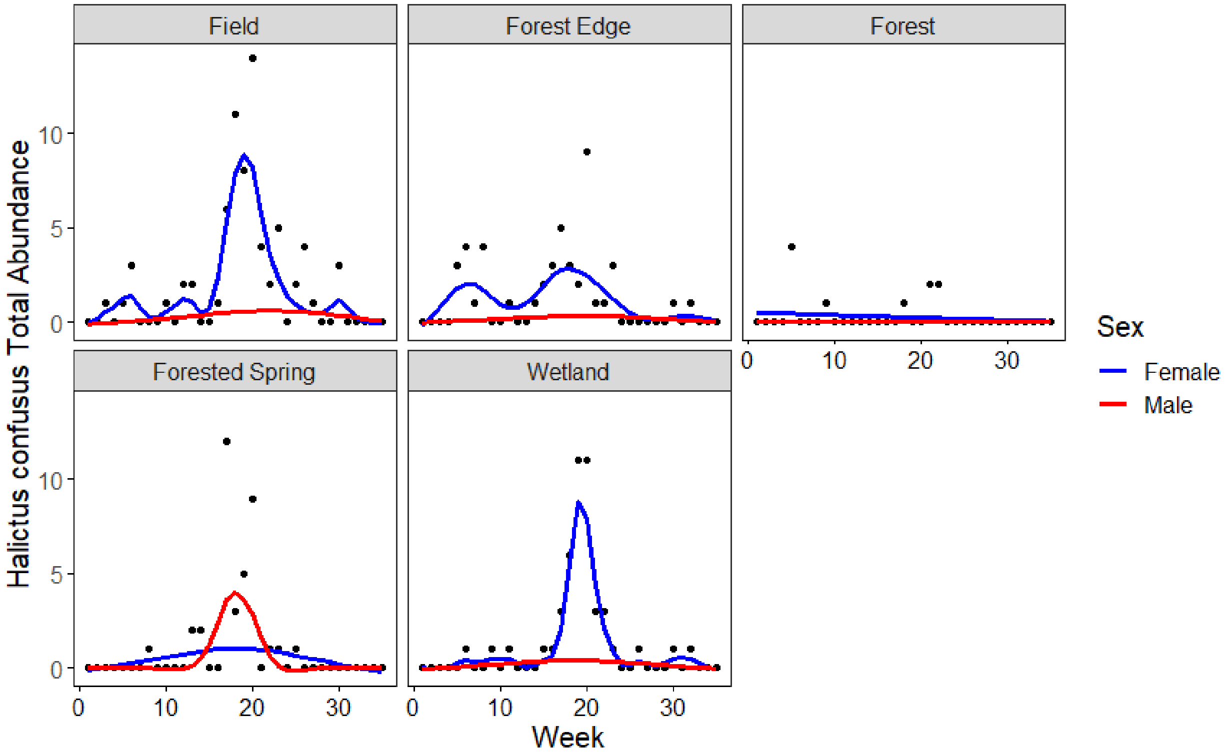

Figure 30: Abundance of the Confused Sweat Bee (*Halictus confusus*) across all habitat types and by sex. Black dots represent total number of *Halictus confusus* caught each week.

Halictus ligatus, more commonly known as the Ligated Gregarious Sweat Bee, was found across every habitat and site surveyed (except for site 14, which was a forest spring habitat) (Appendix B). This species was the 5th most abundant species collected out of the 10 target species. Abundance of *Halictus ligatus* was divided by habitat and sex (Figure 31 and Table 24). Female *Halictus ligatus* were found to have a strong preference for Field habitats and to a lesser extent Forest Edges. Their abundance peaked in mid-spring (around week 10) and mid-summer (around week 20). Males had a similar habitat preference to that of the females for Field and Forest Edge habitats, but abundance for males late-summer/early-autumn (around week 25-28). Low male population persisted throughout the collection season in Wetland habitats. All sites with recorded populations of *Halictus ligatus* sustained these populations throughout the survey season. Forests and Forested Springs were not widely utilized by either sex. Overall, *Halictus ligatus* exhibited a bivoltine life cycle with a protogynous mid-spring and mid-summer emergence.

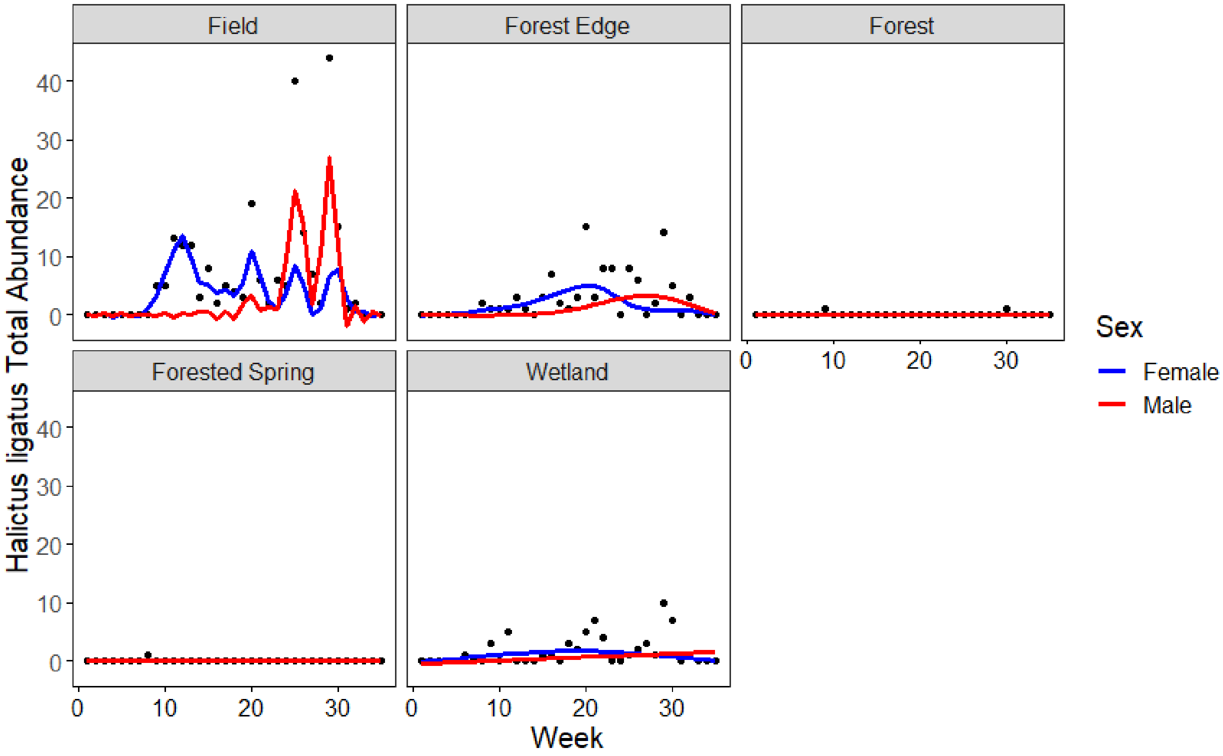

Figure 31: Abundance of the Ligated Gregarious Sweat Bee (*Halictus ligatus*) across all habitat types and by sex. Black dots represent total number of *Halictus ligatus* caught each week.

Table 23: Akaike Information Criterion (AIC) test showing that the interactive model is a significant improvement over the main effects model for the 20 GAM models of the 10 focal bee species. A & B are female, and C & D are male. Main effects model: gam(Species_Sex ~Habitat ~ Habitat +s(Week)). Interactive model: gam(Species_Sex ~Habitat ~ Habitat +s(Week, by= Habitat)).

A Model	*Apis mellifera*	*Ceratina calcarata*	*Ceratina dupla*	*Ceratina mikmaqi*	*Ceratina strenua*
Main Effects	808.7036	1390.935	1351.523	877.1706	757.466
Interaction	801.9179	1353.837	1336.241	870.9473	671.1169

B Model	*Agapostemon virescens*	*Augochlora pura*	*Augochlorella aurata*	*Halictus confusus*	*Halictus ligatus*
Main Effects	1245.845	576.2584	1303.144	658.5454	805.8422
Interaction	1162.064	567.9904	1276.949	604.5113	754.259

C Model	*Ceratina calcarata*	*Ceratina dupla*	*Ceratina mikmaqi*	*Ceratina strenua*
Main Effects	1657.017	1135.608	540.9007	523.7779
Interaction	1594.704	1125.853	522.645	502.9504

D Model	*Agapostemon virescens*	*Augochlora pura*	*Augochlorella aurata*	*Halictus confusus*	*Halictus ligatus*
Main Effects	1421.569	387.8603	528.145	464.5209	949.5605
Interaction	1207.141	364.6668	454.9365	443.9737	911.273

Table 24: GAM comparison of the abundance of bees collected for the 10 focal species in different habitat types over a 35 week period by sex. A & B are female, and C & D are male. A k value of 30 was selected to better fit the models. gam(Species_Sex~Habitat+s(Week, by=Habitat, k=30), method= “REML”)

A	*Apis mellifera*	*Ceratina calcarata*	*Ceratina dupla*	*Ceratina mikmaqi*	*Ceratina strenua*
Habitat	F value	F value	F value	F value	F value
Field	3.829***	5.623*	3.238***	2.764**	7.889***
Forest Edge	0.290	5.947***	0.899	0.215	26.290***
Forest	0.014	0.741	0.348	0.038	0.212
Forested Spring	0.046	0.438	0.003	0.033	0.000
Wetland	1.513	1.696	3.283***	2.584**	3.767***
Habitat	12.020***	7.367***	6.836***	7.975***	41.600***

B	*Agapostemon virescens*	*Augochlora pura*	*Augochlorella aurata*	*Halictus confusus*	*Halictus ligatus*
Habitat	F value	F value	F value	F value	F value
Field	18.940***	0.961	5.316***	11.426***	8.791***
Forest Edge	1.735	0.192	2.042	3.471**	5.254***
Forest	0.005	4.711***	0.003	0.539	0.001
Forested Spring	0.006	0.008	0.000	1.910	0.012
Wetland	0.546	4.196*	0.024	8.017***	1.928
Habitat	52.470***	4.168**	17.700***	10.510***	33.590***

C	*Ceratina calcarata*	*Ceratina dupla*	*Ceratina mikmaqi*	*Ceratina strenua*
Habitat	F value	F value	F value	F value
Field	124.087***	5.479***	9.037***	0.640
Forest Edge	0.397	7.444***	0.530	4.135***
Forest	6.360***	2.629	0.714	0.000
Forested Spring	0.078	0.361	0.000	0.000
Wetland	0.728	9.197***	0.823	0.067
Habitat	71.940***	7.941***	5.358***	7.573***

D	*Agapostemon virescens*	*Augochlora pura*	*Augochlorella aurata*	*Halictus confusus*	*Halictus ligatus*
Habitat	F value	F value	F value	F value	F value
Field	304.475***	0.682	5.051***	1.671	12.115***
Forest Edge	9.587***	2.315*	12.211***	0.634	3.041*
Forest	0.009	5.005***	0.004	0.000	0.000
Forested Spring	0.635	0.011	0.000	6.768***	0.000
Wetland	8.927***	4.204**	1.250	0.857	2.664
Habitat	447.500***	2.448*	18.830***	2.265*	11.490***

DISCUSSION

In this study I investigated bee or wasp communities numbers over the flight season in a variety of habitats on the landscape and made inferences about movement across these habitats. Components of the landscape, such as the floral resources available, the richness of floral resources, and the vegetation community were also studied. My 10 focal bee species, which were abundant and easily identifiable, show how differently species are interacting with the landscape. The abundances of the species that were found in each habitat and site varied, and significant differences and movements were recorded. Habitat was found to be a significant factor along with sex and week/time in observing changes in the pollinator communities. Resource availability appeared to play a lesser role and pollinator abundance was not always correlated with resource abundance (Table 21). The results of this study could have broad ranging impacts on pollinator conservation and restoration activities. I did find evidence of population movement and selective preference of habitat that differed by sex for bees on the landscape. Future pollinator conservation projects should look at the impacts of heterogeneity on the landscape in the area they are being conducted to provide the greatest chance for conservation success.

Vegetation Community

Overall, the landscape of the McMaster Research and Conservation Corridor is quite diverse. The plant communities at each site were quite speciose, even for a site under more urban pressures. Wetlands were more diverse overall and forests were the least diverse. Wetland and forest sites at MFNP had lower %cover of introduced species than sites found at McMaster University. This relationship was not present in the field and forest edge sites, where the breakdown of introduced and native species remained fairly consistent between the two geographic areas. Support is lended to the theory that wetlands and forests are more susceptible to invasion than fields and meadows (Rose & Hermanutz, 2004; Zedler & Kercher, 2004; Junk et al., 2006; Matthews et al., 2009). If wetlands and forests are more sensitive to disturbance pressures, it would likely indicate that their pollinator communities would also be sensitive. Floristic quality was supposed to indicate the habitat quality of my given sites. The FQI scores trees higher than most forbs and therefore forests ended up with the highest FQI values. This could lead to the incorrect assumption that forests would be the highest quality habitats for pollinators. In this case the FQI was a poor estimate of the quality of forest sites. It did however provide appropriate scoring for the other three habitats, fields, forest edges, and wetlands. Future studies should consider treating the understory and canopy as two separate FQI values.

Overall bee and wasp abundance did not appear to be directly correlated with overall floral resource availability. The abundance of pollinators and the abundance and richness of floral resources followed similar curves, however there was a time delay between the two of them. Bee and wasp abundance would peak approximately 5 weeks before that of floral resources. Interestingly, bee abundance followed a similar trend to introduced floral species richness and abundance, whereas wasps followed a similar trend to native floral species richness and abundance. Introduced floral species were found to have a spring peak, as well as correlated with overall bee abundance. Whereas native floral species were correlated with an autumn/late-summer peak, as was overall wasp abundance. It is unclear what this relationship may mean for plant-pollinator interactions in this area and if the native plant-pollinator interactions are being interrupted (Dante et al., 2013; Flo et al., 2018). Introduced species are evidently important sources of pollen and nectar for bees and wasps early on in the spring season. This is an important consideration when looking to support a local pollinator community through restoration practices. If early flowering native species are not present, it is imperative to allow introduced species to remain to provide the needed floral resources on the landscape. In these such cases introduced species may be able to fill these resource voids (Mandelik et al., 2012; Guezen & Forrest, 2021).

Wasp Community

Wasps aretaxonomically much more diverse than their bee counterparts and many of them provide pollination services, even if accidentally (Aluri et al., 1998; Brock et al., 2021). Research is lacking on the seasonal and habitat differences of the wasp community, because conservation groups and researchers typically cover the charismatic bees. Wasps play an important role in the environment beyond their role in pollination. They are experts at stabilizing invertebrate populations through their parasitism, where most wasps will provision their nests with paralyzed prey. Adults visit flowers to access pollen and nectar resources or to hunt (Cope et al., 2019; Brock et al., 2021). From the 7 most abundant families analyzed it was clear that there was habitat specialization and preference. Vespid wasps associated with open areas in the forest edges and fields. Dryinids were clear forest specialists, as they were collected in large numbers only in forests and forested springs. All other families showed an overall generalist lack of preference for a specific habitat. Since this study only looked at the family level it is possible that other preferences and patterns exist at the genus or species level. Wasp activity and abundance peaked in the mid-summer for all habitats, although they were most abundant in forests. This indicates that even though wasps have greater diversity than bees, their life history on the landscape is not as complex. Wasps are following similar abundance cycles irrespective to habitat type. This could be due to other factors not looked at in this study, such as the abundance of their prey source. The importance of wasps as pollinators is often overlooked and any pollinator conservation/restoration projects should look to enhance wasp habitats alongside bees.

Bee Community

Although overall bees were most abundant in the spring, the intricacies of their relationship within the landscape and season were more complicated. Different families were observed as having different relationships with the landscape. Andrenids were the only family to heavily utilize forest habitats, with habitat being a statistically significant factor across all families (p=*). When the 10 focal species were analyzed, a wide range of landscape preferences and movements were found. What was most interesting is that there were significant differences between male and female bees of the same species in where they would forage and be present on the landscape. Since pan and vane traps are meant to mimic flowers, it can be assumed that all collected bees were attempting to forage on the traps. This area of pollinator research is not well studied, but the results support other studies in the field (Roswell et al., 2019; Urban-Mead et al., 2021). The interactions between species, sex, and habitat were all statistically significant. Proving that male and female bees do not follow the same habitat-use cycles. This has important ramifications for conservation work, as now both life histories must be considered for effective restoration.

The introduced *Apis mellifera* appears to have little impact, impact in this scenario being the level of interspecies competition, on competition within forest communities, as it rarely forages in them. It does however have a large impact on open field habitats where it is a major source of competition with our native bees (Schaffer et al., 1983; Gross, 2001; Thomson, 2004; Hatfield et al., 2018; Russo et al., 2021; Page & Williams, 2022). Wetlands also appear to be impacted but not until much later at the end of the season. As polylectic generalists, honey bees have the ability to forage on a wide variety of flowers. From a conservation lens, excluding honey bees from high quality meadows and other open field types would be extremely beneficial to native bees. Since it is their primary foraging habitat, by excluding them from that area you would be opening up the resources to native bees (Goulson, 2003; Cane & Tepedino, 2016; Bommarco et al., 2021).

Forests were consistently being used the least amongst the focal species and appear to not have many specialist bees, except for *Augochlora pura* identified in this study which favoured forest habitats. Species did not appear to follow floral abundance trends between different habitats. The abundance of bees of a focal species was tied to a specific habitat, but not the amount of resources present. Some observed habitats had similar resource availability (i.e. Field and Forest Edge), but differing proportions of bee community present when surveying. This suggests another factor at play, which I believe to be habitat preference. Species that had a bimodal distribution were reported as bivoltine and species with a unimodal distribution were reported as univoltine (Vickruck, 2010; Cordeo, 2011; Richards et al., 2011; Onuferko, 203; Shell & Rehan, 2015). However, the specific life history traits and requirements for the 10 focal species were not identified for this project. These life history traits may be able to provide more information on the differences we see in the bee community. Even closely related groups, like the four species of *Ceratina sp.* (all small bodied carpenter bees of roughly the same size), all showed distinctly different habitat preferences that varied based off of sex and species. More research is needed in this field to appreciate and comprehend the intricacies at play and to better understand the movement seen on the landscape. With a habitat preference that changes by sex and time of year for a given species any restoration or conservation activities for that species or group of species must focus its efforts on all utilized habitats. Failure to do this will potentially disrupt the species life history pattern and lead to its decline from a given area (Roswell et al., 2019; Bogusch et al., 2020; Urban-Mead et al., 2021). All habitat types surveyed were utilized at different times of the year and by different species and sexes. Showing the need for habitat complexity and heterogeneity on the landscape to create diverse and resilient bee communities.

CONCLUSION

This study proves that there is movement of bees and wasps on the landscape in this region and the critical role habitat heterogeneity likely plays in their life cycles. Additional research in this area should look at attempting to replicate these results at other localities and compare larger spatial scales. These results are supported by the notion that heterogeneity on the landscape leads to diversity on said landscape (Kremen et al., 2018; Vickruck et al., 2019; Bogusch et al., 2020). Restoring habitat for pollinators is critically important, but what should be considered in these conservation strategies is the importance of already existing habitats and remnant pockets on the landscape. Protecting these pockets from further development/loss can be critical to maintaining a local population of bee or another insect. Once lost from a location recolonization is not always possible or will have a large timescale. Additionally, with movement on the landscape by sexes within a species, it is important to realize that by losing or not providing a particular desired habitat, we are losing an environment necessary for that species life history. This may cause the species to not be able to persist at its present location or be able to colonize any new locations, leading to the loss or absence of that species from a given landscape (Roswell et al., 2019; Bogusch et al., 2020; Urban-Mead et al., 2021). Protecting existing heterogeneity to prevent this from happening is critically important. This goes hand in hand with changing how land managers and conservation organizations evaluate pollinators on the landscape and their approaches to restoration or re-creation of habitats. It is time to move away from the concept of continuous meadows and prairies and to move to a mosaic concept where a variety of habitats are placed and protected on the landscape. This will ensure that all stages of a pollinator’s life are protected and that the preferences in species and sexes are realized and will hopefully lead to more successful restoration and conservation projects.

WORKS CITED

Aluri, J. S. R., Reddi, C. S. & Das, K. R. (1998). Temporal dioecism and pollination by wasps and bees in Allophylus serratus (Roxb.) Radlk. (Sapindaceae). *Plant Species Biology* 13, 1–5.

Andrachuk, H. (2014). The quality of citizen scientist's bee observations: An evaluation of Pollinator Watch at Royal Botanical Gardens and the rare Charitable Research Reserve. University of Waterloo.

Ascher, J.S. and Pickering, J. (2020). Discover Life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). http://www.discoverlife.org/mp/20q?guide=Apoidea_species.

Arduser, M. (2019). *Hoplitis* of the tallgrass prairie region and eastern North America.

Baldock, K. C., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Morse, H., Osgathorpe, L. M., Potts, S. G., Robertson, K. M., Scott, A. V., Staniczenko, P. P., Stone, G. N., Vaughan, I. P., & Memmott, J. (2019). A systems approach reveals urban pollinator hotspots and conservation opportunities. *Nature Ecology & Evolution*, *3*(3), 363–373. https://doi.org/10.1038/s41559-018-0769-y

Ballare, K. M., Neff, J. L., Ruppel, R., and Jha, S.. (2019). Multi-scalar drivers of biodiversity: local management mediates wild bee community response to regional urbanization. *Ecological Applications* 29(3):e01869. 10.1002/eap.1869

Batra, S.W.T. (1980). Ecology, Behavior, Pheromones, Parasites and Management of the Sympatric Vernal Bees *Colletes inaequalis*, *C. thoracicus*, and *C. validus*. *Journal of the Kansas Entomological Society*, 53(3): pp. 509-538.

Bee City Canada. (2022). Bee City Canada. Retrieved from https://beecitycanada.org/

Bennett, A.B. & Isaacs, R. (2014). Landscape composition influences pollinators and pollination services in perennial biofuel plantings. *Agriculture, Ecosystems & Environment*, 193:1-8. DOI:10.1016/j.agee.2014.04.016.

Benton, T.G., Vickery, J.A., Wilson, J.D. (2003). Farmland biodiversity: is habitat heterogeneity the key?. *Trends Ecol Evol* 18(4):182–188

Bogusch, P., Heneberg, P. & Astapenková, A. (2020). Habitat requirements of wetland bees and wasps: several reed-associated species still rely on peaty meadows and other increasingly rare wetland habitats. *Wetlands Ecol Manage* 28, 921–936. https://doi.org/10.1007/s11273-020-09758-5

Bohart, R.M., & Kimsey, L.S. (1979). Key To The Species Of Ectemnius In America North Of Mexico With Notes And Description Of A New Species (Hymenoptera, Sphecidae). *Proceedings of the Entomological Society of Washington*, 81(3), 486-498.

Bommarco, R., Lindstrom, S.A.M., Raderschall, C.A., Gagic, V., Lundin, O. (2021). Flower strips enhance abundance of bumble bee queens and males in landscapes with few honey bee hives. *Biological Conservation*, 263(1093636). doi.org/10.1016/j.biocon.2021.109363

Bradley, J.C. (1917). Contributions toward a Monograph of the Mutillidae and Their Allies of America North of Mexico. IV. A Review of the Myrmosidae. *Transactions of the American Entomological Society*, 43(3), 247-290. http://www.jstor.org/stable/25076972.

Brittain, C.A., Vighi, M., Bommarco, R., Settele, J., & Potts, S.G. (2010). Impacts of a pesticide on pollinator species richness at different spatial scales. *Basic and Applied Ecology*, 11(2):106-115. doi.org/10.1016/j.baae.2009.11.007

Brock, R.E., Cini, A., & Sumner, S. (2021). Ecosystem services provided by aculeate wasps. *Biological Reviews*, 96: 1645-1675. doi: 10.1111/brv.12719

Brown, C.S., Bugg, R.L. (2001) Effects of established perennial grasses on introduction of native forbs in California. *Restoration Ecology*, 9:38–48

Brown, M.J.F. & Paxton, R.J. (2009). The conservation of bees: a global perspective. *Apidologie*, 40: 410-416. DOI: 10.1051/apido/2009019

Buck, M., Marshall, S.A. and Cheung D.K.B. (2008). Identification Atlas of the Vespidae (Hymenoptera, Aculeata) of the northeastern Nearctic region. *Canadian Journal of Arthropod Identification* No. 5: 492 pp. https://doi: 10.3752/cjai.2008.05.

Buck, M., Paiero, S.M., & Marshall, S.A. (2005). New records of native and introduced aculeate Hymenoptera from Ontario, with keys to eastern Canadian species of *Cerceris* (Crabronidae) and eastern Nearctic species of *Chelostoma* (Megachilidae). *Journal of the Entomological Society of Ontario*, 136: 37-52.

Bulmer, M. G. (1983). Models for the evolution of protandry in insects. *Theoretical Population Biology*, *23*(3), 314–322. https://doi.org/10.1016/0040-5809(83)90021-7

Bukovinszky, T., Verheijen, J., Zwerver, S., Klop, E., Biesmeijer, J. C., Wäckers, F. L., Prins, H. H. T., & Kleijn, D. (2017). Exploring the relationships between landscape complexity, wild bee species richness and reproduction, and pollination services along a complexity gradient in the Netherlands. *Biological Conservation*, *214*, 312–319. https://doi.org/10.1016/j.biocon.2017.08.027

Cane, J.H. (2001). Habitat Fragmentation and Native Bees: a Premature Verdict?. *Conservation Ecology*, 5(1).

Cane, J.H. & Tepedino, V.J. (2016). Gauging the Effect of Honey Bee Pollen Collection on Native Bee Communities. *Conservation Letters*, 10(2), 205–210. doi: 10.1111/conl.12263

Carrié, R., Andrieu, E., Ouin, A., & Steffan-Dewenter, I. (2017). Interactive effects of landscape-wide intensity of farming practices and landscape complexity on wild bee diversity. *Landscape Ecology*, *32*(8), 1631–1642. https://doi.org/10.1007/s10980-017-0530-y

City of Toronto (2016). Bees of Toronto: A guide to their remarkable world. *City of Toronto Biodiversity Series*.

Colla, S.R. (2022). The potential consequences of 'bee washing' on wild bee health and conservation. *International Journal for Parasitology: Parasites and Wildlife*, 18: 30-32. doi.org/10.1016/j.ijppaw.2022.03.011

Colla, S.R. & Dumesh, S. (2010). The Bumble Bees of Southern Ontario: Notes on Natural History and Distribution. Journal of the Entomological Society of Ontario, Vol. 141, p39-68. 30p.

Colla, S.R., Otterstatter, M.C., Gegear, R.J., Thomson, J.D., (2006). Plight of the bumble bee: pathogen spillover from commercial to wild populations. *Biol. Conserv*. 129 (4), 461–467.

Committee on the Status of Pollinators in North America (2007). Status of Pollinators in North America. *National Academies Press*

Connelly, H., Poveda, K., & Loeb, G. (2015). Landscape simplification decreases wild bee pollination services to strawberry. *Agriculture, Ecosystems & Environment*, 211: 51-56. doi.org/10.1016/j.agee.2015.05.004.

Cope, G.C., Campbell, J.W., Grodsky, S.M., Ellis, J.D. (2019). Evaluation of nest-site selection of ground-nesting bees and wasps (Hymenoptera) using emergence traps. *The Canadian Entomologist*, 151: 260–271. doi:10.4039/tce.2019.3

Corbet, S. A., Bee, J., Dasmahapatra, K., Gale, S., Gorringe, E., La Ferla, B., Moorhouse, T., Trevail, A., Van Bergen, Y., & Vorontsova, M. (2001). Native or exotic? double or single? evaluating plants for pollinator-friendly gardens. *Annals of Botany*, *87*(2), 219–232. https://doi.org/10.1006/anbo.2000.1322

Cordeo, R.L. (2011). Annual Variation in Bee Community Structure in the Context of Disturbance (Niagara Region, South-Western Ontario). Department of Biological Sciences, Brock University.

Coutinho, J. G., Garibaldi, L. A., & Viana, B. F. (2018). The influence of local and landscape scale on single response traits in bees: A meta-analysis. *Agriculture, Ecosystems & Environment*, *256*, 61–73. https://doi.org/10.1016/j.agee.2017.12.025

Crane, J.H. (2016). Adult pollen diet essential for egg maturation by a solitary *Osmia* bee. *Journal of Insect Physiology*, 95: 105-109. doi.org/10.1016/j.jinsphys.2016.09.011.

Cranmer, L., McCollin, D., & Ollerton, J. (2012). Landscape structure influences pollinator movements and directly affects plant reproductive success. *Oikos*, 121: 562-568. DOI:10.1111/j.1600-0706.2011.19704.x.

Dante, S. K., Schamp, B. S., & Aarssen, L. W. (2013). Evidence of deterministic assembly according to flowering time in an old-field Plant Community. *Functional Ecology*, *27*(2), 555–564. https://doi.org/10.1111/1365-2435.12061

Daubenmire, R. (1959) A canopy-coverage method of vegetational analysis. *Northwest Science*, 33:43–64

Droege, S. (2015). The very handy manual: How to catch and identify bees and manage a collection. USGS Bee Inventory and Monitoring Lab (BIML), Patuxent Wildlife Research Center, Beltsville, Maryland.

Dumesh, S., Sheffield, C.S. (2012). Bees of the Genus *Dufourea* Lepeletier (Hymenoptera: Halictidae: Rophitinae) of Canada. *Canadian Journal of Arthropod Identification* No. 18. https://doi: 10.3752/cjai.2012.20.

Eeraerts, M., Clymans, R., Kerckvoorde, V. V., & Beliën, T. (2022). Nesting material, phenology and landscape complexity influence nesting success and parasite infestation of a trap nesting bee. *Agriculture, Ecosystems & Environment*, *332*, 107951. https://doi.org/10.1016/j.agee.2022.107951

Farrar, J. L. (2017). *Trees in Canada*. Natural Resources Canada, Canadian Forest Service and Fitzhenry & Whiteside Ltd.

Fawcett, F.V.E., Minckley, R.L., and Neff, J.L. (2019). "CHAPTER 3. The Solitary Bee Life Cycle". The Solitary Bees: Biology, Evolution, Conservation. *Princeton: Princeton University Press*. pp. 37-69. https://doi.org/10.1515/9780691189321-004.

Felderhoff, J., Gathof, A.K., Buchholz, S., Egerer, M. (2022). Vegetation complexity and nesting resource availability predict bee diversity and functional traits in community gardens. *Ecological Applications*. DOI: 10.1002/eap.2759.

Fisogni, A., de Manincor, N., Bertelsen, C. D., & Rafferty, N. E. (2022). Long-term changes in flowering synchrony reflect climatic changes across an elevational gradient. *Ecography*, *2022*(2). https://doi.org/10.1111/ecog.06050

Flo, V., Bosch, J., Arnan, X., Primante, C., Martín González, A. M., Barril-Graells, H., & Rodrigo, A. (2018). Yearly fluctuations of flower landscape in a Mediterranean scrubland: Consequences for Floral Resource Availability. *PLOS ONE*, *13*(1). https://doi.org/10.1371/journal.pone.0191268

Fox, J. and Weisberg, S. (2019). An {R} Companion to Applied Regression, Third Edition. Thousand Oaks CA: Sage. https://socialsciences.mcmaster.ca/jfox/Books/Companion/

Frantine-Silva, W., Augusto, S. C., Tosta, T. H., Pacheco, A. S., Kotelok-Diniz, T., Apolinário da Silva, C., & Sofia, S. H. (2021). Genetic diversity and population structure of orchid bees from the Brazilian Savanna. *Journal of Apicultural Research*, *60*(3), 385–395. https://doi.org/10.1080/00218839.2021.1898788.

Fredenburg, A.N. (2020). Diversity, phenology, and host associations of wild bees (Hymenoptera: Anthophila) in Thunder Bay, Ontario. Master of Science Thesis, Faculty of Natural Resources Management, Lakehead University, Thunder Bay, ON. 83 pp.

Freiria, G.A., Ruim, J.B., de Souza, R.F., & Sofia, S.H. (2012). Population structure and genetic diversity of the orchid bee Eufriesea violacea (Hymenoptera, Apidae, Euglossini) from Atlantic Forest remnants in southern and southeastern Brazil. *Apidologie,* 43: 392-402. doi.org/10.1007/s13592-011-0104-y.

Fye, R.E. (1972). The effect of forest disturbances on populations of wasps and bees in northwestern Ontario (Hymenoptera: Aculeata). *The Canadian Entomologist*, 104: 1623-1633. doi.org/10.4039/Ent1041623-10

Galili, T. (2015). dendextend: an R package for visualizing, adjusting, and comparing trees of hierarchical clustering. *Bioinformatics*. DOI: 10.1093/bioinformatics/btv428

Galpern, P., Best, L. R., Devries, J. H., & Johnson, S. A. (2021). Wild bee responses to cropland landscape complexity are temporally-variable and taxon-specific: Evidence from a highly replicated pseudo-experiment. *Agriculture, Ecosystems & Environment*, *322*, 107652. https://doi.org/10.1016/j.agee.2021.107652

Gardner, J., & Gibbs, J. (2022). New and little-known Canadian *Lasioglossum* (Dialictus) (Hymenoptera: Halictidae) and an emended key to species. *The Canadian Entomologist*, 154(1), E3. doi:10.4039/tce.2021.47

GBIF.org (December 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.5bkzjz

Gibbs, J. (2010). Revision of the metallic species of Lasioglossum (Dialictus) in Canada (Hymenoptera, Halictidae, Halictini). *Zootaxa*, 2591, 1-382. 10.11646/zootaxa.2591.1.1.

González-Varo, J. P., Biesmeijer, J. C., Bommarco, R., Potts, S. G., Schweiger, O., Smith, H. G., Steffan-Dewenter, I., Szentgyörgyi, H., Woyciechowski, M., & Vilà, M. (2013). Combined effects of global change pressures on animal-mediated pollination. *Trends in Ecology & Evolution*, *28*(9), 524–530. https://doi.org/10.1016/j.tree.2013.05.008

Goulet, H., & Huber, J.T. (1993). Hymenoptera of the world: An identification guide to families. Agriculture Canada.

Goulson, D. (2003). Effects of introduced bees on native ecosystems. *Annu. Rev. Ecol. Evol. Syst*, 34: 1-26. doi: 10.1146/annurev.ecolsys.34.011802.132355

Goulson, D., Lye, G.C., & Darvill, B. (2008). The decline and conservation of bumblebees. *Annual review of entomology*.

Goulson, D., Nicholls, E., Botias, C., & Rotheray, E.L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347(6229). DOI: 10.1126/science.1255957.

Grixti, J.C. & Packer, L. (2006). Changes in the bee fauna (Hymenoptera: Apoidea) of an old field site in southern Ontario, revisited after 34 years. *The Canadian Entomologist*, 138: 147–164. doi.org/10.4039/n05-034

Gross, C.L. (2001). The effect of introduced honeybees on native bee visitation and fruit-set in *Dillwynia juniperina* (Fabaceae) in a fragmented ecosystem. *Biological Conservation*, 102: 89-95.

Guezen, J. M., & Forrest, J. R. (2021). Seasonality of floral resources in relation to bee activity in Agroecosystems. *Ecology and Evolution*, *11*(7), 3130–3147. https://doi.org/10.1002/ece3.7260

Hall, D.M. & Martins, D.J. (2020). Human dimension to insect pollinator conservation. *Current Opinion in Insect Science*, 38: 107-114. doi.org/10.1016/j.cois.2020.04.001.

Hall, M.A., Stavert, J.R., Saunders, M.E., Barr, S., Haberle, S.G., & Rader, R. (2021). Pollen–insect interaction meta-networks identify key relationships for conservation in mosaic agricultural landscapes. *Ecological Applications*, 32(4): e2537. DOI: 10.1002/eap.2537.

Hallett, P.E. (2001). A method for 'Hiving' solitary bees and wasps. *American Bee Journal*, 133 – 1136.

Hallett, A. C., Mitchell, R. J., Chamberlain, E. R. & Karron, J. D. (2017). Pollination success following loss of a frequent pollinator: the role of compensatory visitation by other effective pollinators. *AoB PLANTS* 9, plx020.

Hallowell, A. C. (2001). *Fern finder: A guide to native ferns of central and Northeastern United States and Eastern Canada*. Nature Study Guild.

Haokip, S.W., Shankar, K., and Lalrinngheta, J.. (2020) Climate change and its impact on fruit crops. *J Pharmacogn Phytochem.* 9(1):435-438.

Harris, J. G., & Harris, M. W. (2001). *Plant identification terminology: An illustrated glossary*. Spring Lake.

Hatfield, R.G., Jepsen, S., Vaughan, M., Black, S., & Lee-Mader, E. (2018). An overview of the potential impacts of honey bees to native bees, plant communities, and ecosystems in wild landscapes: Recommendations for land managers. The Xercex Society for Invertebrate Conservation.

Heinrich, G. H. (1960). Synopsis of Nearctic Ichneumoninae Stenopneusticae with particular reference to the Northeastern Region (Hymenoptera): Part I introduction, key to Nearctic genera of Ichneumoninae Stenopneusticae and synopsis of the Protichneumonini North of Mexico. *Memoirs of the Entomological Society of Canada*, *92*(S15), 5–87. https://doi.org/10.4039/entm9215fv.

Heinrich, G. H. (1961a). Synopsis of Nearctic Ichneumoninae Stenopneusticae with particular reference to the Northeastern Region (Hymenoptera): Part III Synopsis of the Ichneumoni: Genera *Ichneumon* and *Thyrateles*. *Memoirs of the Entomological Society of Canada*, *93*(S21), 211–368. https://doi.org/10.4039/entm9321fv.

Heinrich, G. H. (1961b). Synopsis of Nearctic Ichneumoninae Stenopneusticae with particular reference to the Northeastern Region (Hymenoptera): Part V Synopsis of the Ichneumonini: Genera *Protopelmus, Patrocloides, Probolus, Stenichneumon, Aoplus, Limonethe, Hybophorellus, Rubicundiella, Melanichneumon, Stenobarichneumon, Platylabops, Hoplismenus, Hemihoplis, Trogomorpha*. *Memoirs of the Entomological Society of Canada*, *93*(S26), 511–671. https://doi.org/10.4039/entm9326fv.

Hladik, M.L., Vandever, M., & Smalling, K.L. (2016). Exposure of native bees foraging in an agricultural landscape to current-use pesticides. *Science of the Total Environment*, 542: 469-477. doi.org/10.1016/j.scitotenv.2015.10.077

Hopwood, J.L. (2008). The contribution of roadside grassland restorations to native bee conservation. *Biological Conservation*, 141(10): 2632-2640. doi.org/10.1016/j.biocon.2008.07.026

Horstmann, S. (2021). Ecological traps in bees and butterflies. Swedish University of Agricultural Sciences, Department of Ecology.

Hristov, P., Neov, B., Shumkova, R., & Palova, N. (2020). Significance of Apoidea as Main Pollinators. Ecological and Economic Impact and Implications for Human Nutrition. *Diversity*, 12(280). doi:10.3390/d12070280.

Irazuzta, S. (n.d.). Unpublished [Thesis in preparation]. Department of Biology, McMaster University.

Johnson, A.L., Fetters, A.M. & Ashman, T.L. (2017). *New Physiologist*, 215: 1298-1305.

Junk, W. J., Brown, M., Campbell, I. C., Finlayson, M., Gopal, B., Ramberg, L., & Warner, B. G. (2006). The comparative biodiversity of seven globally important wetlands: A synthesis. *Aquatic Sciences*, *68*(3), 400–414. https://doi.org/10.1007/s00027-006-0856-z

Käpylä, M. (1978). Bionomics of five wood-nesting solitary species of bees (Hym., Megachilidae), with emphasis on flower relationships. *Biological Research Reports of the University of Jyväskylä* 5:3–89.

Kassambara, A., Mundt, F. (2020). factoextra: Extract and Visualize the Results of Multivariate Data Analyses. R package version 1.0.7, <https://CRAN.R-project.org/package=factoextra>.

Kim, J.Y. (1999). Influence of resource level on maternal investment in a leaf-cutter bee (Hymenoptera: Megachilidae). *Behav Ecol* 10:552–556.

Kleczkowski, A., Ellis, C., Hanley, N., & Goulson, D. (2017). Pesticides and Bees: ecological-economic modelling of bee populations on farmland. *Ecological Modelling*, 360, pp. 53-62.

Kline, O. & Joshi, N.K. (2020). Mitigating the Effects of Habitat Loss on Solitary Bees in Agricultural Ecosystems. *Agriculture*, 10(115). doi:10.3390/agriculture10040115.

Koh, I., Lonsdorf, E.V., Williams, N.M., Brittain, C., Isaacs, R., Gibbs, J., Ricketts, T.H. (2016). Modeling the status, trends, and impacts of wild bee abundance in the United States. *Proceedings of the National Academy of Sciences*, 113 (1), pp. 140-145. doi.org/10.1073/pnas.1517685113

Kratschmer, S., Pachinger, B., Schwantzer, M., Paredes, D., Guzmán, G., Goméz, J. A., Entrenas, J. A., Guernion, M., Burel, F., Nicolai, A., Fertil, A., Popescu, D., Macavei, L., Hoble, A., Bunea, C., Kriechbaum, M., Zaller, J. G., & Winter, S. (2019). Response of wild bee diversity, abundance, and functional traits to Vineyard Inter-row management intensity and landscape diversity across Europe. *Ecology and Evolution*, 9(7), 4103–4115. https://doi.org/10.1002/ece3.5039

Kratzer, C.A. (2022). The Social Wasps of North America. *Owlfly LLC Publishing*.

Kremen, C., M'Gonigle, L. K., & Ponisio, L. C. (2018). Pollinator community assembly tracks changes in floral resources as restored hedgerows mature in agricultural landscapes. *Frontiers in Ecology and Evolution*, *6*. https://doi.org/10.3389/fevo.2018.00170

Laverty, T.M., & Harder, L.D. (1988). The bumble bees of Eastern Canada. *The Canadian Entomologist*, 120(11): 965-987. doi:10.4039/Ent120965-11.

LeCroy, K.A., Savoy-Burke, G., Carr, D.E., Delaney, D.A., (2020). Decline of six native mason bee species following the arrival of an exotic congener. *Sci. Rep*. 10 (1), 1–9.

Levy, S. (2011). The pollinator crisis: What's best for bees. Nature, 479.

MacIvor, S.J., de Keyzer, C.W., Marshall, M.S., Thurston, G.S., & Onuferko, T.M. (2022). Establishment of the non-native horned face bee *Osmia cornifrons* and the taurus mason bee *Osmia taurus* (Hymenoptera: Megachilidae) in Canada. *PeerJ*. DOI 10.7717/peerj.14216.

MacKay, P.A. & Knerer, G. (1979). Seasonal occurrence and abundance in a community of wild bees from an old field habitat in southern Ontario. *The Canadian Entomologist*, 111: 367-376. doi.org/10.4039/Ent111367-3

Majewska, A.A. & Altizer, S. (2018). Planting gardens to support insect pollinators. *Conservation Biology*, 34(1): 15-25. doi.org/10.1111/cobi.13271.

Mandelik, Y., Winfree, R., Neeson, T., & Kremen, C. (2012). Complementary habitat use by wild bees in agro-natural landscapes. *Ecological Applications*, *22*(5), 1535–1546. https://doi.org/10.1890/11-1299.1

Martins, R.P., Antonini, Y., da Silveira, F.A., West, S.A. (1999). Seasonal variation in the sex allocation of a neotropical solitary bee. *Behavioral Ecology*, Volume 10, Issue 4, Pages 401–408. https://doi.org/10.1093/beheco/10.4.401.

Matthews, J. W., Peralta, A. L., Soni, A., Baldwin, P., Kent, A. D., & Endress, A. G. (2009). Local and landscape correlates of non-native species invasion in restored wetlands. *Ecography*, *32*(6), 1031–1039. https://doi.org/10.1111/j.1600-0587.2009.05863.x

McCravy, K.W. (2018). A Review of Sampling and Monitoring Methods for Beneficial Arthropods in Agroecosystems. *Insects*, 9(4):170. https://doi.org/10.3390/insects9040170

McHaffie, M.B. (2020). Evaluating the success of Ontario roadside restorations – an ecosystem approach. Department of Biology, McMaster University.

Medina, R.G., Fairbairn, D., Bustillos, A., Moo-Valle, H., Medina, S., and Quezada-Euan, J.J.G. (2016). Variable patterns of intraspecific sexual size dimorphism and allometry in three species of eusocial corbiculate bees. *Insect.* Soc. 63, 493–500. https://doi.org/10.1007/s00040-016-0491-1

Miljanic, A.S., Loy, X., Gruenewald, D.L., Dobbs, E.K., Gottlieb, I.G.W., Fletcher, R.J., and Brosi, B.J. (2019). Bee communities in forestry production landscapes: interactive effects of local-level management and landscape context. *Landscape Ecol* 34, 1015–1032. https://doi.org/10.1007/s10980-018-0651-y

MOECP (2020). Bumble bee diversity and abundance study. Ontario Ministry of the Environment, Conservation and Parks. Retrieved from https://data.ontario.ca/dataset/bumble-bee-diversity-and-abundance-survey

Moncada, K. (2003). The Role of Native Bees in Prairie Restoration. *Restoration and Reclamation Review*, 8(1).

Native Plant Trust. (2022). *Full key: Which group best describes your plant?* Native Plant Trust: Go Botany. Retrieved from https://gobotany.nativeplanttrust.org/full/

Natural Heritage Information Centre. (2022). *All species list*. Ontario Ministry of Natural Resources and Forestry. Retrieved from https://www.ontario.ca/page/get-natural-heritage-information

Ne'eman, G., Shavit, O., Shaltiel, L., Shmida, A. (2006). Foraging by Male and Female Solitary Bees with Implications for Pollination. *J Insect Behav.* 19, 383–401. https://doi.org/10.1007/s10905-006-9030-7

Nemésio, A., Silva, D.P., Nabout, J.C., & Varela, S. (2016). Effects of climate change and habitat loss on a forest-dependent bee species in a tropical fragmented landscape. *Insect Conservation and Diversity*, 9: 149-160. doi: 10.1111/icad.12154

Newcomb, L. (1989). *Newcomb's wildflower guide.* Little, Brown.

New Horizons Supported Services Inc. (n.d.). *Bee Bowl services: New Horizons Supported Services, Inc*. Bee Bowl Services | New Horizons Supported Services, Inc. Retrieved from https://www.nhssi.org/bee-bowl-services

NSERC-CANPOLIN. (2009). Sampling Protocol. http://www.uoguelph.ca/canpolin/Sampling/protocols.html

Olynyk, M., Westwood, A. R., & Koper, N. (2021). Effects of natural habitat loss and edge effects on wild bees and pollination services in remnant prairies. *Environmental Entomology, 50*(3), 732–743. https://doi.org/10.1093/ee/nvaa186

Onuferko, T.M. (2013). Restoration and succession of a bee community in southern St. Catharines, Ontario, within a ten-year study period. Faculty of Mathematics and Science, Brock University.

Onuferko, T.M., Kutby, R., & Richards, M.H. (2015). A list of bee species (Hymenoptera: Apoidea) recorded from three municipalities in the Niagara region of Ontario, including a new record of *Lasioglossum furunculum* Gibbs (Halictidae) in Canada. *Journal of the Entomological Society of Ontario*, 146: 3-22.

Onuferko, T.M. (2017). Cleptoparasitic Bees of the Genus *Epeolus* Latreille (Hymenoptera: Apidae) in Canada. *Canadian Journal of Arthropod Identification* No. 30. https://doi:10.3752/cjai.2017.30.

Otieno, M., Sidhu, C.S., Woodcock, B.A., Wilby, A., Vogiatzakis, I.N., Mauchline, A.L., Gikungu, M.W., and Potts, S.G. (2015). Local and landscape effects on bee functional guilds in pigeon pea crops in Kenya. *J Insect Conserv* 19, 647–658. https://doi.org/10.1007/s10841-015-9788-z

Packer, L., Genaro, J.A., and Sheffield C.S. (2007). The Bee Genera of Eastern Canada. *Canadian Journal of Arthropod Identification,* No. 3. https://doi: 10.3752/cjai.2007.03.

Page, M.L. & Williams, N.M. (2022). Honey bee introductions displace native bees and decrease pollination of a native wildflower. *Ecology*. doi: 10.1002/ecy.3939.

Papanikolaou, A.D., Kuhn, I., Frenzel, M., Kuhlmann, M., Poschlod, P., Potts, S.G., Roberts, S.P.M., & Schweiger, O. (2017). Wild bee and floral diversity co-vary in response to the direct and indirect impacts of land use. *Ecosphere*, 8(11). doi.org/10.1002/ecs2.2008.

Parker, F. D. (1962). On the subfamily Astatinae, with a systematic study of the genus *Astata* of America North of Mexico (Hymenoptera: Sphecidae). *Annals of the Entomological Society of America*, *55*(6), 643–659. https://doi.org/10.1093/aesa/55.6.643.

Parmesan, C., Ryrholm, N., Stefanescu, C., Hill, J.K., Thomas, C.D., Descimon, H., Huntley, B., Kaila, L., Kullberg, J., Tammaru, T., Tennent, W.J., Thomas, J.A., Warrant, M. (1999). Poleward shifts in geographical ranges of butterfly species associated with regional warming, *Nature* 399, 579–583.

Peterson, J.H., Roitberg, B.D. & Peterson, J.H. (2006). Impacts of flight distance on sex ratio and resource allocation to offspring in the leafcutter bee, *Megachile rotundata*. *Behav Ecol Sociobiol* 59, 589–596. https://doi.org/10.1007/s00265-005-0085-9,

Pindar, A.N. (2013). The effect of fire disturbance on bee community composition in oak savannah habit at in southern Ontario, Canada. Department of Biology, York University.

Polley, H.W., Wilsey, B.J. and Derner, J.D. (2007), Dominant species constrain effects of species diversity on temporal variability in biomass production of tallgrass prairie. *Oikos*, 116: 2044-2052. https://doi-org/10.1111/j.2007.0030-1299.16080.x

Portman, Z.M., Bruninga-Socolar, B., Cariveau, D.P. (2020). The State of Bee Monitoring in the United States: A Call to Refocus Away From Bowl Traps and Towards More Effective Methods, *Annals of the Entomological Society of America*, 113 (5), 337–342, https://doi.org/10.1093/aesa/saaa010

Portman, Z.M., Arduser, M., Lane, I.G., & Cariveau, D.P. (2022). A review of the Augochloropsis (Hymenoptera, Halictidae) and keys to the shiny green Halictinae of the midwestern United States. *ZooKeys*, 1130: 103–152. https://doi.org/10.3897/zookeys.1130.86413.

Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J., & Vanbergen, A.J. (2016). *Nature*, 540: 220-229. doi.org/10.1038/nature20588.

Pound, M.J., Vinkenoog, R., Hornby, S., Benn, J., Goldberg, S., Keating, B. & Woollard, F. (2022). Determining if honey bees (*Apis mellifera*) collect pollen from anemophilous plants in the UK. *Palynology*. DOI: 10.1080/01916122.2022.2154867.

Persson, A.S., Rundlöf, M., Clough, Y., and Smith, H.G. (2015). Bumble bees show trait-dependent vulnerability to landscape simplification. *Biodivers Conserv* 24, 3469–3489. https://doi.org/10.1007/s10531-015-1008-3

Prendergast, K. S., Menz, M.H.M., Dixon, K.W., & Bateman, P.W. (2020). The relative performance of sampling methods for native bees: an empirical test and review of the literature. *Ecosphere* 11(5):e03076. 10.1002/ecs2. 3076

Pyke, G.H., Thomson, J.D., Inouye, D.W., & Miller, T.J. (2016). Effects of climate change on phenologies and distributions of bumble bees and the plants they visit. *Ecosphere* 7(3):e01267. 10.1002/ecs2.1267

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rehan, S. & Sheffield, C. (2011). Morphological and molecular delineation of a new species in the *Ceratina dupla* species-group (Hymenoptera: Apidae: Xylocopinae) of eastern North America. *Zootaxa*, 2873. 35-50. 10.11646/zootaxa.2873.1.3.

Richards, M. H., Rutgers-Kelly, A., Gibbs, J., Vickruck, J. L., Rehan, S. M., & Sheffield, C. S. (2011). Bee diversity in naturalizing patches of Carolinian grasslands in southern Ontario, Canada. *The Canadian Entomologist*, *143*(3), 279–299. https://doi.org/10.4039/n11-010

Rivernider, R., Venturini, E., & Drummond, F.A. (2017). *Phleum pratense* (Poales: Poaceae), a Pollen Forage for Native Bumble Bees Bombus Latrielle (Hymenoptera: Apidae). *J. of the Kansas Entomological Society,* 90(1):63-68. doi.org/10.2317/0022-8567-90.1.63.

Romankova, T. (2003). Bees of genus *Colletes* of Ontario (Hymenoptera, Apoidea, Colletidae). *Journal of the Entomological Society of Ontario*, 134: 91-106.

Romankova, T. (2007). Bees of the genus *Hylaeus* of Ontario (Hymenoptera, Apoidea, Colletidae). *Journal of the Entomological Society of Ontario,* 138: 137-154.

Rose, M., Hermanutz, L. (2004). Are boreal ecosystems susceptible to alien plant invasion? Evidence from protected areas. *Oecologia* 139, 467–477. https://doi.org/10.1007/s00442-004-1527-1.

Roswell, M., Dushoff, J., & Winfree, R. (2019). Male and female bees show large differences in floral preference. *PLOS ONE*, *14*(4). https://doi.org/10.1371/journal.pone.0214909

Royer, F., & Dickinson, R. (1999). *Weeds of Canada and the Northern United States: A guide for identification*. University of Alberta Press.

Russo, L., de Keyzer, C.W., Harmon-Threatt, A.N., LeCroy, K.A., & MacIvor, S. (2021). The managed-to-invasive species continuum in social and solitary bees and impacts on native bee conservation. *Current Opinion in Insect Science*, 46:43–49. doi.org/10.1016/j.cois.2021.01.001

Rutgers-Kelly, A.C. & Richards, M.H. (2013). Effect of meadow regeneration on bee (Hymenoptera: Apoidea) abundance and diversity in southern Ontario, Canada. *The Canadian Entomologist*, 145: 655–667. doi.org/10.4039/tce.2013.42

Schäffler, I. and Dötterl, S. (2011). A day in the life of an oil bee: phenology, nesting, and foraging behavior. *Apidologie* 42:409–424.

Schaffer, W.M., Zeh, D.W., Buchmann, S.L., Kleinhans, S., Schaffer, V.M., & Antrim, J. (1983). Competition for nectar between introduced honey bees and native North American bees and ants. *Ecology*, 64(3) pp. 564-577.

Scheper, J., Bommarco, R., Holzschuh, A., Potts, S. G., Riedinger, V., Roberts, S. P., Rundlöf, M., Smith, H. G., Steffan-Dewenter, I., Wickens, J. B., Wickens, V. J., & Kleijn, D. (2015). Local and landscape-level floral resources explain effects of wildflower strips on wild bees across four European countries. *Journal of Applied Ecology*, *52*(5), 1165–1175. https://doi.org/10.1111/1365-2664.12479

Sexton, A.N. & Emery, S.M. (2020). Grassland restorations improve pollinator communities: a meta-analysis. Journal of Insect Conservation, 24: 719-726. https://doi.org/10.1007/s10841-020-00247-x.

Sheffield, C. S., Kevan, P. G., & Smith, R. F. (2003). Bee Species of Nova Scotia, Canada, with New Records and Notes on Bionomics and Floral Relations (Hymenoptera: Apoidea). *Journal of the Kansas Entomological Society*, 76(2), 357–384. http://www.jstor.org/stable/25086122

Sheffield, C.S., Ratti, C., Packer, L., Griswold, T. (2011). Leafcutter and Mason Bees of the Genus *Megachilidae* Latreille (Hymenoptera: Megachilidae) in Canada and Alaska. *Canadian Journal of Arthropod Identification* No. 18. https://doi.org/10.3752/cjai.2011.18.

Shreeves, G. and Field, J. (2008). Parental care and sexual size dimorphism in wasps and bees. *Behav Ecol Sociobiol* 62, 843–852. https://doi.org/10.1007/s00265-007-0510-3

Siede, R., Eickhoff, B., Freyer, C., Windpassinger, S., & Buchler, R. (2021). The bioenergy crop *Sorghum bicolor* is a relevant pollen source for honey bees (*Apis mellifera*). *GCB Bioenergy*, 13(7): 1149-1161. DOI: 10.1111/gcbb.12835

Soroye, P., Newbold, T., Kerr, J. (2020). Climate change contributes to widespread declines among bumble bees across continents. *Science*, 367: 685-688. DOI: 10.1126/science.aax8591

SpringStar. (2020). *Moth preventatives for storage, home and garden*. SpringStar. Retrieved from https://www.springstar.net/collections/outdoor-products/products/

Steffan-Dewenter, I. (2002). Landscape context affects trap-nesting bees, wasps, and other natural enemies. *Ecological Entomology*, 27: 631-637.

Taniguchi, S. (1956). Biological Studies on the Japanese bees (III) : request in flower-visiting of infrasocial bees. 兵庫農科大学

Terrell, E.E. & Batra, S.W.T. (1984). Insects Collect Pollen of Eastern Wildrice, Zizania aquatica (Poaceae). *Castanea*, 49(1): 31-34.

Thomson, D. (2004). Competitive interactions between the invasive European honey bee and native bumble bees. *Ecology*, 85(2) pp. 458-470.

Tonietto, R.K., Ascher, J.S. and Larkin, D.J. (2017). Bee communities along a prairie restoration chronosequence: similar abundance and diversity, distinct composition. *Ecol Appl*, 27: 705-717. https://doi-org /10.1002/eap.1481

Tonietto, R.K. & Larkin, D.J. (2017). Habitat restoration benefits wild bees: A meta-analysis. *Journal of Applied Ecology*, 55: 582-590.

Tronstad, L., Bell, C. & Crawford, M. (2022) Choosing collection methods and sample sizes for monitoring bees. *Agricultural and Forest Entomology*, 24(4), 531– 539. Available from: https://doi.org/10.1111/afe.12518

Turner, M. G. (2005). Landscape ecology: What is the State of the science? *Annual Review of Ecology, Evolution, and Systematics*, *36*(1), 319–344. https://doi.org/10.1146/annurev.ecolsys.36.102003.152614

Turner, M.G., Gardner, R.H., O'Neill, R.V. (2001). Landscape Ecology in Theory and Practice. *New York: Springer-Verlag*. 401 pp.

Turo, K.J., Spring, M.R., Sivakoff, F.S., de la flor, Y.A.D., & Gardiner, M.M. *Journal of Applied Ecology*, 58(1): 58-69. doi.org/10.1111/1365-2664.13773

Urban-Mead, K. R., Muñiz, P., Gillung, J., Espinoza, A., Fordyce, R., van Dyke, M., McArt, S. H., & Danforth, B. N. (2021). Bees in the trees: Diverse spring fauna in temperate forest edge canopies. *Forest Ecology and Management*, *482*, 118903. https://doi.org/10.1016/j.foreco.2020.118903

Urban-Mead, K.R., Walter, E., Mcart, S.H., and Danforth, B.N. (2022). Nearly half of spring-flying male Andrena bees consume pollen, but less than female conspecifics. *Apidologie* 53, 49. https://doi.org/10.1007/s13592-022-00951-4

USGS (n.d.). *Floristic Quality Index: An Assessment Tool for Restoration Projects and Monitoring Sites in Coastal Louisiana*. United States Geological Survey.

Vanbergen, A.J. & Insect Pollinator Initiative (2013). Threats to an ecosystem service: pressures on pollinators. *Front Ecol Environ*, 11(5): 251–259. doi:10.1890/120126.

Vickruck, J. (2010). The nesting biology of *Ceratina* (Hymenoptera: Apidae) in the Niagara Region: New species, nest site selection and parasitism. *Department of Biological Sciences, Brock University*.

Vickruck, J. L., Best, L. R., Gavin, M. P., Devries, J. H., & Galpern, P. (2019). Pothole wetlands provide reservoir habitat for native bees in prairie croplands. *Biological Conservation*, *232*, 43–50. https://doi.org/10.1016/j.biocon.2019.01.015

Voss, E. G., & Reznicek, A. A. (2012). *Field Manual of Michigan Flora*. Univ. of Michigan Press.

Shell, W.A., Rehan, S.M. (2016). Recent and rapid diversification of the small carpenter bees in eastern North America. *Biological Journal of the Linnean Society*, Volume 117, Issue 3, Pages 633–645. https://doi.org/10.1111/bij.12692.

Weber, S. (2021). Revegetation with native plants: a test of best practices. Department of Biology, McMaster University.

Wharton, R.A., Marsh, P.M., & Sharkey, M.J. (1997). Manual of the New World Genera of the Family Braconidae (Hymenoptera). *The International Society of Hymenopterists*.

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. *Springer-Verlag New York*.

Wiklund, C. and Fagerström, T. (1977). Why do males emerge before females?. *Oecologia* 31, 153–158. https://doi.org/10.1007/BF00346917

Williams, P., Thorp, R., Richardson, L., & Colla, S. (2014). Bumble bees of North America. Princeton University Press.

Wilson, R.S., Keller, A., Shapcott, A., Leonhardt, S.D., Sickel, W., Hardwick, J.L., Heard, T.A., Kaluza, B.F., & Wallace, H.M. (2021). Many small rather than few large sources identified in long-term bee pollen diets in agroecosystems. *Agriculture, Ecosystems & Environment*, 310 (107296). doi.org/10.1016/j.agee.2020.107296.

Wood, S.N. (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society* (B) 73(1):3-36.

Zedler, J. B., & Kercher, S. (2004). Causes and consequences of invasive plants in wetlands: Opportunities, opportunists, and outcomes. *Critical Reviews in Plant Sciences*, *23*(5), 431–452. https://doi.org/10.1080/07352680490514673

APPENDIX A: PLANT SPECIES LISTS

A table listing the species that have been identified as part of the vegetation surveys and floral surveys and their associated localities. Blue indicates a forest edge habitat, grey indicates a field habitat, salmon indicates a wetland habitat, pink indicates a forest habitat, and green indicates a forested spring habitat. Presence of a species of genus is denoted with an 'X'.

Family	Species	Authority	S Rank	Coef. Con.	Coef. Wet.	McMaster Forest Nature Preserve								McMaster University					
						Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14
Aceraceae	*Acer negundo*	L.	S5	0	0			X				X					X	X	X
Aceraceae	***Acer platanoides***	**L.**	**SE5**	0	5				X						X				X
Aceraceae	*Acer rubrum*	L.	S5	4	0								X						
Aceraceae	*Acer saccharinum*	L.	S5	5	3			X								X			
Aceraceae	*Acer saccharum*	Marsh.	S5	4	-3	X			X	X	X	X	X	X	X			X	X
Aceraceae	*Acer × freemanii*	E. Murr.	SNA	6	-5		X							X	X				
Alismataceae	*Alisma triviale*	Pursh	S5	1	-5							X							
Alismataceae	*Sagittaria latifolia*	Willd.	S5	4	-5							X							
Anacardiaceae	*Rhus typhina*	L.	S5	1	3	X	X				X					X			X
Anacardiaceae	*Toxicodendron radicans var. radicans*	(Linnaeus) Kuntze	S5	2	0					X	X		X	X	X		X	X	X
Anacardiaceae	*Toxicodendron radicans var. rydbergii*	(Small ex Rydberg) Erskine	S5	2	0				X							X			
Apiaceae	*Aegopodium podagraria*	L.	SE5	0	0							X					X		
Apiaceae	*Cicuta maculata var. maculata*	L.	S5	6	-5							X							
Apiaceae	*Cryptotaenia canadensis*	(L.) DC.	S5	5	0						X	X	X						
Apiaceae	***Daucus carota***	**L.**	**SE5**	0	5	X	X	X	X		X		X		X	X	X		
Apiaceae	***Torilis japonica***	**(Houtt.) DC.**	**SE4**	0	3			X	X		X	X	X	X		X		X	
Apocynaceae	*Apocynum cannabinum var. cannabinum*	L.	S5	3	0		X	X	X		X					X	X		
Apocynaceae	*Asclepias incarnata ssp. incarnata*	L.	S5	6	-5												X		
Apocynaceae	*Asclepias syriaca*	L.	S5	0	5			X			X			X	X		X		

Apocynaceae	***Vincetoxicum rossicum***	**(Kleopov) Barbarich**	**SE5**	0	5											X			X
Araceae	*Arisaema triphyllum*	(L.) Schott	S5	5	-3			X	X		X		X	X	X			X	X
Araceae	*Symplocarpus foetidus*	(L.) Salisb. ex Nutt.	S5	7	-5							X		X			X	X	X
Asteraceae	*Achillea borealis var. borealis*	Bongard	S5	0	3	X	X									X			
Asteraceae	*Ageratina altissima var. altissima*	(Linnaeus) R.M. King & H. Robinson	S5	5	3	X		X	X	X	X	X	X	X	X	X	X	X	X
Asteraceae	*Ambrosia artemisiifolia*	L.	S5	0	3	X									X	X		X	
Asteraceae	*Ambrosia trifida*	L.	S5	0	0												X		
Asteraceae	***Arctium sp.***		**SE5**	0	3					X		X	X		X				
Asteraceae	*Bidens cernua*	L.	S5	2	-5							X					X		
Asteraceae	*Bidens frondosa*	L.	S5	3	-3			X		X		X	X	X	X		X	X	X
Asteraceae	***Cichorium intybus***	**L.**	**SE5**	0	5	X	X		X										
Asteraceae	***Cirsium arvense***	**(L.) Scop.**	**SE5**	0	3		X	X	X					X	X	X	X		X
Asteraceae	***Cirsium vulgare***	**(Savi) Ten.**	**SE5**	0	3		X	X							X	X	X		
Asteraceae	*Erechtites hieraciifolius var. hieraciifolius*	(Linnaeus) Rafinesque ex de Candolle	S5	2	3												X		
Asteraceae	*Erigeron annuus*	(L.) Pers.	S5	0	3	X				X	X			X	X	X	X	X	
Asteraceae	*Erigeron philadelphicus var. philadelphicus*	L.	S5	1	-3	X	X					X	X	X	X	X	X	X	X
Asteraceae	*Erigeron pulchellus var. pulchellus*	Michaux	S5	7	3						X								
Asteraceae	*Erigeron strigosus*	Muhl. ex Willd.	S5	4	3	X	X	X	X		X	X	X	X	X	X	X		
Asteraceae	*Eupatorium perfoliatum*	L.	S5	2	-3							X					X		
Asteraceae	*Euthamia graminifolia*	(L.) Nutt.	S5	2	0	X	X	X	X		X	X				X	X		
Asteraceae	*Eutrochium maculatum*	(L.) E.E. Lamont	S5	3	-5			X				X					X		
Asteraceae	***Helianthus tuberosus***	**L.**	**SU**	0	0							X							
Asteraceae	*Heliopsis helianthoides*	(L.) Sweet	S4S5	3	3	X													
Asteraceae	***Pilosella caespitosa***	**(Dumort.) P.D. Sell. & C. West**	**SE5**	0	5	X	X		X							X			
Asteraceae	***Hieracium laevigatum ssp. tridentatum***	**(Fries) Celakovský**	**SE1**	0		X										X			
Asteraceae	***Inula helenium***	**L.**	**SE5**	0	3			X											

Asteraceae	*Lactuca biennis*	(Moench) Fern.	S5	6	0						X								
Asteraceae	***Lapsana communis***	**L.**	**SE5**	0	3				X	X	X	X	X	X	X		X	X	X
Asteraceae	***Leucanthemum vulgare***	**Lam.**	**SE5**	0	5	X	X		X		X				X		X		X
Asteraceae	*Nabalus albus*	(L.) Hook.	S5	6	3														X
Asteraceae	***Picris hieracioides***	**L.**	**SE5**	0	5	X	X		X										
Asteraceae	*Rudbeckia hirta*	L.	S5	0	3	X	X	X	X										
Asteraceae	*Solidago altissima var. altissima*	L.	S5	1	3	X	X	X	X		X	X		X		X	X	X	X
Asteraceae	*Solidago caesia var. caesia*	L.	S5	5	3				X	X			X						X
Asteraceae	*Solidago canadensis var. canadensis*	L.	S5	1	3														X
Asteraceae	*Solidago flexicaulis*	L.	S5	6	3							X	X				X		X
Asteraceae	*Solidago gigantea var. gigantea*	Aiton	S5	4	-3												X	X	
Asteraceae	*Solidago juncea*	Ait.	S5	3	5	X	X	X	X								X		
Asteraceae	*Solidago nemoralis ssp. nemoralis*	Aiton	S5	2	5	X	X		X										
Asteraceae	*Solidago patula*	Muhl. ex Willd.	S4	8	-5							X							
Asteraceae	***Sonchus arvensis***	**L.**	**SE5**	0	3	X										X	X		X
Asteraceae	***Sonchus oleraceus***	**L.**	**SE5**	0	3										X				X
Asteraceae	*Symphyotrichum cordifolium*	(L.) Nesom	S5	5	5	X			X			X	X						
Asteraceae	*Symphyotrichum ericoides var. ericoides*	(Linnaeus) G.L. Nesom	S5	4	3	X	X	X	X		X								
Asteraceae	*Symphyotrichum laeve var. laeve*	(Linnaeus) Á. Löve & D. Löve	S5	7	3	X	X		X										
Asteraceae	*Symphyotrichum lanceolatum ssp. lanceolatum*	(Willdenow) G.L. Nesom	S5	3	-3	X		X	X		X	X				X	X		
Asteraceae	*Symphyotrichum lateriflorum*	(L.) A.& D. Löve	S5	3	0			X	X	X	X	X	X	X	X	X	X	X	X
Asteraceae	*Symphyotrichum novae-angliae*	(L.) Nesom	S5	2	-3	X	X	X	X		X					X	X		
Asteraceae	***Symphyotrichum novi-belgii***	**(Linnaeus) G.L. Nesom**		0							X								

Asteraceae	*Symphyotrichum oolentangiense*	(Riddell) Nesom	S4	9	5	X	X		X										
Asteraceae	*Symphyotrichum pilosum var. pilosum*	(Willdenow) G.L. Nesom	S5	1	3	X	X		X										
Asteraceae	*Symphyotrichum puniceum var. puniceum*	(Linnaeus) Á. Löve & D. Löve	S5	6	-5			X				X				X	X	X	
Asteraceae	*Symphyotrichum urophyllum*	(Lindl.) Nesom	S4	6	5	X	X	X	X	X	X		X						
Asteraceae	***Taraxacum erythrospermum***	**Andrz. ex Bess.**	**SE5**	0	5	X		X	X		X	X			X	X	X	X	X
Asteraceae	***Taraxacum officinale***	**G.H. Weber ex Wiggers**	**SE5**	0	3	X	X	X	X		X	X	X	X	X	X	X	X	X
Asteraceae	***Tragopogon dubius***	**Scop.**	**SE5**	0	5	X			X										
Asteraceae	***Tragopogon pratensis***	**L.**	**SE5**	0	5	X	X		X										
Asteraceae	***Tussilago farfara***	**L.**	**SE5**	0	3							X	X				X		X
Asteraceae	*Xanthium strumarium*	L.	S5	2	0												X		
Balsaminaceae	*Impatiens capensis*	Meerb.	S5	4	-3			X				X				X	X	X	X
Balsaminaceae	*Impatiens pallida*	Nutt.	S4	7	-3						X								
Berberidaceae	***Berberis thunbergii***	**DC.**	**SE5**	0	3					X			X	X	X	X		X	
Berberidaceae	*Podophyllum peltatum*	L.	S5	5	3					X			X			X			X
Betulaceae	***Alnus glutinosa***	**(L.) Gaertn.**	**SE4**	0	-3							X					X	X	
Betulaceae	*Betula alleghaniensis*	Britt.	S5	6	0														X
Betulaceae	*Betula papyrifera*	Marsh.	S5	2	3				X					X					X
Betulaceae	*Carpinus caroliniana ssp. virginiana*	(Marsh.) Furlow	S5	6	0				X										X
Betulaceae	*Corylus cornuta ssp. cornuta*	Marshall	S5	5	3									X					
Betulaceae	*Ostrya virginiana*	(P. Mill.) K. Koch	S5	4	3				X				X		X				
Bignoniaceae	***Catalpa speciosa***	**(Warder ex Barney) Warder ex Engelm.**	**SE1**	0	3										X				
Boraginaceae	***Echium vulgare***	**L.**	**SE5**	0	5		X												
Boraginaceae	*Hackelia virginiana*	(L.) I.M. Johnston	S5	5	3						X		X	X	X			X	X
Boraginaceae	***Myosotis arvensis***	**(L.) Hill**	**SE4**	0	3	X		X				X	X					X	
Boraginaceae	***Myosotis scorpioides***	**L.**	**SE5**	0	-5							X					X	X	

Boraginaceae	***Myosotis stricta***	**Link ex Roemer & J.A. Schultes**	**SE4**	0	5										X	X	X	X	
Boraginaceae	***Myosotis sylvatica***	**Ehrh. ex Hoffmann**	**SE4**	0	5							X							X
Boraginaceae	***Pulmonaria officinalis***	**L.**	**SE1**	0								X						X	
Brassicaceae	***Alliaria petiolata***	**(Bieb.) Cavara & Grande**	**SE5**	0	0	X			X	X	X	X	X	X	X		X	X	X
Brassicaceae	***Barbarea vulgaris***	**Ait. f.**	**SE5**	0	0			X			X	X			X		X		
Brassicaceae	***Brassica nigra***	**(L.) W.D.J. Koch**	**SE5**	0	5												X		
Brassicaceae	***Capsella bursa-pastoris***	**(L.) Medik.**	**SE5**	0	3										X				
Brassicaceae	*Cardamine pensylvanica*	Muhl. ex Willd.	S5	6	-3							X			X			X	
Brassicaceae	***Erucastrum gallicum***	**(Willd.) O.E. Schulz**	**SE5**	0	5		X												
Brassicaceae	***Hesperis matronalis***	**L.**	**SE5**	0	3	X				X	X	X	X	X	X	X	X	X	
Brassicaceae	***Nasturtium officinale***	**Ait.**	**SE**	0	-5							X						X	
Brassicaceae	*Rorippa palustris*	(L.) Bess.	S5	3	-5							X							
Campanulaceae	*Lobelia siphilitica*	L.	S5	6	-3			X				X						X	
Caprifoliaceae	***Lonicera maackii***	**(Rupr.) Maxim.**	**SE2**	0	5							X		X	X	X		X	X
Caprifoliaceae	***Lonicera morrowii***	**Gray**	**SE3**	0	3	X	X	X	X		X	X				X	X		
Caprifoliaceae	***Lonicera sp.***			0										X					
Caprifoliaceae	***Lonicera tatarica***	**L.**	**SE5**	0	3			X			X					X	X		X
Caprifoliaceae	*Sambucus canadensis*	L.	S5	5	-3			X											
Caprifoliaceae	*Sambucus racemosa*	L.	S5	5	3					X			X						
Caprifoliaceae	*Symphoricarpos albus*	(L.) Blake	S5	7	3								X						
Caprifoliaceae	*Viburnum acerifolium*	L.	S5	6	5												X	X	
Caprifoliaceae	*Viburnum lentago*	L.	S5	4	0									X					X
Caprifoliaceae	***Viburnum opulus ssp. opulus***	**L.**	**SE3?**	0	-3	X		X				X							X
Caryophyllaceae	***Cerastium fontanum ssp. vulgare***	**(Hartman) Greuter & Burdet**	**SE5**	0	3	X		X	X		X				X	X	X		
Caryophyllaceae	***Dianthus armeria ssp. armeria***	**L.**	**SE5**	0	5						X				X				
Caryophyllaceae	***Stellaria media***	**(L.) Vill.**	**SE5**	0	3			X							X				
Celastraceae	*Celastrus scandens*	L.	S5	3	3		X				X								
Celastraceae	***Euonymus fortunei***	**(Turcz.) Hand.-Maz.**	**SE2**	0	5										X				X

Chenopodiaceae	***Atriplex patula***	**L.**	**SE5**	0	-3									X					
Climaciaceae	*Climacium dendroides*	(Hedw.) Web. & Mohr	S5	0								X							
Clusiaceae	***Hypericum perforatum ssp. perforatum***	**L.**	**SE5**	0	5	X	X	X	X		X		X		X	X	X		
Clusiaceae	*Hypericum punctatum*	Lam.	S5	5	0				X										
Conocephalaceae	*Conocephalum salebrosum*	Szweykowski, Buczkowska & Odrzykoski	S5	0								X							
Convolvulaceae	*Calystegia sepium*	Brummitt	S5	2	0												X		
Convolvulaceae	***Convolvulus arvensis***	**L.**	**SE5**	0	5											X			
Cornaceae	*Cornus alternifolia*	L. f.	S5	6	3					X	X	X	X						X
Cornaceae	*Cornus florida*	L.	S2?	7	3				X										
Cornaceae	*Cornus racemosa*	Lam.	S5	2	0	X	X	X	X		X	X		X	X	X	X		X
Cornaceae	*Cornus sericea*	L.	S5	2	-3												X		
Cupressaceae	*Juniperus virginiana var. virginiana*	L.	S5	4	3	X	X		X										
Cupressaceae	*Thuja occidentalis*	L.	S5	4	-3														X
Cyperaceae	*Carex albursina*	Sheldon	S5	7	5									X	X				
Cyperaceae	*Carex alopecoidea*	Tuckerman	S4	6	-3						X								
Cyperaceae	*Carex aurea*	Nutt.	S5	4	-3	X	X	X											
Cyperaceae	*Carex blanda*	Dewey	S5	3	0				X	X	X	X	X			X	X	X	X
Cyperaceae	*Carex cephalophora*	Muhl. ex Willd.	S5	5	3			X					X						
Cyperaceae	*Carex cristatella*	Britt.	S5	3	-3			X		X		X					X		X
Cyperaceae	*Carex deweyana var. deweyana*	Schweinitz	S5	6	3						X								
Cyperaceae	*Carex granularis*	Muhl. ex Willd.	S5	3	-3	X	X	X								X			
Cyperaceae	*Carex hystericina*	Muhl. ex Willd.	S5	5	-5													X	X
Cyperaceae	*Carex laevivaginata*	(Kukenth.) Mackenzie	S4	8	-5							X							X
Cyperaceae	*Carex pensylvanica*	Lam.	S5	5	5				X	X			X	X					X
Cyperaceae	*Carex platyphylla*	Carey	S4S5	7	5				X				X						
Cyperaceae	*Carex rosea*	Schkuhr ex Willd.	S5	2	5			X	X	X		X	X		X			X	X
Cyperaceae	*Carex scabrata*	Schwein.	S5	8	-5							X							

Cyperaceae	*Carex sparganioides*	Muhl. ex Willd.	S4S5	5	3									X					
Cyperaceae	***Carex spicata***	**Huds.**	**SE5**	0	3	X		X			X					X			X
Cyperaceae	*Carex vulpinoidea*	Michx.	S5	3	-5			X									X		
Cyperaceae	*Cyperus erythrorhizos*	Muhl.	S4	6	-5							X							
Cyperaceae	*Schoenoplectus tabernaemontani*	(K. C. Gmelin) Palla	S5	5	-5							X							
Cyperaceae	*Scirpus atrovirens*	Willd.	S5	3	-5			X										X	
Dipsacaceae	***Dipsacus fullonum***	**L.**	**SE5**	0	3			X									X		
Dryopteridaceae	*Athyrium filix-femina var. angustum*	(Willd.) Lawson	S5	4	0					X				X					
Dryopteridaceae	*Cystopteris bulbifera*	(L.) Bernh.	S5	5	-3									X					
Dryopteridaceae	*Dryopteris carthusiana*	(Vill.) H.P. Fuchs	S5	5	-3						X	X		X	X				X
Dryopteridaceae	*Dryopteris intermedia*	(Muhl. ex Willd.) Gray	S5	5	0					X									
Dryopteridaceae	*Matteuccia struthiopteris var. pensylvanica*	(Willd.) Morton	S5	5	0													X	
Dryopteridaceae	*Onoclea sensibilis*	L.	S5	4	-3							X	X	X					
Dryopteridaceae	*Polystichum acrostichoides*	(Michx.) Schott	S5	5	3								X						
Elaeagnaceae	***Elaeagnus umbellata***	**Thunb.**	**SE3**	0	3	X	X	X	X		X								
Equisetaceae	*Equisetum arvense*	L.	S5	0	0		X	X				X				X		X	X
Euphorbiaceae	*Acalypha rhomboidea*	Raf.	S5	0	3										X				
Fabaceae	*Amphicarpaea bracteata*	(L.) Fern.	S5	4	0					X	X	X					X		
Fabaceae	*Apios americana*	Medik.	S5	6	-3							X							
Fabaceae	***Cercis canadensis***	**L.**	**SX**	0	3														X
Fabaceae	*Desmodium canadense*	(L.) DC.	S4	5	0		X												
Fabaceae	***Gleditsia triacanthos***	**L.**	**S2?**	0	0									X					
Fabaceae	*Hylodesmum glutinosum*	(Muhl. ex Willd.) H. Ohashi & R.R. Mill	S4	6	5						X								
Fabaceae	***Lotus corniculatus***	**L.**	**SE5**	0	3	X	X	X	X		X	X					X		
Fabaceae	***Medicago lupulina***	**L.**	**SE5**	0	3	X	X	X	X			X			X	X			X
Fabaceae	***Melilotus albus***	**Medik.**	**SE5**	0	3		X		X									X	
Fabaceae	***Melilotus officinalis***	**(L.) Lam.**	**SE5**	0	3	X			X						X			X	

Fabaceae	***Securigera varia***	**(L.) Lassen**	**SE5**	0	5											X	X		
Fabaceae	***Trifolium hybridum***	**L.**	**SE5**	0	3	X		X	X						X	X			
Fabaceae	***Trifolium pratense***	**L.**	**SE5**	0	3	X	X		X						X	X			
Fabaceae	***Trifolium repens***	**L.**	**SE5**	0	3	X		X	X						X	X			X
Fabaceae	***Vicia cracca***	**L.**	**SE5**	0	5	X	X	X	X		X								
Fabaceae	***Vicia tetrasperma***	**(L.) Schreb.**	**SE5**	0	5	X		X	X		X								
Fagaceae	*Fagus grandifolia*	Ehrh.	S4	6	3					X			X						
Fagaceae	*Quercus alba*	L.	S5	6	3					X									
Fagaceae	*Quercus rubra*	L.	S5	6	3				X	X			X		X				X
Geraniaceae	*Geranium maculatum*	L.	S5	6	3									X			X		X
Geraniaceae	*Geranium robertianum*	L.	S5	2	3					X			X	X	X				X
Grossulariaceae	*Ribes americanum*	P. Mill.	S5	5	-3							X					X		
Grossulariaceae	*Ribes cynosbati*	L.	S5	4	3					X	X	X	X		X			X	X
Hamamelidaceae	*Hamamelis virginiana*	L.	S4S5	6	3									X	X				
Hydrophyllaceae	*Hydrophyllum virginianum var. virginianum*	L.	S5	6	0							X							
Iridaceae	***Iris pseudacorus***	**L.**	**SE4**	0	-5							X					X		
Juglandaceae	*Carya cordiformis*	(Wangenh.) K. Koch	S5	6	0				X	X	X		X	X				X	X
Juglandaceae	*Carya ovata*	(P. Mill.) K. Koch	S5	6	3									X					X
Juglandaceae	*Juglans cinerea*	L.	S2?	6	3						X		X						
Juglandaceae	*Juglans nigra*	L.	S4?	5	3	X		X	X		X	X	X	X		X	X	X	X
Juncaceae	*Juncus articulatus ssp. articulatus*	L.	S5	5	-5			X									X		
Juncaceae	***Juncus compressus***	**Jacq.**	**SE5**	0	-3											X			
Juncaceae	*Juncus dudleyi*	Wieg.	S5	1	-3							X							
Juncaceae	*Juncus effusus ssp. solutus*	(Fern. & Wieg.) Hamet-Ahti	S5	4	-5												X		
Juncaceae	*Juncus tenuis*	Willd.	S5	0	0			X	X						X	X	X		
Juncaceae	*Juncus torreyi*	Coville	S5	1	-3												X		
Lamiaceae	*Clinopodium vulgare ssp. vulgare*	L.	S5	4	5										X	X			
Lamiaceae	***Glechoma hederacea***	**L.**	**SE5**	0	3						X	X				X	X	X	

Lamiaceae	***Leonurus cardiaca ssp. cardiaca***	**L.**	**SE5**	0	5									X	X		X	X	
Lamiaceae	*Lycopus americanus*	Muhl. ex W. Bart.	S5	4	-5			X				X							
Lamiaceae	***Lycopus europaeus***	**L.**	**SE5**	0	-5							X							
Lamiaceae	*Lycopus uniflorus*	Michx.	S5	5	-5												X		
Lamiaceae	***Melissa officinalis ssp. officinalis***	**L.**	**SE1**	0	5													X	
Lamiaceae	*Mentha canadensis*	L.	S5	3	-3			X				X					X		X
Lamiaceae	***Mentha spicata***	**L.**	**SE4**	0	-3										X				
Lamiaceae	***Mentha x piperita***	**L. (pro sp.)**	**SNA**	0	-5												X		
Lamiaceae	*Monarda fistulosa*	L.	S5	6	3	X	X	X	X		X	X				X			
Lamiaceae	*Prunella vulgaris ssp. lanceolata*	(W. Bart.) Hulten	S5	0	0	X	X	X	X									X	
Lamiaceae	***Prunella vulgaris ssp. vulgaris***	**L.**	**SE3**	0	0										X	X			
Lamiaceae	*Pycnanthemum virginianum*	(L.) T. Dur. & B.D. Jackson ex B.L. Robins. & Fern.	S4	6	-3		X												
Lauraceae	*Lindera benzoin*	(L.) Blume	S4	6	-3					X	X								X
Liliaceae	*Allium canadense var. canadense*	L.	S5	8	3	X						X					X		
Liliaceae	*Allium tricoccum var. tricoccum*	Aiton	S4	7	3								X						
Liliaceae	***Asparagus officinalis***	**L.**	**SE5**	0	3						X								
Liliaceae	*Erythronium americanum ssp. americanum*	Ker Gawler	S5	5	5				X	X		X	X						
Liliaceae	*Maianthemum canadense*	Desf.	S5	5	3				X				X						X
Liliaceae	*Maianthemum racemosum*	(L.) Link	S5	4	3				X										X
Liliaceae	*Polygonatum pubescens*	(Willd.) Pursh	S5	5	5								X						
Liliaceae	***Scilla siberica***	**Haw. ex Andr.**	**SE2**	0	5										X			X	
Liliaceae	*Trillium grandiflorum*	(Michx.) Salisb.	S5	5	3								X						X
Lythraceae	***Lythrum salicaria***	**L.**	**SE5**	0	-5			X				X		X		X	X	X	
Magnoliaceae	*Liriodendron tulipifera*	L.	S4	8	3						X								
Mniaceae	*Plagiomnium cuspidatum*	(Hedw.) T. Kop.	S5	0								X							
Moraceae	***Morus alba***	**L.**	**SE5**	0	0											X			X

N/A	Various Unidentified Moss Species		N/A	0		X			X	X	X	X	X	X	X	X			
Oleaceae	*Fraxinus americana*	L.	S4	4	3	X	X	X	X	X	X	X	X	X	X	X	X	X	
Oleaceae	*Fraxinus pennsylvanica*	Marsh.	S4	3	-3	X							X				X		X
Oleaceae	***Ligustrum vulgare***	**L.**	**SE5**	0	3	X					X	X		X			X	X	X
Onagraceae	*Circaea canadensis ssp. canadensis*	(Linnaeus) Hill	S5	2	3			X	X	X	X	X	X	X	X	X	X	X	X
Onagraceae	*Epilobium ciliatum ssp. ciliatum*	Rafinesque	S5	3	-3													X	X
Onagraceae	*Epilobium coloratum*	Biehler	S5	3	-5			X				X					X		
Onagraceae	***Epilobium hirsutum***	**L.**	**SE5**	0	-3							X							
Onagraceae	***Epilobium parviflorum***	**Schreb.**	**SE4**	0	3										X		X		
Onagraceae	*Oenothera biennis*	L.	S5	0	3		X		X		X						X		
Onagraceae	*Oenothera parviflora*	L.	S5	1	3				X										
Orchidaceae	***Epipactis helleborine***	**(L.) Crantz**	**SE5**	0	3								X		X				
Orchidaceae	*Liparis loeselii*	(L.) L.C. Rich.	S4S5	5	-3			X											
Osmundaceae	*Claytosmunda claytoniana*	(Linnaeus) Metzgar & Rouhan	S5	7	0									X					
Oxalidaceae	*Oxalis stricta*	L.	S5	0	3			X	X	X	X	X	X	X	X	X	X	X	X
Papaveraceae	*Sanguinaria canadensis*	L.	S5	5	3						X		X						X
Phytolaccaceae	*Phytolacca americana var. americana*	L.	S4	3	3									X					
Pinaceae	*Picea glauca*	(Moench) Voss	S5	6	3				X										
Pinaceae	*Pinus strobus*	L.	S5	4	3						X	X							
Pinaceae	*Tsuga canadensis*	(L.) Carr.	S5	7	3							X	X	X					
Plantaginaceae	***Plantago lanceolata***	**L.**	**SE5**	0	3	X	X		X							X			
Plantaginaceae	***Plantago major***	**L.**	**SE5**	0	3										X				
Plantaginaceae	*Plantago rugelii*	Dcne.	S5	1	0	X			X						X				
Poaceae	***Agrostis gigantea***	**Roth**	**SE5**	0	-3	X	X	X	X										
Poaceae	*Andropogon gerardii*	Vitman	S4	7	3	X	X												
Poaceae	*Bromus ciliatus*	L.	S5	6	-3							X					X		
Poaceae	***Bromus inermis***	**Leyss.**	**SE5**	0	5	X			X		X					X	X		
Poaceae	***Bromus japonicus***	**Thunb. ex Murr.**	**SE4**	0	3			X											

Poaceae	*Calamagrostis canadensis*	(Michx.) Beauv.	S5	4	-5	X		X			X					X			
Poaceae	***Dactylis glomerata***	**L.**	**SE5**	0	3	X	X	X	X		X	X	X		X	X	X	X	X
Poaceae	*Danthonia spicata*	(L.) Beauv. ex Roemer & J.A. Schultes	S5	5	5	X													
Poaceae	*Dichanthelium implicatum*	(Scribner) Kerguélen	S5	3	0		X	X											
Poaceae	*Echinochloa muricata*	(Beauv.) Fern.	S5	4	-5							X			X		X		
Poaceae	*Elymus hystrix*	L.	S5	5	5	X													
Poaceae	***Elymus repens***	**(L.) Gould**	**SE5**	0	3	X	X	X											
Poaceae	*Elymus virginicus*	L.	S5	5	-3		X	X	X	X	X	X	X	X					X
Poaceae	***Festuca rubra ssp. rubra***	**L.**	**SE5**	0	3				X							X			
Poaceae	***Glyceria maxima***	**(Hartman) Holmb.**	**SE4**	0	-5												X	X	
Poaceae	*Glyceria striata var. striata*	(Lamarck) Hitchcock	S5	3	-5							X	X	X				X	X
Poaceae	***Holcus lanatus***	**L.**	**SE2**	0	3													X	
Poaceae	*Leersia virginica*	Willd.	S4	6	-3					X			X	X	X				
Poaceae	***Lolium arundinaceum***	**(Schreb.) S.J. Darbyshire**	**SE5**	0	3	X	X	X	X							X	X	X	
Poaceae	***Lolium perenne***	**L.**	**SE4**	0	3		X								X				
Poaceae	***Lolium pratense***	**(Huds.) S.J. Darbyshire**	**SE5**	0	3	X	X									X			
Poaceae	*Oryzopsis asperifolia*	Michx.	S5	6	5					X									
Poaceae	*Panicum virgatum*	L.	S4	6	0	X	X												
Poaceae	*Phalaris arundinacea var. arundinacea*	L.	S5	0	-3							X				X	X	X	X
Poaceae	***Phleum pratense***	**L.**	**SE5**	0	3	X	X	X	X		X					X			
Poaceae	***Phragmites australis ssp. australis***	**(Cavanilles) Trinius ex Steudel**	**SE5**	0	-3												X		
Poaceae	***Poa annua***	**L.**	**SE5**	0	3										X				
Poaceae	***Poa compressa***	**L.**	**SE5**	0	3	X	X	X											
Poaceae	***Poa nemoralis***	**L.**	**SE4**	0	3				X			X	X	X	X			X	
Poaceae	*Poa palustris*	L.	S5	5	-3			X										X	
Poaceae	***Poa pratensis ssp. pratensis***	**L.**	**SE5**	0	3	X	X	X	X		X					X	X		

Poaceae	***Setaria pumila***	**(Poir.) Roemer & J.A. Schultes**	**SE5**	0	0										X	X			
Poaceae	***Setaria viridis var. viridis***	**(Linnaeus) Palisot de Beauvois**	**SE5**	0	5										X				
Poaceae	*Sorghastrum nutans*	(L.) Nash	S4	8	3	X	X												
Poaceae	*Poaceae sp. 1*																		X
Polygonaceae	***Persicaria hydropiper***	**(Michx.) Small**	**SE5**	0	-5							X					X		
Polygonaceae	***Persicaria maculosa***	**Gray**	**SE5**	0	-3							X		X	X				
Polygonaceae	*Persicaria virginiana*	Gaertn.	S4	6	0					X	X	X	X	X	X		X	X	X
Polygonaceae	***Polygonum aviculare ssp. aviculare***	**L.**	**SE5**	0	3										X				
Polygonaceae	***Rumex crispus***	**L.**	**SE5**	0	0										X		X		
Polygonaceae	***Rumex obtusifolius***	**L.**	**SE5**	0	-3							X	X	X	X	X	X	X	
Portulacaceae	*Claytonia virginica*	L.	S5	5	3						X		X						
Primulaceae	*Lysimachia ciliata*	L.	S5	4	-3			X				X					X		
Primulaceae	***Lysimachia nummularia***	**L.**	**SE5**	0	-3												X	X	
Pteridaceae	*Adiantum pedatum*	L.	S5	7	3									X					
Ranunculaceae	*Actaea pachypoda*	Ell.	S5	6	5					X									
Ranunculaceae	*Anemonastrum canadense*	(Linnaeus) Mosyakin	S5	3	-3							X							
Ranunculaceae	*Anemone virginiana*	L.	S5	4	3	X	X	X	X		X								
Ranunculaceae	*Aquilegia canadensis*	L.	S5	5	3	X	X												
Ranunculaceae	*Caltha palustris*	L.	S5	5	-5							X							X
Ranunculaceae	*Clematis virginiana*	L.	S5	3	0												X		
Ranunculaceae	*Ranunculus abortivus*	L.	S5	2	0			X	X		X	X	X	X	X	X			
Ranunculaceae	***Ranunculus acris***	**L.**	**SE5**	0	0	X		X	X			X			X	X	X	X	X
Ranunculaceae	*Ranunculus recurvatus var. recurvatus*	Poiret	S5	4	-3	X		X	X			X		X	X			X	
Ranunculaceae	***Ranunculus repens***	**L.**	**SE5**	0	0												X	X	
Ranunculaceae	*Ranunculus sceleratus*	L.	S5	2	-5							X			X				
Ranunculaceae	*Thalictrum pubescens*	Pursh	S5	5	-3												X		
Rhamnaceae	***Frangula alnus***	**P. Mill.**	**SE5**	0	0												X		
Rhamnaceae	***Rhamnus cathartica***	**L.**	**SE5**	0	0	X	X	X	X	X	X	X	X		X	X	X	X	X
Rosaceae	*Agrimonia gryposepala*	Wallr.	S5	2	3	X		X	X		X	X							

Rosaceae	*Amelanchier arborea*	(Michx. f.) Fern.	S5	5	3									X					X
Rosaceae	*Crataegus crus-galli var. crus-galli*	L.	S4	4	0							X							
Rosaceae	*Crataegus sp.*			4		X	X	X	X		X	X		X					
Rosaceae	*Fragaria vesca ssp. americana*	(Porter) Staudt	S5	4	3								X						X
Rosaceae	*Fragaria virginiana ssp. virginiana*	Miller	S5	2	3	X	X	X	X		X								
Rosaceae	*Geum canadense*	Jacq.	S5	3	0		X	X	X	X	X	X	X	X	X	X	X	X	X
Rosaceae	***Geum urbanum***	**L.**	**SE3**	0	5	X		X	X	X	X	X	X	X	X	X	X	X	X
Rosaceae	***Geum × catlingii***	**Bernard & Gauthier**	**SNA**	0	3					X		X		X				X	
Rosaceae	***Malus pumila***	**P. Mill.**	**SE4**	0	5						X								
Rosaceae	***Potentilla indica var. indica***	**(Andrews) Th. Wolf**	**SE1**	0	3										X			X	X
Rosaceae	*Potentilla norvegica*	L.	S5	0	0										X				
Rosaceae	***Potentilla recta***	**L.**	**SE5**	0	5	X			X		X								X
Rosaceae	***Prunus avium***	**(L.) L.**	**SE4**	0	5									X				X	X
Rosaceae	*Prunus serotina var. serotina*	Ehrhart	S5	3	3				X	X			X	X	X			X	X
Rosaceae	*Prunus virginiana var. virginiana*	L.	S5	2	3														X
Rosaceae	***Rosa multiflora***	**Thunb. ex Murr.**	**SE5**	0	3	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rosaceae	***Rosa rubiginosa var. rubiginosa***	**L.**	**SE4**	0	3		X	X			X								
Rosaceae	*Rubus allegheniensis*	Porter	S5	2	3				X	X	X								
Rosaceae	*Rubus idaeus ssp. strigosus*	(Michx.) Focke	S5	2	3	X	X	X	X	X	X			X	X		X		
Rosaceae	*Rubus occidentalis*	L.	S5	2	5	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rosaceae	*Rubus odoratus*	L.	S5	3	5					X		X	X						
Rubiaceae	*Galium aparine*	L.	S5	4	3	X					X	X	X	X	X		X	X	X
Rubiaceae	*Galium circaezans*	Michx.	S5	7	3								X						
Rubiaceae	***Galium odoratum***	**(L.) Scop.**	**SE1**	0	5									X					X
Rubiaceae	*Galium palustre*	L.	S5	5	-5							X			X		X		
Rubiaceae	*Galium triflorum*	Michx.	S5	4	3	X		X		X	X	X	X	X	X				

Salicaceae	*Populus grandidentata*	Michx.	S5	5	5								X						
Salicaceae	*Salix discolor*	Muhl.	S5	3	-3						X								
Salicaceae	*Salix eriocephala*	Michx.	S5	4	-3							X							
Salicaceae	***Salix euxina***	**I.V. Belyaeva**	**SE**	0	0												X	X	
Salicaceae	*Salix nigra*	Marsh.	S4	6	-5							X					X		
Salicaceae	***Salix purpurea***	**L.**	**SE4**	0	-3											X	X		
Scrophulariaceae	***Chaenorhinum minus ssp. minus***	**(Linnaeus) Lange**	**SE5**	0	5														X
Scrophulariaceae	*Chelone glabra*	L.	S5	7	-5							X							
Scrophulariaceae	***Linaria vulgaris***	**P. Mill.**	**SE5**	0	5						X								X
Scrophulariaceae	*Scrophularia marilandica*	L.	S4	7	3							X							
Scrophulariaceae	***Verbascum thapsus ssp. thapsus***	**L.**	**SE5**	0	5									X		X			
Scrophulariaceae	***Veronica filiformis***	**Sm.**	**SE2**	0	5							X			X				
Scrophulariaceae	***Veronica officinalis***	**L.**	**SE5**	0	5			X	X	X	X		X	X	X	X			X
Scrophulariaceae	*Veronica peregrina ssp. peregrina*	L.	S5	0	0											X			
Scrophulariaceae	***Veronica persica***	**Poir.**	**SE4**	0	5										X				
Scrophulariaceae	***Veronica serpyllifolia***	**L.**	**SE5?**	0	0										X	X			
Smilacaceae	*Smilax ecirrata*	(Engelm. ex Kunth) S. Wats.	S3?	6	5								X						
Smilacaceae	*Smilax herbacea*	L.	S4?	5	0						X								
Solanaceae	***Solanum dulcamara***	**L.**	**SE5**	0	0							X		X				X	X
Sparganiaceae	*Sparganium eurycarpum*	Engelm. ex Gray	S5	3	-5							X							
Sphagnaceae	*Sphagnum sp.*			0								X							
Thelypteridaceae	*Thelypteris palustris var. pubescens*	(Lawson) Fern.	S5	5	-3							X							
Tiliaceae	*Tilia americana*	L.	S5	4	3	X			X				X			X		X	X
Typhaceae	***Typha angustifolia***	**L.**	**SE5**	0	-5													X	
Typhaceae	*Typha latifolia*	L.	S5	1	-5							X							
Ulmaceae	*Celtis occidentalis*	L.	S4	8	0										X				
Ulmaceae	*Ulmus americana*	L.	S5	3	-3			X				X							
Ulmaceae	*Ulmus sp.*													X					

Unknown	*Unknown dicot sp. 1*										X								
Unknown	*Unknown dicot sp. 2*													X					
Unknown	*Unknown dicot sp. 3*																X		
Urticaceae	*Boehmeria cylindrica*	(L.) Sw.	S5	4	-5							X		X		X	X	X	
Urticaceae	*Laportea canadensis*	(L.) Weddell	S5	6	-3							X		X	X	X		X	
Urticaceae	*Pilea pumila*	(L.) Gray	S5	5	-3						X	X	X	X	X		X	X	
Urticaceae	*Urtica gracilis ssp. gracilis*	Aiton	S5	2	0							X		X	X		X	X	
Valerianaceae	***Valeriana officinalis***	**L.**	**SE3**	0	3				X										
Verbenaceae	*Phryma leptostachya var. leptostachya*	L.	S4S5	6	3						X							X	
Verbenaceae	*Verbena hastata*	L.	S5	4	-3			X									X		
Verbenaceae	*Verbena urticifolia*	L.	S5	4	0				X		X	X	X	X	X		X	X	
Violaceae	***Viola odorata***	**L.**	**SE2**	0	5										X				
Violaceae	*Viola pubescens*	Ait.	S5	5	3							X							
Violaceae	*Viola rostrata*	Pursh	S5	6	3					X									
Violaceae	*Viola sororia*	Willd.	S5	4	0						X	X		X	X	X	X	X	
Vitaceae	*Parthenocissus quinquefolia*	(L.) Planch.	S4?	6	3			X			X	X	X	X	X		X		
Vitaceae	*Parthenocissus vitacea*	(Knerr) A.S. Hitchc.	S5	4	3	X		X	X	X	X				X	X		X	X
Vitaceae	*Vitis aestivalis*	Michx.	S4	7	3					X				X					
Vitaceae	*Vitis riparia*	Michx.	S5	0	0	X	X	X	X	X	X	X	X		X	X	X	X	X

APPENDIX B: BEE SPECIES LISTS

A table listing the species that have been identified to date for this project and their associated localities. Most specimens remain unidentified and have been left at the genus level. Blue indicates a forest edge habitat, grey indicates a field habitat, salmon indicates a wetland habitat, pink indicates a forest habitat, and green indicates a forested spring habitat. Presence of a species of genus is denoted with an 'X'.

Family	Genus	Subgenus	Species	Authority	S Rank	Nesting	Lecty	McMaster Forest Nature Preserve								McMaster University					
								Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14
ANDRENIDAE																					
	Andrena	*Andrena*	*mandibularis*	Robertson, 1892	S5	Ground	Polylectic				X										
	Andrena	*Euandrena*	*algida*	Smith, 1853	S5	Ground	Polylectic				X										
	Andrena	*Larandrena*	*miserabilis*	Cresson, 1872	S5	Ground	Polylectic											X			
	Andrena	*Leucandrena*	*erythronii*	Robertson, 1891	S2S3	Ground	Monolectic										X				
	Andrena	*Melandrena*	*dunningi*	Cockerell, 1898	S5	Ground	Polylectic									X					
	Andrena	*Ptilandrena*	*distans*	Provancher, 1888	S2S3	Ground	Monolectic											X			
	Andrena	*Simandrena*	*nasonii*	Robertson, 1895	S5	Ground	Polylectic												X		
	Andrena	*Taeniandrena*	*wilkella*	Kirby, 1802	SE	Ground	Polylectic											X			
	Andrena	*Trachandrena*	*spiraeana*	Robertson, 1895	S3S5	Ground	Polylectic												X		
	Andrena		*sp.*			Ground		X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Calliopsis	*Calliopsis*	*andreniformis*	Smith, 1853	S5	Ground	Polylectic	X	X	X								X		X	
	Pseudopanurgus	*rudbeckiae group*	*aestivalis*	Robertson, 1895	S3S5	Ground	Polylectic						X						X		

	Pseudopanurgus		*sp.*			Ground					X							X			
APIDAE																					
	Anthophora	*Melea*	*bomboides*	Kirby, 1837	S5	Wood-cavity excavator	Polylectic			X		X	X								
	Anthophora	*Clisodon*	*terminalis*	Cresson, 1869	S5	Wood-cavity excavator	Polylectic	X						X		X	X		X	X	
	Apis	*Apis*	*mellifera*	Linnaeus, 1758	SE	Hive Box	Polylectic	X	X	X	X	X	X	X		X	X	X	X	X	X
	Bombus	*Cullumanobombus*	*rufocinctus*	Cresson, 1863	S5	Ground	Polylectic			X											
	Bombus	*Pyrobombus*	*impatiens*	Cresson, 1863	S5	Ground	Polylectic			X											
	Bombus	*Pyrobombus*	*mixtus*	Cresson, 1878	S5	Ground	Polylectic		X												
	Bombus	*Pyrobombus*	*vagans*	Smith, 1854	S5	Ground	Polylectic			X		X									
	Bombus		*sp.*			Ground		X	X	X	X	X	X	X	X			X	X	X	
	Ceratina	*Zadontomerus*	*calcarata*	Robertson, 1900	S5	Stem-carpenter	Polylectic	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Ceratina	*Zadontomerus*	*dupla*	Say, 1837	S5	Stem-carpenter	Polylectic	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Ceratina	*Zadontomerus*	*mikmaqi*	Rehan and Sheffield, 2011	S5	Stem-carpenter	Polylectic	X	X	X	X	X	X	X	X		X	X	X	X	
	Ceratina	*Zadontomerus*	*strenua*	Smith, 1879	S3S4	Stem-carpenter	Polylectic	X	X	X	X		X	X	X		X	X	X		
	Epeolus		*autumnalis*	Robertson, 1902	S3	Cleptoparasite	None						X					X			
	Holcopasites		*calliopsidis*	Linsley, 1943	S3	Cleptoparasite	None	X													
	Melissodes	*Eumelissodes*	*trinodis*	Robertson, 1901	S3S4	Ground	Oligolectic											X			
	Melissodes		*sp.*			Ground		X	X	X	X		X	X		X	X	X	X	X	
	Nomada		*sp.*			Cleptoparasite	None	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Peponapis	*Peponapis*	*pruinosa*	Say, 1837	S2S3	Ground	Oligolectic	X			X		X	X							

	Xylocopa	*Xylocopoides*	*virginica*	Linnaeus, 1771	S4S5	Wood-cavity excavator	Polylectic	X	X	X						X			X		
COLLETIDAE																					
	Colletes	*americanus group*	*americanus*	Cresson, 1868	S4	Ground	Oligolectic		X												
	Colletes	*inaequalis group*	*inaequalis*	Say, 1937	S5	Ground	Polylectic	X						X							
	Colletes		*sp.*			Ground		X	X	X	X	X	X	X	X		X	X	X	X	
	Hylaeus	*Hylaeus*	*annulatus*	Linnaeus, 1758	S5	Stem-cavity renter	Polylectic						X								
	Hylaeus		*sp.*			Stem-cavity renter		X	X	X	X	X	X	X		X	X	X	X	X	X
HALICTIDAE																					
	Agapostemon	*Agapostemon*	*sericeus*	Förster, 1771	S5	Ground	Polylectic	X		X			X	X			X	X	X	X	X
	Agapostemon	*Agapostemon*	*virescens*	Fabricius, 1775	S5	Ground	Polylectic	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Augochlora	*Augochlora*	*pura*	Say, 1837	S5	Wood-cavity excavator	Polylectic	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Augochlorella	*aurata group*	*aurata*	Smith, 1853	S5	Ground	Polylectic	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Augochloropsis	*Paraugochloropsis*	*metallica*	Fabricius, 1793	S4S5	Ground	Polylectic	X	X	X	X		X	X				X			
	Dufourea		*monardae*	Viereck, 1924	S2S3	Ground	Monolectic	X	X	X		X	X	X							
	Halictus	*Odontalictus*	*ligatus*	Say, 1837	S5	Ground	Polylectic	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Halictus	*Protohalictus*	*rubicundus*	Christ, 1791	S5	Ground	Polylectic	X	X	X	X		X	X		X	X	X			X
	Halictus	*Seladonia*	*confusus*	Smith, 1853	S5	Ground	Polylectic	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Lasioglossum	*Dialictus*	*anomalum*	Robertson, 1892	S5	Ground	Polylectic		X												
	Lasioglossum	*Dialictus*	*cressonii*	Robertson, 1890	S5	Wood-cavity excavator	Polylectic	X											X		
	Lasioglossum	*Dialictus*	*fattigi*	Mitchell, 1960	S5	Ground	Polylectic							X							

	Lasioglossum	*Dialictus*	*hitchensi*	Gibbs, 2012	S5	Ground	Polylectic											X			
	Lasioglossum	*Dialictus*	*laevissimum*	Smith, 1853	S5	Ground	Polylectic	X										X			
	Lasioglossum	*Dialictus*	*paradmirandum*	Knerer and Atwood, 1966	S4	Ground	Polylectic		X						X						
	Lasioglossum	*Dialictus*	*pilosum*	Smith, 1853	S5	Ground	Polylectic							X							
	Lasioglossum	*Dialictus*	*smilacinae*	Robertson, 1897	S4	Ground	Polylectic						X								
	Lasioglossum	*Dialictus*	*subviridatum*	Cockerell, 1938	S5	Wood-cavity excavator	Polylectic					X	X								
	Lasioglossum	*Dialictus*	*versatum*	Robertson, 1902	S4S5	Ground	Polylectic	X													
	Lasioglossum	*Dialictus*	*weemsi*	Mitchell, 1960	S4	Ground	Polylectic						X								
	Lasioglossum	*Hemihalictus*	*birkmanni*	Crawford, 1906	S4	Ground	Polylectic									X		X		X	
	Lasioglossum	*Hemihalictus*	*foxii*	Robertson, 1895	S5	Ground	Polylectic												X		
	Lasioglossum	*Hemihalictus*	*lustrans*	Cockerell, 1897	SU	Ground	Polylectic								X						
	Lasioglossum	*Lasioglossum*	*acuminatum*	McGinley, 1986	S5	Ground	Polylectic					X		X	X						
	Lasioglossum	*Sphecodogastra*	*quebecense*	Crawford, 1907	S5	Ground	Polylectic								X			X			
	Lasioglossum		*sp.*					X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Sphecodes		*clematidis*	Robertson, 1897	S3	Cleptoparasite	None	X													
	Sphecodes	*dichrous group*	*prosphorus*	Lovell and Cockerell, 1907	S3	Cleptoparasite	None	X						X				X		X	
	Sphecodes		*sp.*			Cleptoparasite	None	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MEGACHILIDAE																					
	Anthidiellum	*Loyolanthidium*	*notatum*	Latreille, 1809	S5	Constructed Resin	Polylectic		X												

Anthidium	*Anthidium*	*manicatum*	Linnaeus, 1758	SE	Cavity Renter	Polylectic	X					X					X	X	X	
Anthidium	*Proanthidium*	*oblongatum*	Illiger, 1806	SE	Cavity Renter	Polylectic	X	X	X	X		X	X				X			
Chelostoma	*Foveosmia*	*campanularum*	Kirby, 1802	SE	Cavity Renter	Monolectic						X								
Chelostoma	*Gyrodromella*	*rapunculi*	Lepeletier, 1841	SE	Cavity Renter	Monolectic	X										X			
Chelostoma		*sp.*					X	X	X	X			X		X	X	X	X	X	
Coelioxys	*Boreocoelioxys*	*rufitarsis*	Smith, 1854	S3S4	Cleptoparasite	None	X	X												
Hoplitis	*Alcidamea*	*pilosifrons*	Cresson, 1864	S5	Cavity Renter	Polylectic	X	X							X					
Hoplitis	*Alcidamea*	*producta*	Cresson, 1864	S5	Cavity Renter	Polylectic		X							X		X			
Hoplitis		*sp.*					X	X	X			X	X		X		X	X	X	X
Megachile		*sp.*					X	X	X	X		X	X				X	X		
Osmia	*Diceratosmia*	*conjuncta*	Cresson, 1864	S3S4	Snail Shell	Polylectic	X	X	X	X		X				X			X	
Osmia	*Melanosmia*	*distincta*	Cresson, 1864	S5	Cavity Renter	Polylectic									X					
Osmia	*Osmia*	*cornifrons*	Radoszkowski, 1887		Cavity Renter	Polylectic		X			X	X	X	X	X	X	X		X	
Osmia	*Osmia*	*taurus*	Smith, 1873		Cavity Renter	Polylectic										X				
Osmia		*sp.*			Cavity Renter	Polylectic	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Stelis	*Stelis*	*lateralis*	Cresson, 1864	S3S4	Cleptoparasite	None		X									X			

APPENDIX C: WASP SPECIES LISTS

A table listing the species that have been identified to date for this project and their associated localities. Most specimens remain unidentified and have been left at the family level. Blue indicates a forest edge habitat, grey indicates a field habitat, salmon indicates a wetland habitat, pink indicates a forest habitat, and green indicates a forested spring habitat. Presence of a species of genus is denoted with an 'X'.

				McMaster Forest Nature Preserve								McMaster University					
Family	Genus	Species	Authority	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14
ARGIDAE	Not Identified							X									
ASTATIDAE																	
	Astata	*unicolor*	Say, 1824	X		X	X		X	X		X	X		X		
BETHYLIDAE	Not Identified			X	X	X	X	X	X		X	X		X	X	X	X
BRACONIDAE	Not Identified			X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Chelonus	*sp.*		X			X	X	X	X	X	X		X	X	X	
CERAPHRONIDAE	Not Identified			X													
CHALCIDIDAE	Not Identified			X		X	X		X	X						X	X
CHRYSIDIDAE	Not Identified			X	X	X	X		X	X	X	X			X	X	X
CRABRONIDAE	Not Identified			X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Alysson	*sp.*					X									X	
	Crabro	*sp.*								X							
	Ectemnius	*cephalotes*	Olivier, 1792														X
	Ectemnius	*continuus*	Fabricius, 1804												X	X	
	Ectemnius	*sp.*		X		X	X	X	X	X		X	X	X		X	X
	Epinysson	*sp.*		X				X	X		X			X			X
	Gorytes	*sp.*												X			
	Nysson	*sp.*					X	X	X		X						
	Pemphredon	*sp.*														X	
	Saygorytes	*phaleratus*	Say, 1837				X										

	Trypoxylon	*sp.*		X	X	X	X	X	X	X	X	X	X	X	X	X	X
CYNIPIDAE	Not Identified			X		X	X	X	X	X	X	X	X		X		
DIAPRIIDAE	Not Identified			X	X	X	X	X	X	X	X	X	X	X	X	X	X
DRYINIDAE	Not Identified			X		X	X	X	X	X	X	X	X		X	X	X
EUCHARITIDAE	Not Identified			X	X		X			X	X						
EULOPHIDAE	Not Identified			X		X		X	X		X		X		X	X	X
EUPELMIDAE	Not Identified						X	X			X						
EURYTOMIDAE	Not Identified			X	X	X	X	X	X			X		X		X	X
FIGITIDAE	Not Identified			X			X	X	X	X	X	X	X	X	X	X	X
ICHNEUMONIDAE	Not Identified			X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Ichneumon	*chasmodops*	Heinrich, 1961					X			X						
	Oedemopsis	*davisi*	Carlson, 1979	X				X			X						
	Pimpla	*sp.*				X	X	X			X	X					
	Rubicundiella	*mucronata*	Provancher														X
	Rubicundiella	*sp.*				X						X	X			X	
	Theronia	*hilaris*	Say, 1829								X						
ISMARIDAE	Not Identified							X									
MEGASPILIDAE	Not Identified			X		X		X	X		X		X		X		X
MUTILLIDAE	Not Identified															X	
MYMARIDAE	Not Identified								X		X	X					
MYRMOSIDAE																	
	Myrmosa	*unicolor*	Say, 1824				X	X	X				X				
ORMYRIDAE	Not Identified				X												
PHILANTHIDAE																	
	Philanthus	*sp.*				X											
PLATYGASTRIDAE	Not Identified			X	X			X	X	X	X	X	X		X	X	X
POMPILIDAE	Not Identified			X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Ceropales	*maculata*	Fabricius, 1775			X	X		X			X	X				
PROCTOTRUPIDAE	Not Identified						X	X				X				X	X

PTEROMALIDAE	Not Identified			X	X	X	X	X	X	X	X	X	X	X	X	X	X
RHOPALOSOMATIDAE	Not Identified									X							
SCELIONIDAE	Not Identified				X	X	X	X	X	X	X	X	X	X	X	X	X
	Trimorus	*sp.*								X	X						
SPARASIONIDAE	Not Identified								X								
SPHECIDAE																	
	Ammophila	*nigricans*	Dahlbom, 1843	X													
	Ammophila	*sp.*				X								X			
	Isodontia	*sp.*				X											
	Sphex	*ichneumoneus*	Linnaeus, 1758	X		X											
TENTHREDINIDAE	Not Identified			X	X	X	X	X	X	X	X	X			X	X	X
	Strongylogaster	*sp.*															X
TIPHIDIDAE	Not Identified			X	X							X		X			
	Tiphia	*sp.*												X			
TORYMIDAE	Not Identified					X	X	X	X								
TRIGONALIDAE	Not Identified											X					
VESPIDAE	Not Identified			X	X	X	X		X	X	X	X	X	X			X
	Ancistrocerus	*adiabatus*	Saussure, 1852							X				X		X	
	Ancistrocerus	*albophaleratus*	de Saussure, 1855									X					
	Ancistrocerus	*campestris*	de Saussure, 1852		X	X											
	Ancistrocerus	*catskill*	de Saussure, 1853												X		
	Dolichovespula	*arenaria*	Fabricius, 1775						X	X	X		X			X	X
	Dolichovespula	*maculata*	Linnaeus, 1763													X	
	Eumenes	*crucifera*	Provancher, 1888	X										X			
	Eumenes	*fraternus*	Say, 1824	X	X	X	X										
	Euodynerus	*foraminatus*	de Saussure, 1853						X								
	Euodynerus	*planitarsis*	Bohart, 1945												X		
	Parancistrocerus	*pedestris*	de Saussure, 1855				X		X	X	X			X			

	Parancistrocerus	*pensylvanicus*	de Saussure, 1855	X			X										
	Parancistrocerus	*perennis*	de Saussure, 1857									X					
	Polistes	*dominula*	Christ, 1791		X				X							X	X
	Polistes	*fuscatus*	Fabricius, 1793	X	X	X	X		X	X				X		X	
	Vespula	*flavopilosa*	Jacobson et al., 1978	X				X	X								
	Vespula	*maculifrons*	Buysson, 1905	X		X	X	X	X	X		X	X	X		X	X
	Vespula	*vidua*	Saussure, 1854						X	X		X			X	X	
	Vespula	*vulgaris*	Linnaeus, 1758			X											