

Buzzing Through Canada's Maritime Provinces:
Unveiling Wild Bee Community Dynamics Amidst
Habitat Changes and Blooming Landscapes

by

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ABSTRACT

The decline of wild pollinators, particularly bees, poses a global threat to terrestrial ecosystems. While habitat loss and agricultural intensification are recognized culprits, the complex relationship between wild bee communities, floral resources, and varied habitats remains understudied. Focusing on the forest landscapes of the Maritime Provinces in Canada, we conducted surveys across 47 sites, encompassing forests, agriculture, and pastures. Contrary to previous findings in other regions, our results indicate higher wild bee species abundance and richness in agricultural and pasture habitats compared to uncleared forests. However, our results also suggested that the wild bee community composition across the three habitats was similar. Floral resources demonstrated habitat and seasonal dependencies, influencing wild bee communities differently among the habitats. Our findings underline the need for specialized conservation strategies, balancing agricultural productivity with biodiversity preservation, and highlight avenues for future research on wild bee populations and their complex interactions with diverse ecosystems.

DEDICATION

To the resilient spirits of all the young minds who were once told their dreams were too vast, their aspirations unattainable, and their intellect insufficient. For every little girl and boy who was discouraged from pursuing their passions and made to believe their chosen path lacked honor or respect. May this research stand as a testament to the unyielding determination within each of you, proving that barriers can be overcome, dreams can be realized, and paths less traveled can lead to greatness. Your curiosity, creativity, and perseverance are the driving forces behind this dedication. If I could turn my dreams into realities, you can as well. You possess the power to chart your own course, defy expectations, and embrace your unique journey with unwavering determination. In honoring your unwavering spirit, this work is dedicated to all those who dare to challenge limitations, break stereotypes, and forge ahead despite the discouraging words spoken. May you find inspiration and strength to continue shaping your own destinies, undeterred by anyone's narrow perceptions.

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Chapter 1: General Introduction

¹The transformation of natural or seminatural habitats into agricultural and pasture fields plays a significant role in biodiversity loss (Morrison & Mendenhall, 2020). This conversion leads to habitat loss, which, in turn, results in biotic homogenization, reduced species diversity, lower population numbers, and a decline in functional diversity (Morrison & Mendenhall, 2020; Rodrigues et al., 2012; Pringle et al., 2019). Understanding the overarching issue of habitat loss and its consequences for biodiversity has many benefits (Fuller et al., 2005), as it involves the destruction and degradation of habitats resulting in the displacement or extinction of species (Fuller et al., 2005). However, to gain a deeper understanding of the impact of habitat loss on ecosystems, it is crucial to focus on specific ecosystems that are particularly affected, such as forest habitats. When forests are converted to agricultural or pasture lands, it affects groups of

¹ ChatGPT, among other tools, was used to polish the presentation of the text in this chapter. I wrote the entire thesis myself however, in areas where I found myself struggling with my writing skills, I used ChatGPT for help. For example, for sentences that were too long, I asked ChatGPT to make them concise without losing any information. Each time ChatGPT provided me with an output, I reviewed it to ensure it was saying what I wanted it to say. In cases where it did not, I tried to work through it myself or asked my supervisors for help. Overtime, I learned how to better make my sentences more concise and so my use of ChatGPT decreased over the months. I reviewed all output, considered what suggestions to use, and remain responsible for all content.

species differently. It is important to note that all species are impacted in some way by the loss and change of their habitats (Viña et al., 2008).

The transformation of forest habitat into agriculture and pasture fields can have both positive and negative consequences for wildlife (MacGregor-Fors & Schondube, 2010). On the positive side, converting forests to agricultural land can open new habitats for species adapted to open areas. For example, birds in agricultural regions benefit from a wider variety of habitats and food sources compared to their forest-dwelling counterparts (Elsen et al., 2016). Moreover, some birds that play roles in pollination and seed dispersal initially thrive as farming activities increase, although their numbers decline with more intense agriculture (Tschardt et al., 2008). On the contrary, the conversion of forest habitat into agricultural and pasture fields also brings about adverse effects on wildlife. Forests are intricate ecosystems, offering a multitude of resources and microhabitats for a diverse range of species. When forests are cleared for agriculture or pasture, numerous species lose their homes and struggle to survive in the altered landscape (Hansen et al., 2013). This can result in local extinctions and an overall decrease in biodiversity (Hansen et al., 2013). The conversion of forests to monoculture agriculture can lead to a loss of species richness and a decrease in the availability of resources for animals (Warren-Thomas et al., 2015). The conversion of forest habitat into agricultural land often involves the use of intensive farming practices, such as the application of pesticides and fertilizers. These chemicals can have detrimental effects on animals, including direct toxicity and indirect effects through the disruption of food chains and ecosystems (Beckmann et al., 2019). These contrasting findings highlight the responses of individual species to habitat conversion, highlighting the significance of

research into the specific ecological needs of various species and the resultant impacts on a species-by-species basis.

Sometimes an unexpected consequence of habitat alteration is a mismatch between animal preference for, and performance in, alternative habitats. An ecological trap occurs when an animal is attracted to a habitat that appears to be suitable based on certain cues, but in reality, it provides lower fitness compared to other available habitats (Sievers et al., 2017). The formation of ecological traps is often influenced by human-induced environmental changes, such as habitat alteration, pollution, and urbanization, which can disrupt animal cues, affect habitat quality, and decrease biodiversity (Sievers et al., 2017; Hale et al., 2019). Ecological traps can have significant impacts on animals, affecting their behaviour, habitat selection, and ultimately their fitness and population persistence. The consequences of ecological traps can be detrimental to animal populations as they can lead to reduced survival and reproduction rates, ultimately impacting population size and persistence (Penteriani et al., 2018). Ecological traps can also increase extinction risk and reduce ecosystem resilience (Swearer et al., 2021).

Habitat loss and fragmentation collectively stand as global threats to biodiversity, giving rise to continuous discussions concerning their full extent of harm (Fahrig, 2003; Ewers & Didham, 2005; Fletcher et al., 2018). While research reveals a multitude of effects resulting from habitat fragmentation on different species (Fletcher et al., 2018), the relationship between habitat loss and its implications for diversity and ecosystem functioning varies between species (Gonzalez et al., 2009). For example, in some instances, habitat fragmentation can benefit songbirds by reducing nest predators (Lichstein et al., 2002). However, in other instances, habitat fragmentation can lead to a

decrease in pollinator diversity and a simplification of pollination systems in agricultural landscapes (Chacoff & Aizen, 2005). The disruption of plant-pollinator interactions by habitat fragmentation can detrimentally affect plant reproductive success (Girão et al., 2007). This further indicates the value of investigating the ecological requirements of different species in different habitats.

While attention is more often paid to effects of habitat loss and fragmentation on charismatic taxa like birds and mammals, we need to understand their effects on insects too. Insect pollination is paramount for agriculture, biodiversity, and food security, underlining the urgency of conserving pollinators and their habitats, even in cases where immediate human benefits may not be readily apparent. Various studies have emphasized the significance of pollination for food production and security (Gallai et al., 2009; Nagano et al., 2021; Lander, 2019). About 75% of plant crops rely on insect pollinators (Manson et al., 2022). However, with 40% of insect species facing extinction, the decline of insect pollinators threatens these essential services (Manson et al., 2022). Safeguarding pollination is critical as global food demand is set to double or triple by 2050, and agriculture heavily depends on these services (Manson et al., 2022). Besides their role in farming, insect pollinators such as wild bees also aid in biodiversity conservation and ecosystem health (Russo et al., 2022). Protecting their habitats is a key strategy for their conservation (Russo et al., 2022).

Wild bees are essential pollinators in both natural and agricultural ecosystems, playing a crucial role in the pollination of plants. The alteration of habitats and the surrounding landscape can significantly impact wild bee populations and has implications for habitat restoration and conservation efforts. Habitat fragmentation, which is a

common consequence of landscape alteration, can disrupt the connectivity between habitats, making it more difficult for wild bees to move between suitable foraging and nesting sites. Habitat fragmentation can result in a decrease in wild bee populations and a loss of biodiversity (Haddad et al., 2015). While habitat restoration can enhance wild bee populations, the effectiveness of different habitat types and restoration methods in supporting these communities varies (Tonietto & Larkin, 2017). It is important to note that specific habitat types, particularly semi-natural habitats, significantly supported and enhanced the overall diversity of the pollinator population across the landscape (Eeraerts & Isaacs, 2023). Understanding the diverse habitat needs of wild bee populations is vital for researchers and conservationists to effectively manage and conserve these communities, though it's crucial to recognize that different bee species possess distinct environmental requirements.

Wild bees have varying habitat preferences based on nesting and pollen specialization. Some solitary bees, with smaller foraging ranges, favor seminatural habitats like grasslands and orchard meadows (Steffan-Dewenter et al., 2002). Conversely, it has been found that some bumblebees exhibit less dependence on specific habitats (Steffan-Dewenter et al., 2002). A habitat for wild bees should offer ample nectar and pollen throughout their active season. Overall, the impact of changing landscapes on wild bee communities is complex and can vary depending on factors such as habitat type, landscape context, season, floral resources etc. Understanding these interactions aids in developing effective conservation and restoration measures to support wild bee populations and maintain ecosystem functioning. The understanding of these interactions

provides insight into the specific factors influencing wild bee communities, offering a clearer understanding of the dynamics within the wild bee community.

We aimed to investigate the diversity of bee species across various habitat types in the Maritime provinces, focusing on the transformation of forests into agricultural or pasture lands and their associated floral resources. To achieve this, we selected 47 sites across three Maritime provinces to represent agricultural, pasture, and forest habitats. These sites were carefully chosen based on specific suitability criteria outlined in Chapter 2's method section. We utilized pollinator-specific traps to sample wild bee communities, identifying collected bees using keys and genetic barcoding. Floral resources were assessed through transects. Our statistical analysis centered on assessing the species abundance and richness of wild bees and flowers. Various tests were conducted to explore the effects of habitat, time of visit, and forest cover on wild bee populations. Additionally, we analyzed both bumblebee and non-bumblebee data, examining the relationship between wild bee and floral abundance. Non-bumblebee grouping refers to all members of family Apidae except those belonging to the genus *Bombus*. We predicted that a preference for disturbed habitats among wild bees in the Maritime provinces would result in higher bee species abundance and richness in agricultural and pasture habitats compared to forest habitats. Furthermore, we anticipated observing higher floral species abundance and richness in agricultural and pasture areas if the bee communities exhibited greater richness and abundance in those habitats.

Author Contributions

The initial experimental framework was conceptualized by Dr. Jess Vickruck. I authored the manuscript, designed field protocols, coordinated & conducted the fieldwork, processed the insects, ID'd them and analyzed the data, all with valuable guidance, help and support from Dr. Stephen B. Heard and Dr. Jess Vickruck.

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Chapter 2: The Impact of Habitat Alteration and Floral Resources on Wild Bee Communities in the Maritime Provinces, Canada.

2.1 Introduction

In recent years, the decline of wild pollinators, especially bees, has emerged as a significant global concern (Rahimi et al., 2021). Bees, with over 20,000 different species across seven families known to date, play a crucial role as pollinators in terrestrial ecosystems (Michener, 2007). However, the species richness and abundance of wild bee communities has been decreasing (Lajos et al., 2021). While some previous studies have mainly focused on managed bees, like honeybees, there is now a growing emphasis on understanding the contribution of unmanaged, wild bees for crop pollination (Cutler et al., 2015). Studies on wild bees have gathered increasing attention due to their pivotal role (Morandin & Winston, 2005). They serve as indicators of anthropogenic impacts, encompassing factors such as pesticide usage, climate change, and land disturbances, on pollinator populations (Park et al., 2015).

Among insects, bees (superfamily Apoidea) are the top pollinators, contributing to the pollination of wild plants and agricultural crops (Lozada-Gobilard et al., 2021). However, since habitat loss and agricultural intensification pose a significant global concern (Moreaux et al., 2021) modifying habitats could potentially lead to a decrease in wild bee populations. Understanding how habitat loss and agricultural intensification affect wild bees in a variety of different habitats is crucial to prevent further biodiversity loss. The rise in habitat alteration has led to a decline in insect biodiversity due to the

disruption of crucial resources such as flowering plants in supporting the insect community (Galpern et al., 2021; Carrie et al., 2012).

Important resources for wild bees include both food (nectar and pollen) and habitat. The two are linked, because habitat may include both suitable sites for nesting as well as food plants. Most bees thrive in areas rich in nectar and pollen, serving as suitable foraging habitats with vital energy sources and nutrients (Gathmann & Tschardt 2002). Different species have varying nesting requirements; bees, for instance, utilize habitats ranging from the ground to wood and various cavities. In regions with agricultural intensification and habitat fragmentation, the breaking apart of habitat can lead to a lack of resources for certain species (Fahrig, 2003). Specialist bees reliant on specific floral or nesting resources may be particularly affected by habitat alteration compared to other more generalist species (Evans, 2016) due to the lack of appropriate nesting habitat or flowering plants. Some studies indicate that habitats unaffected by agricultural intensification, such as tall grass prairies, semi-natural lands, wetlands etc., support more diverse and successful bee communities, as habitat alteration could diminish available resources (Evans et al., 2016; Clough et al., 2014; Lazaro et al., 2016). Furthermore, wild bee species richness is linked to the diversity of habitats and resources within localized areas, as many species depend on a range of specific habitats to sustain their populations (Rivers-Moore et al., 2020). This suggests the importance of considering not only local habitat and resources but also those available within a routine flight distance. For instance, bee communities at a pasture site surrounded by more pasture might differ from those at a pasture site surrounded by forest, which aligns with our study findings.

Considering the availability and quality of floral resources is essential for gaining insight into how wild bee populations and communities function and change over time. Wild bees and flowering plants engage in a mutualistic relationship that has evolved over millions of years (Holzschuh et al., 2011). Generally, when a bee visits a flower, it acquires nectar or pollen as a food source, while in most cases aiding in plant reproduction by transferring pollen from one flower to another (Corbet *et al.*, 2015). The availability of floral resources significantly impacts bee communities, as a major loss in floral resources can have adverse effects on bee species abundance and richness (Scheper *et al.*, 2015). In general, the species abundance and richness of bees and flowers tend to be positively correlated (Cutler *et al.*, 2015, Klein *et al.*, 2006 & Theodorou *et al.*, 2020). However, we don't know enough about how different habitats affect the variety of flowers and types of wild bees, since not all bees respond the same way to changes in their environment. The response of wild bees depends a lot on the habitat requirements of the species. Some bees, categorized as either floral specialists or floral generalists, exhibit distinct flower preferences (Minckley et al., 2013). Which results in different wild bee species being attracted to specific flowers in an area, thereby shaping the variety of bees encountered, as some bees may favor particular flowers for their nectar or pollen (Minckley et al., 2013).

Previous studies have made significant contributions to our understanding of the mutualistic relationship between wild bee communities and floral resources, with a particular focus on comparing agriculture with prairie/grassland/old-field habitats (McNeil et al., 2020; Lane et al., 2020). These studies have explored various aspects of this relationship, including the impact of floral resource availability on bee diversity and

abundance (Kratschmer et al., 2019; Lane et al., 2020), the role of floral resources in supporting pollinator health and immune function (McNeil et al., 2020), and the importance of floral resource supplementation for native bee communities (Russo et al., 2013). However, few studies have been conducted in areas where the dominant non-agriculture landscape is forest as opposed to grassland, with the Maritime provinces of Canada (New Brunswick, Nova Scotia, and Prince Edward Island) being an example. The Maritimes offer forest habitats characterized by a blend of temperate and boreal ecosystems. Their coastal geography and diverse landscapes create a rich variety of forested environments. These forests play a vital role in the region's biodiversity and provide essential ecosystem services. Given the scarcity of research conducted in the area and the presence of agricultural, pasture and forest habitats, the Maritime provinces present an excellent opportunity to investigate how agricultural intensification impacts wild bee communities in forest to cropland conversions.

Our main objective was to investigate the impact of habitat alteration and floral resource availability on the composition of wild bee communities in the Maritime provinces. While studies conducted in other places, such as the prairies, croplands, and semi-natural grasslands reported that wild bees were mostly found in uncleared habitats (Evans 2016, Millard *et al*, 2021, Clough *et al* 2014 & Lazaro *et al* 2016), preliminary observations conducted in New Brunswick, Canada reported finding more bumblebees in agricultural and pasture fields (Meed 2021). Based on these considerations, our hypothesis is that if bees in the Maritime provinces prefer agricultural and pasture sites with a lot of floral resources over uncleared habitats, we would expect to observe higher bee abundance and richness in agriculture and pasture habitats compared to forest

habitats. Additionally, if floral species within agricultural and pasture habitats exhibit greater species abundance and richness, we would also predict a higher species richness and abundance of bees in those areas. Overall, our study conducted surveys of wild bees and floral resources at 47 sites across the Maritime provinces, encompassing forested, agricultural, and pasture sites. Through these surveys, we examined species richness and species abundance patterns of wild bees and flowers, emphasizing differences in floral and wild bee communities among the various site types.

2.2 Methods

Site Selection

We chose 47 sites (Figure 1) across the Canadian provinces of New Brunswick (19 sites), Nova Scotia (18 sites), and Prince Edward Island (10 sites). These sites were selected to encompass three distinct habitat categories: agricultural (19 sites), pasture (11 sites), and forest (17 sites). Our site selection process originated from a larger research initiative conducted by Agriculture and Agri-Food Canada, aimed at exploring the spatial patterns of microbial and invertebrate species richness and diversity in soil. Researchers from Agriculture and Agri-Food Canada chose approximately 500 sites across Atlantic Canada, representing diverse habitat types, soil composition and land usage. Due to time constraints preventing a comprehensive study of all 500 locations, we chose to work at a subset of these sites. Agriculture and Agri-Food Canada defined their agricultural sites as sites including annual and perennial crops (exclude grasslands). They defined they pasture sites as sites that were periodically cultivated and included tame grasses and other perennial crops such as alfalfa and clover grown alone or as mixtures for hay, pasture, or

seed. Lastly, they defined their forest sites as sites that are predominantly broadleaf/deciduous forests or treed areas or sites that were a combination of both coniferous and broadleaf classes. They did not consider clearcuts as forests. We selected our points to ensure that we captured the diverse variations present in the dataset. This subset was determined through the application of specific filtering criteria. To accurately identify habitat types surrounding each site we used ArcGIS software (ArcGIS 10.8.2) at 30 meters spatial resolution to estimate the land use types within a 1km radius of our site. This one-kilometer regional percent forest cover radius was chosen to accommodate the typical flight range of bees (Osborne et al. 2007). This spanned a wide range of forest cover, covering from 1.11% to 79.19%, where 13 of our sites were above 50% regional percent forest cover and 34 sites had less than 50% regional percent forest cover. It was difficult for us to find much higher (greater than 80%) regional percent forest cover due to other habitat types like wetlands, lakes, rivers, urban areas etc. in the area. The average percent of forest cover for our agricultural sites was 27.65% (range: 8.54% – 57.86%). The average percent of forest cover for our pasture sites was 25.44% (range: 1.11% - 63.13%). The average percent of forest cover for our forest sites was 44.19% (range: 1.36% - 79.19%). The selected sites were deliberately distributed throughout the provinces to encompass geographic variation. Additionally, sites isolated from others were excluded to ensure efficient travel routes between locations. Sites unsuitable for wild bees, such as coniferous forests and ponds, were eliminated from consideration. Similarly, peat-covered wetlands (bogs) were excluded due to their scarcity across all three provinces. Furthermore, sites with over 5% (equivalent to 15.7 hectares) of urban

development within a one-kilometer radius were removed. Due to all these criteria, we ended up having uneven sampling sites across our different habitat types.

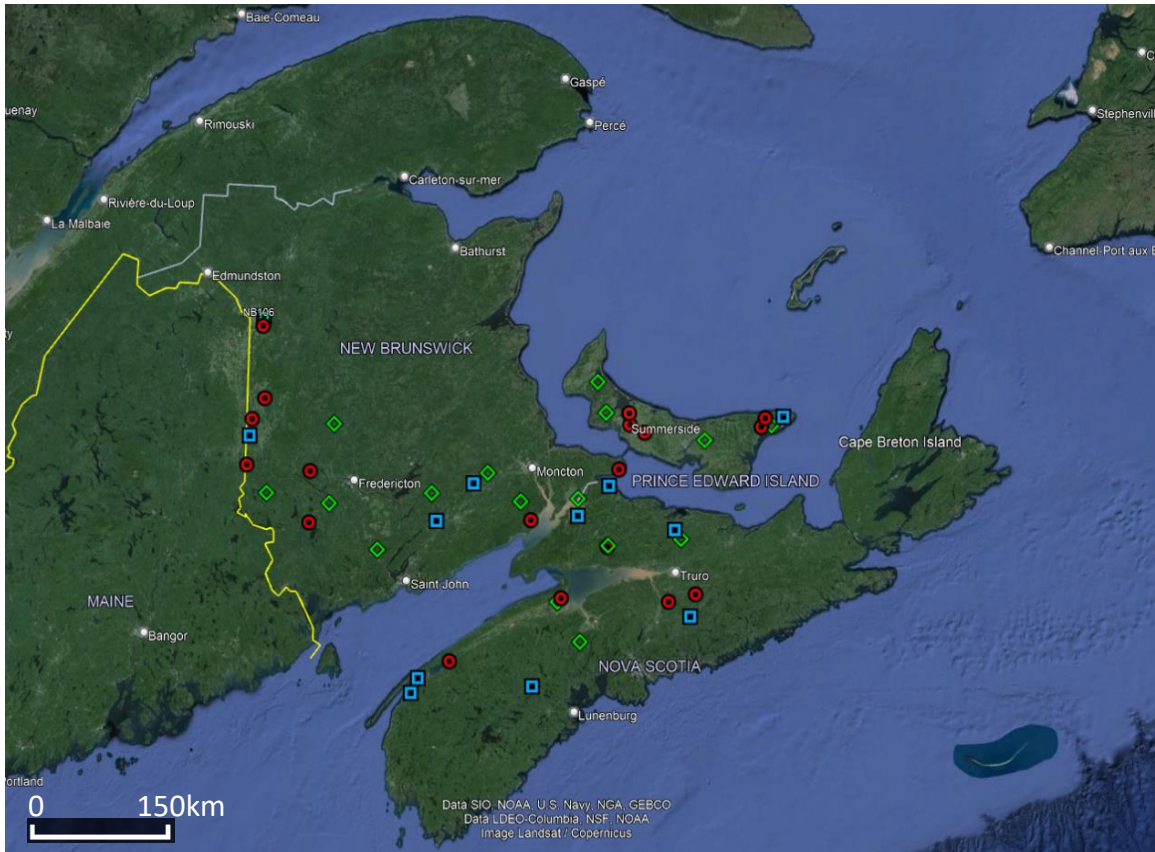


Figure 1: The 47 chosen sites across the Maritime Provinces.

The red circles represent agricultural sites, the blue squares represent pasture sites, and the green diamonds represent forest sites. These sites were selected to encompass three distinct habitat categories: agricultural (19 sites), pasture (11 sites), and forest (17 sites).

"Satellite Imagery of the Maritime Provinces." Google Earth Pro [Version 7.3.6.9345].

<https://www.google.com/earth/>.

Sampling Wild Bee Communities

We collected bees at each site using a combination of blue vane traps and cup traps. A single blue vane trap, which is neon yellow and blue in colour, was positioned at each site, aligned with the surrounding vegetation's height to ensure visibility to bees. Neon yellow and blue vane traps acted as visual cues to attract wild bees, particularly larger species like bumblebees (Hall 2018). In addition, each site featured nine cup traps, with white, blue, and yellow colors, each holding approximately half a litre of propylene glycol. These cup traps were secured to stakes for stability and aimed to capture low-flying ground nesting or parasitic bees. The setup of the site involved placing the blue vane trap in the middle, four cups on either side, and one cup in front of the blue vane (Appendix 1.1). Using ArcGIS software, we divided our site into two distinct regions. The local habitat was designated as the 50m-by-50m area surrounding the trap/transect, while the region extending one kilometer beyond this local habitat was defined as the regional habitat. At six of our forest sites, we also placed one blue vane trap at the bottom of where the tree canopy started, which was roughly 20 meters above the forest floor using a slingshot. We placed these traps to assess if there were any wild bees present in the canopy that we were not capturing in our traps on the forest floor. These traps were placed on the same day as the forest floor traps and were collected the same day as well.

Bees and flowers were sampled twice during the summer to capture differences in wild bee life histories and differing flower phenologies. We deployed traps from May 24th to June 7th, 2022, and again from July 18th to August 2nd, 2022. Roughly two weeks (+/- 1 day) after deployment, we retrieved the traps. Collected bees were transferred to WhirlPak bags containing 100% ethanol. Subsequently, we washed, blow-dried (to

enhance hair fluffiness), and pinned bees. Identification relied on keys from the Discover Life website (Schuh et al, 2010) supplemented with Carril & Wilson, 2021, and Williams et al, 2014.

We encountered several genera that were difficult to identify to the species, prompting us to send a subset of bees to the Centre for Biodiversity Genomics at the University of Guelph in Guelph, Ontario, Canada, for genetic barcoding to confirm and identify the species. Genetic barcoding is a technique that uses a section of the COI gene to uniquely identify an organism. The samples were submitted via the barcode of life data system (BOLD). BOLD is a platform for storing and analyzing data created by the Centre for Biodiversity Genomics in Canada. The COI Identification System within BOLD processes sequences from the 5' region of the mitochondrial Cytochrome c oxidase subunit I gene, providing species-level identifications when possible. However, not every COI barcode entry will include a species-level identification due to potential errors during the processing stage or because sometimes different species have the same barcode (Centre for Biodiversity Genomics, University of Guelph, 2023). After obtaining the sequence, we cross-referenced it with their database to assign a species name to each specimen. While certain specimens achieved a species-level match of 100%, in instances where a 98% portion match of the DNA sequence in our sample corresponded to the reference sample, we selected this option. For specimens with less than a 98% match that couldn't be identified at the species level, they were categorized at the genus level. We then performed morphological sorting and assigned them numerical labels (e.g., *Nomada* sp 1), enabling us to conduct species abundance and richness analyses on these specimens.

Assessing Floral Resources

At each site, we established one floral transect running parallel and one transect running perpendicular to the road used to access the site (Appendix 1.2). The blue vane trap was positioned at the point where both transects intersected. Each flower transect measured 50 meters in length and 1.0 meter in width. We determined that the transect lengths were adequate for thorough observation of nearly all floral resources. In cases where certain resources extended beyond the transects, we documented them at those specific sites. At every site, we identified and tallied all individual stems with open flowers at the time of blue vane and cup trap deployment. For flowers displaying compound arrangements, which involve combining multiple flowers, we counted the capitulescences, as these represented the functional attraction unit for bees. The floral surveys were consistently conducted by the same researcher (ASA) at each site. At eight of our sites, adjustments were made to the standard transect layout due to obstructions like roads, fences, or buildings. These adjustments involved altering the lengths of the transects while preserving the total transect area. For instance, we used configurations such as 35 m + 15 m instead of 25 m + 25 m. Flowers were identified using Boland (2015) and the Seek app (iNaturalist 2022).

Statistical Analysis: Wild Bee Community and Floral Resources

We focused on two key variables: bee abundance and bee species richness. Bee abundance is the total count of wild bee individuals in a site collection, while bee species richness is the total number of different wild bee species. The Simpson diversity index was calculated for sites in all three habitats; however, it yielded no novel insights, instead

aligning with patterns observed in wild bee species abundance and richness (Appendix 1.3, 1.4). We conducted multiple ANCOVAs to examine the main effects and interactions of our independent variables, habitat type, time of visit, and the percentage of forest cover on our dependent variables, wild bee abundance and richness. Further exploration involved post-hoc testing through a Tukey test, facilitating the identification of significantly distinct groups or conditions in cases of multiple group comparisons. We examined how the main effect of sampling period and regional percent forest cover influenced floral species abundance and species richness within habitats, paralleling the analysis performed on the wild bee communities. We used linear regression model to explore potential relationships between floral species abundance and floral species richness with wild bee species abundance and wild bee species richness.

Bumblebees (*Bombus*), comprising 41% of the collected individuals, exhibit distinctive traits such as larger flying radiuses and variations in social behavior, distinguishing them from other members of the wild bee community. Their eusocial nature allows multiple workers from the same nest to be captured in a single trap, unlike solitary bee females, each originating from a different nest. Thus, the colony emerges as the functional unit. While trapping multiple bees from a single nest nearby in certain habitats doesn't tell us much about the habitat's support for wild bees, capturing several solitary female bees in traps indicates diverse nest origins, highlighting their selective use of floral resources in that specific habitat. Examining the influence of our independent variables (habitat, sampling period, and regional percent forest cover) on bumblebees could unveil their specific habitat preferences. Understanding these relationships may shed light on whether these factors contribute to the broader trends observed in the

primary data analysis. To investigate whether bumblebee abundance was driving the overall bee community patterns, we divided the data into two sets: bumblebees and non-bumblebees. The non-bumblebee grouping refers to all members of family Apidae except those belonging to the genus *Bombus*. The same tests were applied to these subsets to determine if bumblebees were masking any patterns in the rest of the population.

We wanted to know if the floral abundance recorded at our different sites predicted wild bee abundance. To do so, we used a linear regression to test for a relationship between wild bee abundance and floral abundance. Finally, for a thorough examination of community composition in each habitat and to assess their distinctions, we used an NMDS plot to visualize community composition as NMDS plots display patterns in similarity in multivariate data. Non-metric multidimensional scaling (NMDS) in R is a statistical technique for visualizing similarities or dissimilarities among objects or samples. The NMDS involves preparing the data matrix, computing dissimilarity or similarity measures based on chosen metrics, applying the NMDS algorithm to derive a lower-dimensional representation preserving original distances, and calculating stress to assess the fit. The resulting plot depicts objects as points in a lower-dimensional space, where distances between points reflect original dissimilarities or similarities.

Enhancements like labels and colors aid interpretation, enabling analysts to identify clusters or trends and interpret underlying data structures. For our plot, we did not transform the data and we had two axes. We used Bray-Curtis dissimilarity as it takes into account species presence/absence, as well as abundance.

We performed all data analysis using R Studio (R version 4.1.2, released on 2021-11-01). The packages employed included ggplot2 (version 3.4.2), dplyr (version 1.1.2),

ggpubr (version 0.6.0), vegan (version 2.6.4), foreign (version 0.8.84), MASS (version 7.3.60), and car (version 3.1.2).

2.3 Results

Wild Bee Species Abundance, Species Richness & Community Composition

During our field season, we collected a total of 3281 wild. Of these, 1332 (~41%) were from the genus *Bombus*, while 1949 (~59%) belonged to 21 other genera. We collected a total of 111 different wild bee species. The most common genera were *Bombus*, *Lasioglossum* and *Andrena*. The most common *Bombus* species collected was *Bombus perplexus* (Appendix S1.7). Wild bee species such as *Andrena ovatula*, *Andrena ceanothi*, and *Andrena erythronii* were solely located in agricultural fields (Appendix S1.7). Pasture fields housed distinct species like *Andrena algida*, *Anthophora bomboides*, etc. (Appendix S1.7). Forested sites, on the other hand, hosted species such as the *Lasioglossum ephialtum/subviridatum/sagax complex* & *Epeoloides pilosula* that were not found in other habitat types. We deployed traps in the canopy of six forest sites to ensure we captured the full range of species present. Our findings revealed that all species collected in the canopy were also captured in traps on the forest floor. As a result, we excluded the canopy data from our analysis.

Wild bee abundance varied across sample sites (ANCOVA, $F_{(1,80)} = 2.9$, $p = 2.6e-3$). Regional percent forest cover had no significant impact on wild bee abundance (Table 2). There were more wild bees in July/August than there were in May/June (Table 2) (Appendix 1.5). Habitat type also held significant influence, revealing significantly higher wild bee abundance in agricultural and pasture sites compared to forest sites

(Table 2) (Figure 2A). This was evident in the pairwise comparisons: forest sites had significantly lower wild bee abundance from agricultural sites ($p = 2.1e-04$), pasture sites were not significantly different from agricultural sites ($p = 0.57$), and pasture sites had significantly higher wild bee abundance from forest sites ($p = 0.026$) (Figure 2A). A summary of these results has been provided (Table 1).

Wild bee species richness also varied across sample sites (ANCOVA, $F_{(1,80)} = 9.9$, $p = 3.8e-11$). Neither regional percent forest cover nor sampling period had a significant impact on wild bee species richness (Table 2). There was an influence of habitat type on wild bee species richness (Table 2) (Figure 3A). Agricultural and pasture sites had higher wild bee species richness compared to forest sites. Wild bee species richness varied significantly among habitat types, with agricultural sites ($p = 1.0e-7$) > pasture sites ($p = 5.8e-3$) > forest sites ($p = 4.0e-7$) (Figure 3A). The NMDS ended successfully with 523 runs and a stress level of 0.22. The NMDS plot showed overlapping patterns, implying a similarity in community composition across the three habitats (Figure 4). While each individual forest has a lower wild bee species richness, when we combine the forest sites, we see that forests overall are capturing roughly the same wild bee species as seen in agricultural and pasture fields.

Bumblebee Species Abundance and Species Richness

Bumblebee abundance varied across sample sites (ANCOVA, $F_{(1,74)} = 1.8$, $p = 5.9e-2$). We observed significant impacts of both habitat ($F_{(2,81)} = 4.2$, $p = 0.01$) and sampling period ($F_{(1,81)} = 4.2$, $p = 0.04$) on bumblebee species abundance. Agricultural and pasture sites exhibited higher bumblebee species abundance from forested areas

(Figure 2B), and July/August data collection recorded a greater number of bumblebees compared to sampling period one. Which is evident in the pairwise comparisons: forest sites had significantly lower species abundance from agricultural sites ($p = 0.007$), pasture sites were not significantly different from agricultural sites in terms of bumblebee species abundance ($p = 0.7$), and pasture sites were not significantly different from forest sites in terms of bumblebee species abundance ($p = 0.1$) (Figure 2B). These findings contrast with those from our analysis of the wild bee community, revealing significant differences between pasture and forest sites. There was no significant impact of regional percent forest cover on bumblebee abundance ($F_{(1,81)} = 0.2$, $p = 0.6$). Bumblebee species richness significant (ANCOVA, $F_{(1,74)} = 7.5$, $p = 1.6e-8$). There was no significant effect of regional percent forest cover ($F_{(1,81)} = 2.3$, $p = 0.1$) and a main effect of sampling period ($F_{(1,81)} = 11.5$, $p = 0.001$), and habitat ($F_{(2,81)} = 17.6$, $p = 4.4e-07$). Bumblebee species richness varied significantly among habitat types, with agricultural sites ($p = 1.0e-7$) not being significantly different from pasture sites ($p = 5.8e-3$) > forest sites ($p = 4.0e-7$) (Figure 3B).

Non-bumblebee Species Abundance and Species Richness

Non-bumblebee abundance varied across sample sites (ANCOVA, $F_{(1,74)} = 2.4$, $p = 1.0e-2$). Non-bumblebee abundance was higher in July/August than in May/June except for the forest habitat, where the species abundance was roughly the same (Appendix 1.6). There was significant impact of habitat on non-bumblebee species abundance; where agricultural and pasture sites exhibited higher non-bumblebee species abundance from forested areas ($F_{(2,81)} = 4.1$, $p = 0.01$). Which is evident in the pairwise comparisons:

forest sites had significantly lower species abundance from agricultural sites ($p = 0.004$), pasture sites were not significantly different from agricultural sites ($p = 0.8$), and pasture sites were not significantly different from forest sites ($p = 0.06$) (Figure 2C). We found a significant interaction between sampling period and regional percent forest cover for floral abundance ($F_{(1,74)} = 6.2$, $p = 0.01$). Non-bumblebee species richness was significant (ANCOVA, $F_{(1,74)} = 6.6$, $p = 1.2e-7$). There was a main effect of habitat ($F_{(2,81)} = 32.1$, $p = 5.4e-11$). This trend was reflected in the pairwise comparisons: forest sites had significantly lower species richness from agricultural sites ($p = 0.1e-7$), pasture sites were significantly different from agricultural sites in terms of species richness ($p = 0.2e-3$), and pasture sites had significantly higher species richness from forest sites ($p = 0.2e-2$) (Figure 3C).

Comparisons Between the Bumblebee and Non-Bumblebee Community

In summary, habitat and sampling period both influenced bumblebee species abundance, bumblebee species richness, and non-bumblebee species abundance (overall $p < 0.05$) (Table 1). However, only habitat, and not sampling period ($p > 0.05$), influenced non-bumblebee species richness ($p < 0.05$).

Table 1: Summary of the significant effects observed for each variable on the species abundance and richness of wild bee data, as well as the specific subsets of bumblebees and non-bumblebee data.

This summary highlights the key findings related to how different factors influence the populations of these essential pollinators in various habitats.

Significant?	Sampling period	Regional percent forest cover	Habitat	Forest - Agriculture	Pasture - Agriculture	Pasture – Forest
Wild Bee Abundance	YES	NO	YES	YES	NO	YES
Wild Bee Species Richness	NO	NO	YES	YES	YES	YES
Bumblebee Abundance	YES	NO	YES	YES	NO	NO
Bumblebee Species Richness	YES	NO	YES	YES	NO	YES
Non-Bumblebee Abundance	YES	NO	YES	YES	NO	NO
Non-Bumblebee Species Richness	NO	NO	YES	YES	YES	YES
Floral Abundance	NO	NO	YES	YES	NO	YES
Floral Species Richness	YES	NO	YES	YES	NO	YES

Table 2: Summary of the two ANCOVA models for factors influencing wild bee abundance and species richness.

The table presents p-values, f-values, and degrees of freedom for factors including sampling period, habitat type, and regional percent forest cover in relation to wild bee abundance and species richness. Significant influences and pairwise comparisons are highlighted.

Dependent Variable	Factor	p-value	F-value	df	Result
Wild Bee Species Abundance	Sampling period	0.02	5.2	(1, 85)	Significant; More bees in July/August
	Habitat Type	0.003	6.3	(2, 85)	Significant; Pairwise differences observed
	Regional percent forest cover	0.28	1.1	(1, 85)	Not Significant
Wild Bee Species Richness	Sampling period	0.16	1.9	(1, 87)	Not Significant
	Habitat Type	4.9e-14	44.4	(2, 87)	Significant; Pairwise differences observed
	Regional percent forest cover	0.6	0.1	(1, 87)	Not Significant

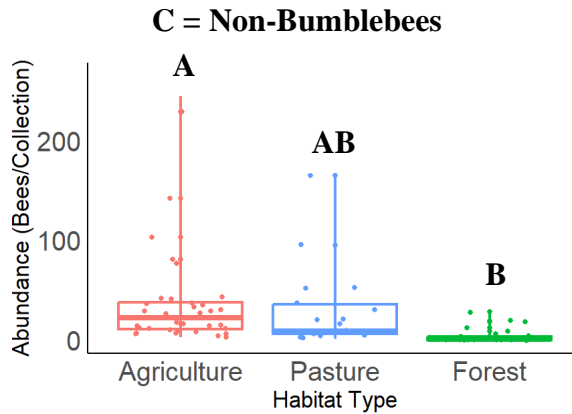
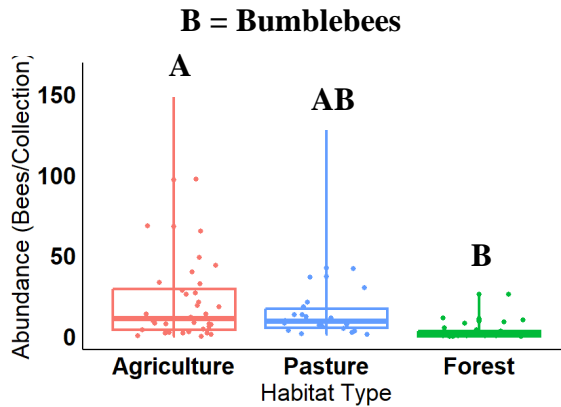
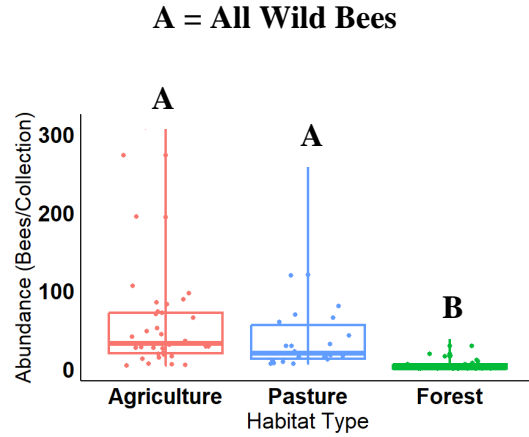


Figure 2: Variation in wild bee species abundance among the three main habitat types (agricultural, pasture, and forest) for the whole dataset (A), bumblebees only (B), and non-bumblebee data (C).

Bars sharing the same letter are not significantly different at $\alpha = 0.05$, and bars that have different letters are significantly different from each other.

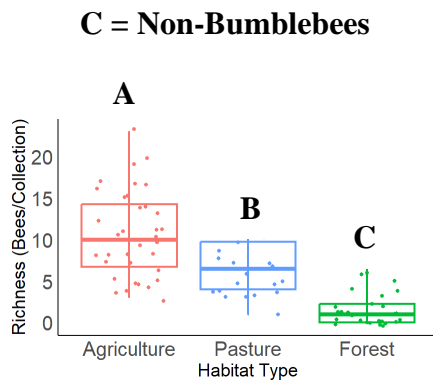
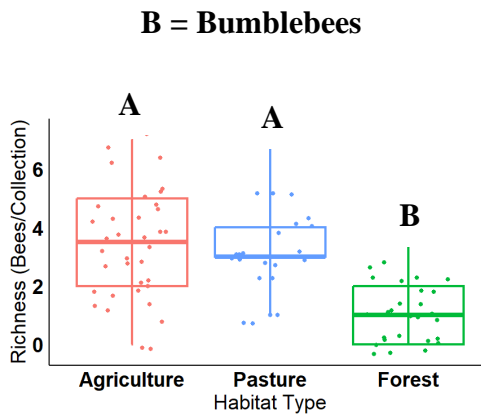
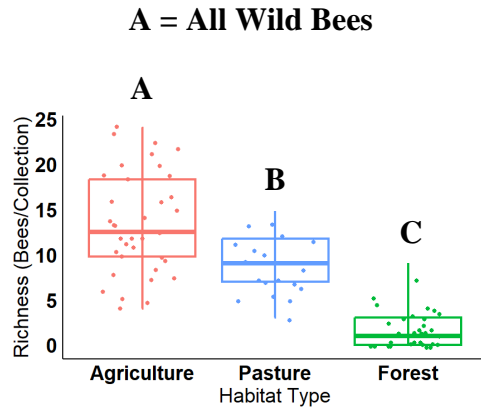


Figure 3: Variations in wild bee species richness among the three main habitat types (agricultural, pasture, and forest) for the whole dataset (A), bumblebees only (B), and non-bumblebee data (C).

Bars sharing the same letter are not significantly different at $\alpha = 0.05$, and bars that have different letters are significantly different from each other.

Stress = 0.22

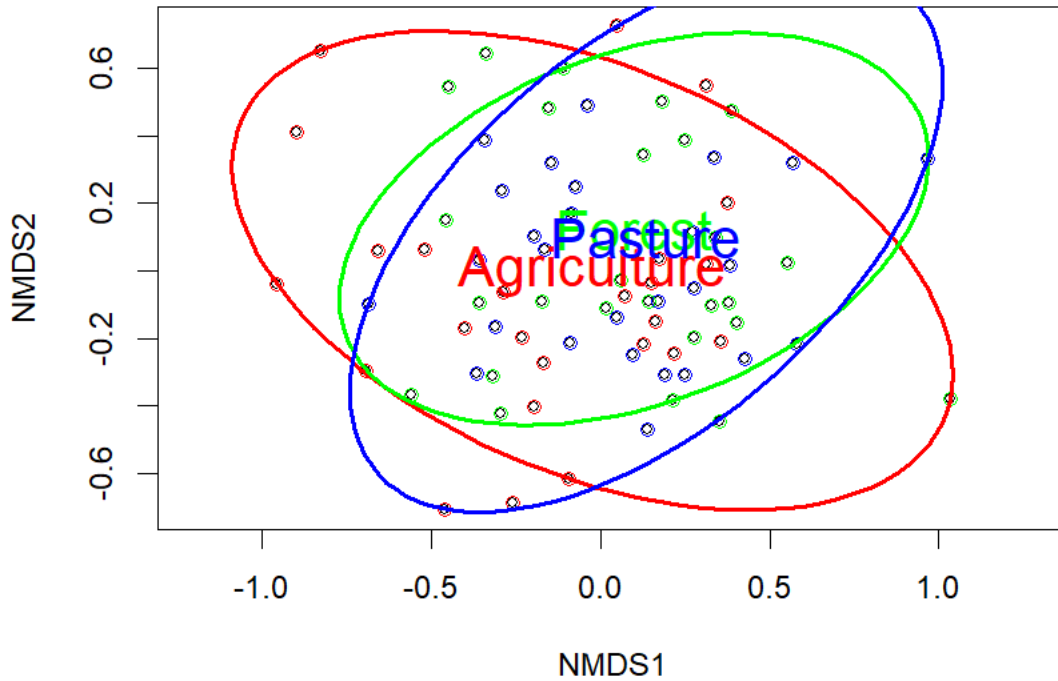


Figure 4: NMDS plot of community composition for all three habitat types across the Maritime provinces, Canada.

The overlapping patterns observed in the plot indicate similar community composition among the three habitats. The blue ellipse represents pasture sites, the red ellipse represents agricultural sites, and the green ellipse represents forests sites. Each point represents a site. The stress value of 0.22 tells us that the distances between points in this plot is a good/ok match to the actual distances between those points in the original data set.

Floral Community

Floral abundance varied across sampled sites (ANCOVA, $F_{(1, 80)} = 3.3$, $p = 7.9e-4$). A significant interaction between sampling period and regional percent forest cover was observed (Table 3). There was no significant relationship between floral abundance and regional percent forest cover for agricultural and pasture sites ($p < 0.05$) (appendix 1.7). Additionally, habitat type had a main effect on floral abundance (Table 3) (Figure 5). Pairwise comparisons indicated that forest sites had significantly lower floral abundance compared to agricultural sites ($p = 1.0e-3$), while no significant difference was observed between pasture and agricultural sites ($p = 0.90$). Pasture sites exhibited significantly higher floral abundance compared to forest sites ($p = 3.0e-3$) (Figure 5).

Floral species richness also varied among sampled sites (ANCOVA, $F_{(1, 80)} = 12.0$, $p = 5.5e-13$). The interaction between sampling period and habitat was significant, where the effect of sampling period changed depending on which habitat, we were sampling in. Specifically, floral species richness was higher in agricultural sites in July/August compared to pasture and forest sites in May/June (Table 3). Both sampling period and habitat had significant effects on floral richness (Table 3). Pairwise comparisons showed that forest sites had significantly lower floral species richness compared to agricultural sites ($p = 1.7e-5$), with no significant difference between pasture and agricultural sites ($p = 0.70$). Pasture sites exhibited significantly higher floral species richness compared to forest sites ($p = 9.2e-6$) (Figure 5). A significant interaction between sampling period and habitat for floral richness was observed ($F_{(2, 78)} = 5.1$, $p = 0.007$). Floral richness was higher in May/June compared to July/August (Figure 6).

Regional percent forest cover did not significantly affect floral richness (Table 3). Floral abundance did not predict wild bee abundance ($p = 0.2$; Figure 7), and floral species richness had no significant impact on wild bee species richness ($p = 0.1$; Figure 8).

Table 3: Summary of the two ANCOVA models for factors influencing floral abundance and richness.

The table presents p-values, f-values, and degrees of freedom for factors including sampling period, habitat type, and regional percent forest cover in relation to floral abundance and richness. Significant influences and pairwise comparisons are highlighted.

Dependent Variable	Factor	p-value	F-value	df	Result
Floral Abundance	Sampling period	0.07	3.2	(1,85)	Significant; More bees in July/August
	Habitat Type	0.001	7.8	(2, 85)	Significant; Pairwise differences observed
	Regional percent forest cover	0.6	0.2	(1,85)	Not Significant
Floral Richness	Sampling period	2.3e-06	25.6	(1,85)	Significant; More flowers in July/August
	Habitat Type	8.4e-07	16.5	(2, 85)	Significant; Pairwise differences observed
	Regional percent forest cover	0.8	0.02	(1, 85)	Not Significant

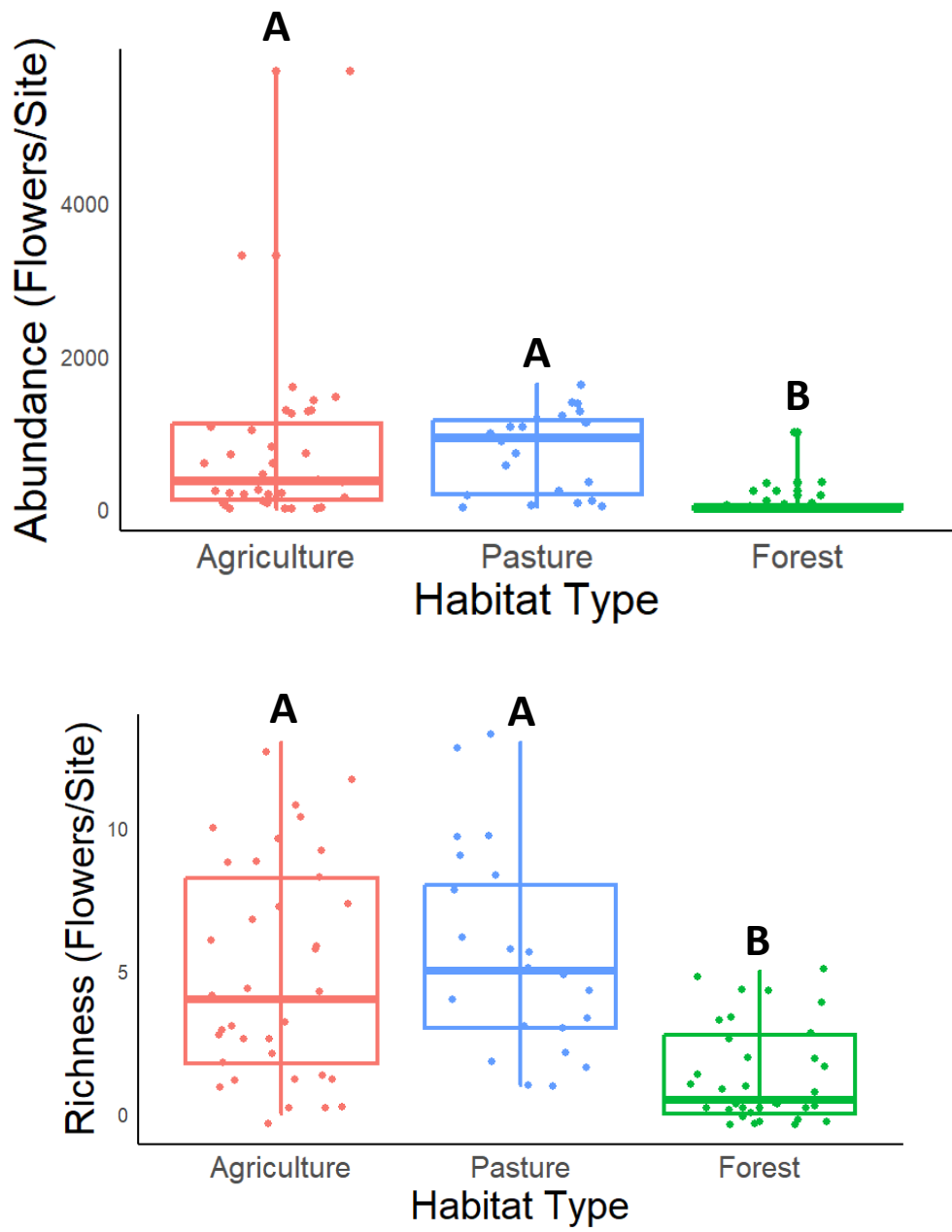


Figure 5: The variation between floral species richness and floral species abundance between the three habitat types.

Bars sharing the same letter are not significantly different at $\alpha = 0.05$, however bars that have different letters are significantly different from each other.

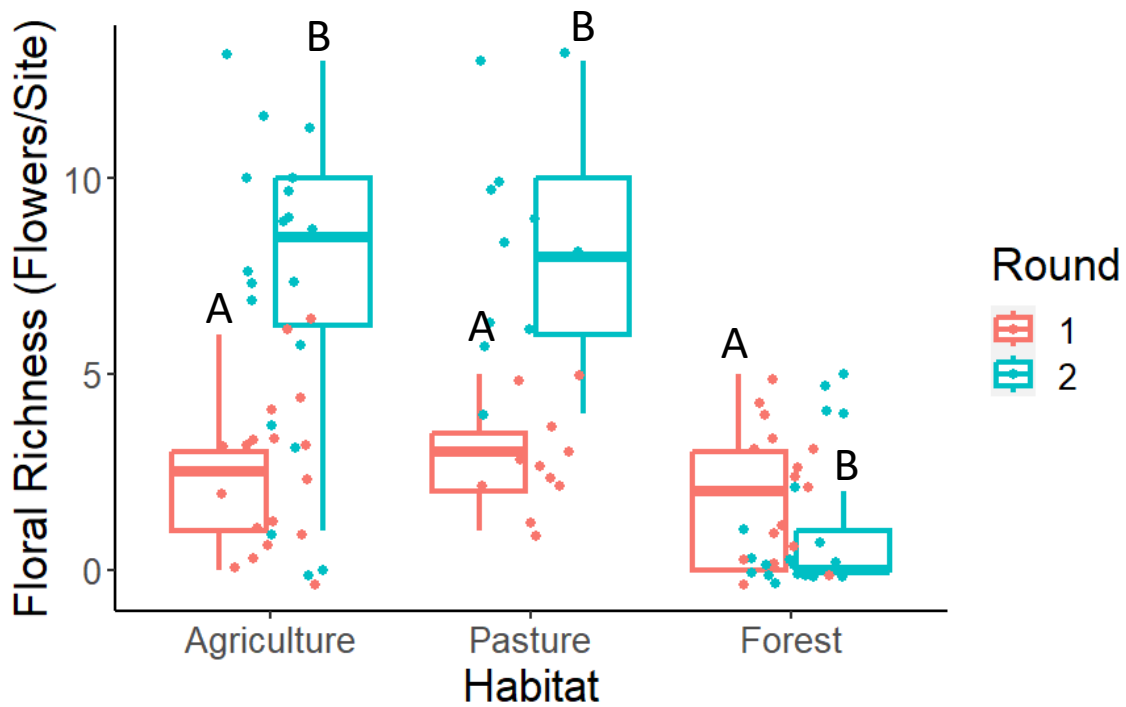


Figure 6: The interaction between floral richness and habitat across sampling periods.

Sampling period 1 represents May/June 2022 and sampling period 2 represents July/August 2022.

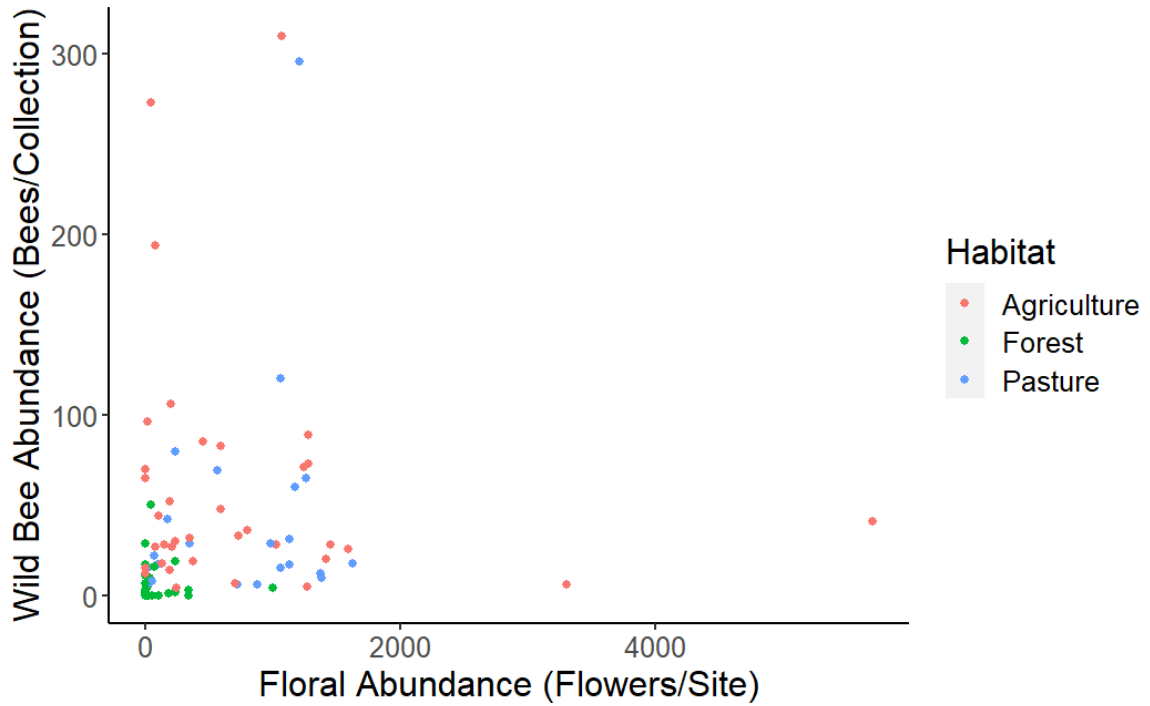


Figure 7: The x-axis represents floral abundance, indicating the quantity or density of floral resources present in agricultural, pasture and forest habitats.

The y-axis represents wild bee abundance, representing the number or density of wild bees observed in the same habitats.

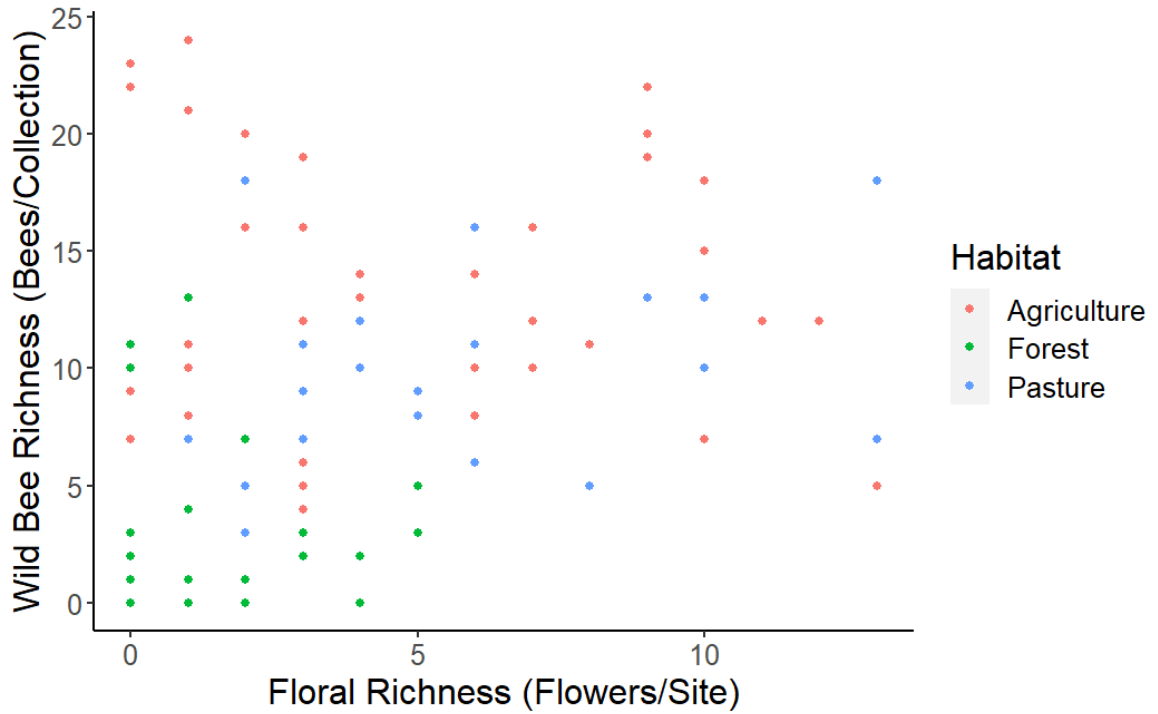


Figure 8: The y-axis represents floral richness, indicating the diversity or variety of floral species present in agricultural, pasture and forest habitats.

On the other hand, the x-axis represents wild bee species richness, representing the diversity or variety of wild bees observed in the same habitats.

2.4 Discussion

Factors Influencing the Wild Bee Community in the Maritime Provinces

Our research strongly supports the hypothesis that habitats experiencing disturbances, such as agricultural and pasture areas, can support a rich and diverse community of wild bees in certain contexts. This stands in contrast to less disturbed habitats like some forested habitats in the Maritime provinces. As predicted, both the type of habitat and sampling period influenced the abundance of wild bee species. We found that only the type of habitat influenced the richness of wild bee species. We also found that the percentage of forest cover in the 1 km radius surrounding the collection site did not have an impact on wild bee species richness and abundance in our model. However, it did predict wild bee abundance and richness in alternative models (Appendix 1.10 and 1.11) when the local habitat was excluded, which can be explained by the fact that the local habitat and 1-km-radius forest cover are correlated (forest sites tended to be in large forests, and field sites in large complexes of fields). While our data does not support a role for regional habitat in influencing wild bee abundance and richness beyond the effect of the local habitat, further work in landscapes where local and regional habitat are less strongly correlated would be interesting.

In addition to our initial hypothesis regarding the wild bee communities, we predicted that the agricultural and pasture habitats with higher bee species richness and abundance would also show increased floral diversity. Our investigation did reveal that habitat type significantly influenced floral species abundance, further supporting the notion that disturbed habitats, such as agricultural and pasture areas, exhibit higher floral

species richness and floral species abundance. Contrary to our expectations, we did not observe any significant relationship between floral species abundance and wild bee species abundance, nor between floral species richness and wild bee species richness. Additionally, both habitat type and sampling period had a significant impact on floral species richness. Floral species richness was higher in agricultural and pasture sites in comparison to forest sites and the species richness was higher during sampling period two compared to sampling period one. This signified an interesting interaction between habitat and time of collection in shaping the floral diversity in the study regions. Once again, regional percent forest cover demonstrated no notable influence on either floral species abundance or floral species richness (Table 1).

Our findings align with the preliminary observations collected by Meed (2021), who similarly observed higher bumblebee species richness in disturbed habitats compared to forested habitats in New Brunswick, Canada. While Meed's study did not identify a significant effect on abundance, that could reflect her smaller sample size. Our findings also align with Abby Malayny (2024), who found there to be a higher wild bee abundance and richness in potato fields in comparison to forests in New Brunswick, Canada (A. Malayny, unpubl. Data). However, our findings contrast with studies conducted in various regions like prairies, croplands, and semi-natural grasslands, which reported higher bee abundance and diversity in undisturbed habitats (Evans, 2016; Clough et al., 2014; Lazaro et al., 2016; Millard et al., 2021). This difference could potentially be attributed to the high prevalence of forests in the Maritime provinces. It is possible that these forests may not offer sufficient floral resources to support a more abundant and rich wild bee community, as demonstrated by Lazaro et al. (2016), who

found that the way we use land surrounding an area can significantly affect the types of plants that grow there, and the number of bees present. A key factor contributing to the differences seen in wild bee species richness and species abundance is the specific nature of habitat disturbance in the Maritime provinces. Unlike the conversion of prairies into agricultural fields, where floral resources are partially eliminated, clearing forest habitats in the Maritime provinces for crops, such as potato fields, may allow early succession flowering species to thrive, as we did find there to be a higher floral species richness and abundance in agricultural and pasture fields compared to forests. Which could also explain our observation of higher species abundance and species richness of wild bees in disturbed habitats compared to uncleared habitats in the Maritime provinces. These findings show the complex interactions between habitat disturbance, floral resources, and wild bee community responses in various habitats. However, our study's limitation lies in the analysis conducted at the community level, where all species were combined and analyzed together rather than looking for patterns at the individual species level. While some patterns emerged, a more focused sampling approach is necessary to gather sufficient data on rare specialists and delve deeper into their characteristics. In our study, we conducted morphological sorting of wild bees. It's possible that what we identified as a single species might actually comprise of two different species. However, this wasn't a significant concern for us because our dataset didn't contain many numbered species. Additionally, we hypothesize that even if we had accidentally combined multiple species, if uncombined, it would have further strengthened the observed patterns we saw between agriculture, pasture, and forested habitats as this would have slightly increased the species richness we were seeing. Investigating wild bees at the species level would offer

insights into how habitat alteration and floral resources uniquely affect each species, thereby enhancing our conservation efforts for wild bee populations.

The interactions between wild bees and landscape composition have been extensively researched. Studies have shown that landscape structure influences competition as solitary wild bees, bumble bees, and honeybees respond to landscape context at different spatial scales (Steffan-Dewenter et al., 2002). Additionally, the importance of habitat area, quality, connectivity, landscape composition, and configuration on wild bees has been studied (Hopfenmüller et al., 2014; Power et al., 2012). It has been highlighted that different types of semi-natural habitat are required to sustain diverse wild bee communities across agricultural landscapes, and that the effect of landscape configuration on wild bees can depend on landscape composition (Maurer et al., 2022; Senapathi et al., 2016). It is crucial to note that while crop fields may seemingly provide abundant floral resources, the potential exposure to herbicides and insecticides could pose threats to wild bee populations in the future (Mallinger et al., 2017). This concept aligns with the notion of an ecological trap, where animals choose habitats that seem superior but are riskier due to rapid environmental changes, highlighting significant conservation and management implications (Hale & Swearer, 2016). Although not part of our study, investigating the correlation between when landowners spray insecticides and pesticides and the number of wild bees found on their properties following the spray, could provide insights into the resilience of future wild bee communities in the Maritime provinces, Canada.

Seasonal Dynamics and Impacts on Bumblebee and Non-Bumblebee Species

Understanding the separate impacts of habitat, sampling period, and forest cover on both bumblebees and non-bumblebees is pivotal, considering the potential influence of a higher number of bumblebees compared to non-bumblebees on the overall results. The species abundance and species richness of bumblebees and non-bumblebee species are influenced differently by sampling period and habitat types. The primary difference arising from the cross-analysis of all wild bee data against both groups (bumblebee and non-bumblebee) lie in bumblebee species richness being higher in July/August, while wild bee data indicated consistent wild bee species richness throughout summer. Different bee species may respond differently to their environment, so it's crucial to account for the variations of response when assessing their populations and needs as it helps in supporting bee populations and effectively guiding conservation and management endeavors. Floral resources change within the season, so the increase in wild bee species richness later in the season, can be connected to the change/increase in floral resources. In addition, this increase can potentially be attributed to the life cycle of bumblebee species, which begins in spring with emerging queens that later establish their colonies by mid-summer (Mola et al., 2021). As colony size increases, capturing additional bumblebee species in July/August becomes more likely compared to May/June when queens are still in the process of forming their colonies. Well-established and larger colonies in July and August enhance the likelihood of encountering a diverse array of bumblebee species. The presence of well-established and larger colonies in July and August increases the chance of encountering a diverse range of bumblebee species. This finding can provide valuable insights to enhance the efficiency of sampling and

monitoring strategies for bee populations across various timeframes. This finding also has significance for biologists, suggesting that the sampling of less common species is more likely later in the season. Additionally, the likelihood of capturing a queen, as we might in early spring, diminishes, preventing potential harm to the entire colony. Jacobsen et al. (2007), Butolo et al (2023), and Novais et al. (2016) all provide insights into the importance of considering seasonal variation in sampling for assessing species richness and composition. Yavuzatmaca (2020) and Tonkin et al. (2017) further emphasize the impact of seasonality on species diversity, indicating that insect communities might be more diverse in certain seasons. Additionally, Stevens & Amarilla-Stevens (2011) highlight the seasonal variation in species abundance, suggesting that the abundance of certain species may vary across different seasons.

The Wild Bee Community in Forested Habitat

Wild bee community composition across the three habitats revealed similar patterns (Appendix 1.9). While the forest sites surveyed exhibited lower wild bee & floral species richness and abundance compared to the agricultural and pasture sites, they shared a similar array of wild bee species. The reason we are seeing this is because even though each individual forest might by chance have a different community composition, when we look at forest sites as a whole, they are sampling from the same overall wild bee community as agricultural and pasture fields. This similarity was seen through overlapping ellipses, indicating substantial species overlap. Notably, only two species (*Lasioglossum ephialtum/subviridatum/sagax complex* & *Epeoloides pilosula*) were exclusively found in the forest, while the majority were present in either agricultural

areas, pasturelands, or both. At our forested sites, bumblebees emerged as the predominant genus we encountered. Additionally, among the species observed in the forest, the majority were soil nesters, comprising a mixture of social and solitary wild bees, with a lot of them having larger body sizes. Observing similar patterns in wild bee communities across different habitats could imply that these different habitats are connected or influence each other in some way within the larger ecosystem. Even when forests have fewer species or lower floral diversity, the presence of certain key bee species in the forest might help maintain ecosystem functions like pollination. Also, most of these species are rarer to find, so the fact that we caught them in one habitat is not unlikely. If we were to remove these rarer species from our analysis, we could have potentially seen more overlap in our community composition, further emphasizing the fact that the community composition between all three habitats is similar. However, it is important to note that our data sampled only after May 24th, 2024, and could be biased as we may have missed collecting wild bees that use the forested habitats earlier in the season.

Wild bee communities in forests have often received limited attention and recognition due to the seemingly lower bee populations (Brosi et al., 2007; Cunningham-Minnick et al., 2022; Eckerter et al., 2022; Galbraith et al., 2019) compared to agricultural or pasture fields. However, these forest bee populations are necessary for sustaining wild bee diversity, in particular, bumblebee communities, as during early spring, the availability of floral resources becomes crucial for queens initiating colonies (Mola et al., 2021). However, we did not conduct sampling for wild bees earlier than the end of May. We speculate that had we collected wild bees at the end of April / beginning

of May, that we might have discovered a greater number of wild bees in forest habitats. This assumption is grounded in the timing of flowering patterns. Given that herbs and tree flowers bloom in forests before floral resources bloom in pasture and agricultural fields, forests could play a crucial role in the success of many wild bee colonies during spring (Mola et al., 2021). Which highlights the potential of forests at the onset of spring, as the open canopy provides pollination opportunities, contributing to the success of colonies every year.

The Relationship Between Floral Resources & the Wild Bee Community

We found that floral richness strongly correlated with the time of collection and habitat type, with agricultural and pasture sites having a higher floral richness in comparison to forests. Notably, floral richness in forested sites showed a distinct seasonal variation, with higher floral richness in May/June as opposed to July/August. In contrast, floral abundance was significantly influenced by the interaction between sampling period and regional percent forest cover where in May/June, as regional percent forest cover was increased, floral abundance increased as well. However, in July/August, floral abundance remained roughly the same as regional percent forest cover increased. These associations can be linked to the seasonal variations in floral diversity and abundance. Forests exhibit higher floral richness during early spring when the canopy is still open (Mola et al., 2021), compared to agricultural and pasture habitats. Intriguingly, while wild bee species richness solely depended on habitat type, the floral resources found at these sites were influenced by both habitat and collection time. This shows the interaction between wild bees and their foraging habitat, where wild bee species richness is determined solely by

habitat type which makes sense as from pollen tracking analysis, we know that wild bees are moving between environments (A. Malayny, unpubl. Data). The floral resources found at these sites are influenced by both habitat and collection time. It emphasizes that the relationship between wild bees and their foraging habitat is not only influenced by the habitat characteristics but also by the time of collection. These findings further support the notion that the relationship between wild bees and their habitat can be habitat/time dependent and understanding that relationship on a species level can have significant implications for conservation efforts to help sustain wild bee populations.

The absence of a significant relationship between wild bee species richness and floral species richness, as well as between wild bee species abundance and floral species abundance, is noteworthy. Although we didn't identify a general relationship, certain floral species might impact bee abundance more than others (Roulston & Goodell 2011). The disconnect between floral resources and wild bees could potentially stem from the distinct floral communities in each habitat, however the analysis needed to confirm this hypothesis would be beyond the scope of our study and could be an avenue for future research. With certain floral species confined to singular habitats (Table S1.9), comparisons across agricultural, pasture, and forest environments become challenging, limiting our ability to draw comprehensive conclusions. However, this research serves as a starting point for deeper investigations into the relationships between floral resources and wild bee populations. Future studies could delve into the specific preferences of wild bee species for these habitat-specific floral resources, shedding light on their foraging behaviors and potential ecological dependencies. Future research could also expand the transect dimensions beyond 50m by 1m, as this could provide a better understanding of

all available floral resources for wild bees, considering their flying radius extends beyond 25m.

Our discovery of a higher species abundance and richness of wild bees in agricultural and pasture fields compared to forests calls for cautious interpretation and consideration of its implications. Forests are not just habitats for wild bees but also vital ecosystems supporting a wide array of biodiversity and providing essential services such as carbon sequestration and water purification. Decisions to cut down forests could have adverse effect on ecosystem functions and on an array of species including wild bees. While more wild bees in agricultural areas may seem promising for pollination services, factors foraging behavior, and the presence of suitable floral resources also influence their effectiveness as pollinators. Furthermore, the quality of habitat in agricultural fields and the impact of agricultural practices, such as pesticide use, on bee health should be considered because if these practices are impacting the population of wild bees, then this instance could be considered an ecological trap. Though our study did not sample in clearcut forests, clearcut forests might be an interesting habitat to examine for wild bees because they may have floral resources that are similar to pasture and agricultural fields and yet have nesting habitat that are not disturbed frequently by agricultural equipment. Conservation agencies should focus on maintaining and restoring diverse habitats, including forests, to strike a balance between agricultural productivity and biodiversity conservation. Continued research into bee populations and their interactions with different ecosystems is essential to inform informed land management and conservation decisions that support both wild bees and broader ecosystem health.

To enhance our understanding of the relationship between disturbed habitats and wild bee communities even more, future studies could incorporate data on crops grown around each site, especially in agricultural sites, as crop type may impact wild bee species abundance & richness and floral resource availability. Investigating whether the wild bee community varies between different types of agricultural fields (e.g., potato vs. grain crops) could yield valuable insights for conservation efforts. Furthermore, exploring the nesting locations of wild bees in relation to their foraging areas within the Maritime provinces would provide valuable insights into the differences in wild bee species richness and abundance across different habitats. Broadening this study to encompass more habitat types throughout the Maritime provinces, such as wetlands, could yield more comprehensive and generalizable results, as wild bee communities extend beyond the three habitats studied. By doing so, we can gain a deeper understanding of the factors influencing wild bee communities and their interactions with floral resources in diverse landscapes.

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3.0 General Discussion

Insights into Wild Bee Populations in Canada's Maritime Provinces

In this thesis I explored some fundamental questions concerning wild bee populations, their relationship with disturbed habitats, floral resources, and seasonal variation in Canada's Maritime provinces. Specifically, I investigated whether disturbed habitats, such as agricultural and pasture fields, can support a more species rich and abundant wild bee community compared to less disturbed areas, such as forests, in the same region. Contrary to observations in other bee habitats such as prairies, croplands, and semi-natural grasslands (Evans 2016, Millard et al, 2021, Clough et al 2014 & Lazaro et al 2016), my study revealed that disturbed habitats, particularly agricultural and pasture fields, supported a higher species richness and abundance of wild bees compared to less disturbed habitats such as forests. Our findings have contributed significantly to our baseline understanding of wild bee populations and their environmental interactions in the Maritime provinces, as prior to this study we had very limited knowledge about the relationship between wild bees and their habitat. Our research highlighted the importance of disturbed habitats like agricultural and pasture fields in supporting wild bee populations. Understanding where they thrive is crucial for conserving their populations, given bees' crucial role as pollinators.

Wild Bee Abundance Changes Across Seasons

In our study, we aimed to address the fluctuations in wild bee populations across various time periods. A clear pattern emerged: higher wild bee abundance consistently occurred across study sites during July/August compared to May/June. This

trend extended beyond mere abundance; the second sampling period consistently exhibited a greater richness of wild bee species than the initial one. The increased diversity of floral resources later in the season, could likely signify a richer supply of resources for various insect species, including bumblebees, thereby fostering higher numbers of bees (Hegland & Boeke, 2006). Additionally, Martínez et al. (2020) noted that the connection between bumblebee abundance and flower density varied throughout the flowering season. Their research suggested that bumblebee populations peaked in the mid-season when resources were more abundant but faced limitations as the season progressed. The fluctuations in bumblebee populations across seasons highlight the impact of changing resource availability. These studies collectively emphasize the critical role of floral resources in shaping wild bee abundance, aligning with our findings of increased floral resources and wild bee activity later in the summer compared to earlier.

Gaining insights into the timing and reasons behind these fluctuations is crucial to understanding how seasonal variations influence diverse bee populations across various habitats. However, it is important to note that seasonal changes can have significant impacts on various animal species. The seasonal availability of floral resources plays a pivotal role in shaping the population of various organisms within ecosystems. During periods of flower blooming, insect populations tend to surge, which in turn benefits species like insectivorous birds. Insectivorous birds often synchronize their foraging behaviors with flowering cycles (Russo, 2016). It's important to recognize that species abundance can fluctuate with seasonal changes. For instance, the increased presence of birds during the summer months might not solely correlate with the blooming of flowers. Instead, this abundance could be more closely tied to the overall reproductive

activity observed in ecosystems during specific times of the year. This activity includes collective breeding and mating behaviors across various species, favored by favorable conditions like longer daylight hours and warmer temperatures. This indicates that there are more factors besides floral resources that can be considered to help explain why we see an increase in wild bee population during July and August. Additionally, generalist insect predators, like certain species of spiders or predatory insects, are indirectly impacted by these floral shifts (Russo 2016). An increase in insects, drawn by the blossoming flowers, provides ample prey, potentially influencing the reproductive success and overall population dynamics of these generalist predators. Moreover, this seasonal availability of flowers also affects insects that prey specifically on bees (Russo 2016). If bees are drawn to these flowers in significant numbers, it could attract specialized bee predators, influencing their population sizes and consequently affecting the broader ecosystem's intricate balance, which could explain the differences in population seen throughout the season.

Although our data provided a short-term baseline analysis, the need for future studies observing wild bee populations across agricultural, pasture, and forest habitats over extended periods becomes evident. Long-term studies are imperative, as prior research has highlighted yearly variations in bee populations due to factors such as food availability and nesting resources (Roulston and Goodell, 2011). Hernandez et al. (2009) emphasized in their review on the ecology of urban bees the importance of collecting data over several years to identify trends linked to habitat needs. This emphasizes the significance of an in-depth examination of wild bee population fluctuations across seasons. While my study couldn't observe these fluctuations over multiple seasons, it

serves as valuable baseline data for the Maritime provinces. Future studies can leverage this information for comparative purposes, shedding light on how the wild bee population is evolving across agricultural, pasture, and forest habitats.

Species Abundance Changes Across Habitat

Agricultural and pasture sites proved to be more favorable habitats for wild bees compared to forest sites. While we did not directly conduct an examination of wild bee population changes before and after habitat disturbance in a single location, our approach involves a broader perspective. The influence of habitat on animal abundance is a complex (Boyce et al., 2015). Habitat selection refers to the process by which animals choose specific environments or areas for various activities such as foraging, nesting, or mating. It is a critical factor in determining animal abundance because the availability and suitability of habitats directly influence the spatial distribution and prevalence of different species within an ecosystem. This association between habitat and animal abundance is complex, shaped by trophic interactions and various ecological factors. For example, within avian populations, the transition of bird species across different vegetation gradients is closely tied to shifting predation risks (LaManna et al., 2015). Such changes along these gradients contribute significantly to the animal abundance witnessed within specific habitats. Furthermore, trophic guilds and the types of forests also hold a considerable influence on the abundance variation of phyllostomid bats, particularly in response to human-induced habitat changes (Carballo-Morales et al., 2020). This emphasizes the pivotal role habitats play in modulating animal abundance. Moreover, the presence of intermediary hosts within disturbed forest habitats has a

discernible impact on the prevalence of nematode parasites among specific animal species. This relationship highlights how disturbances within the habitat can influence the abundance of parasitic nematodes in certain animal populations, showcasing another layer of complexity in the interplay between habitat and animal abundance (Boullosa et al., 2017). Moreover, individual variation in habitat selection mediates landscape-level predictions of functional responses, emphasizing the importance of considering individual differences in understanding habitat use and animal abundance. The role of habitat configuration in shaping animal population processes is also crucial, as it influences habitat-mediated animal movements and population outcomes (He et al., 2020).

In our study, we looked at the influence of regional percent forest cover on wild bee populations, and there appears to be no significant influence on wild bee species abundance or richness. We discovered that the percentage of forest cover within a 1 km radius of the collection site did not influence wild bee species richness and abundance in our model. However, in alternative models it did predict wild bee abundance and richness when the local habitat was excluded. It is hard to predict the effect of forest cover independent of the local habitat, because they are correlated, as forest sites were typically situated in larger forested areas, while field sites were found in extensive fields. Forest cover in the past has been linked to the diversity of animal taxa, with different forms of tree cover influencing the movement capabilities, dependence on forest cover, and resource requirements of various animal taxa (Harvey et al., 2006). The relationship between forest cover and animal populations extends to specific species, such as the chamois, where forest cover has been found to buffer the climate-induced decline of body

mass in these mountain herbivores (Reiner et al., 2021). Likewise, it was found that the abundance and richness of forest specialist species were positively influenced by intermediate forest cover, while generalist species showed no patch-area effect (Pardini et al., 2010). Morante-Filho et al. (2015) classified bird species based on their dependence on native forest habitats and specific food resources, demonstrating varied responses to forest cover reduction in the Brazilian Atlantic Forest. Estavillo et al. (2013) identified a significant finding suggesting the existence of a biodiversity threshold concerning the small mammal community. Their research observed that when forest cover falls below 30%, there's a critical point where species richness among small mammals' peaks. Beyond this threshold, there seems to be a decline in species richness. This indicates that while some level of forest cover is vital for sustaining a diverse population of small mammals, an excessive reduction beyond this identified threshold might negatively impact species richness, leading to a decline in the small mammal community's diversity. These studies collectively highlight the species-specific effects of regional percent forest cover on animal populations, emphasizing the importance of forest cover in shaping biodiversity and ecological processes on some but not all species. However, it is worth considering that many of these studies examined the impact of forest cover within the immediate habitat compared to the broader radius surrounding the sampling site. This difference in scale could explain why some studies observed a relationship while we did not, as our analysis revealed a correlation between habitat and regional percent forest cover where we could not see the effect of regional percent forest cover independent of the local habitat.

Relationship Between Crops and Wild Bee Diversity

The relationship between wild bee abundance and floral abundance was not significant in our study. However, our study lacked data on the specific crops present in agricultural and pasture fields, such as potatoes, corn, blueberries etc. during our collection period, limiting our insight into how particular crops might influence wild bee abundance and diversity. Different crops can attract specific types of wild bees (Rondeau et al., 2022), indicating the necessity for deeper exploration of the connection between wild bees and crops in the Maritime Provinces. For example, some more generalized crops such as zucchini, fava bean, and eggplant have been observed to attract different wild bee types (Greenleaf & Kremen, 2006). Additional studies have indicated that wild bee communities involved in crop pollination are influenced by both surrounding and in-field habitats (Mallinger et al., 2017). Exploring the relationship between wild bees and crops in varied habitats, both on a local and broader scale, holds the potential to develop methods preserving wild bee diversity while ensuring agricultural productivity in the Maritime provinces (Abdouni et al., 2022; Ratti et al., 2008). For instance, investigating whether certain combinations of crops, like growing potato alongside blue berries in proximity, could create a more favorable environment for bee diversity compared to either crop grown individually.

Wild Bees and Floral Diversity

Our research did not find a direct correlation between higher floral diversity and increased wild bee diversity. Our research revealed no direct correlation between higher floral diversity and increased wild bee diversity at individual sites. However, when

data was grouped by habitat type, both bees and flowers exhibited similar patterns, suggesting a potential threshold effect rather than a continuous one (Table S1.9). The significant increase in floral resources from forest to other habitat types appears to be more impactful than nuanced variations. Additionally, interpreting these results requires further details and comparisons, particularly regarding the types of flowers present, which we were not able to do. Other studies have shown a relationship between these floral resources and wild bee communities (Kovács-Hostyánszki et al., 2013; Mallinger et al., 2016; Mandelik et al., 2012; Martins et al., 2018), however, types of flowers and those internal relationships were taken into consideration.

Instead of solely focusing on the total count of different bee species, certain studies propose that targeting conservation efforts towards specific bee species could be more impactful. This approach acknowledges that the presence or absence of particular bee species might hold more significance than merely counting the number of diverse species present (Spiesman et al., 2017; Plascencia & Philpott, 2017). Balancing the abundance of particular flower types with a diverse array of flowers within an area could significantly impact wild bee populations, especially in less disturbed habitats like forests (Spiesman et al., 2017).

The Role of Forests

We observed a higher wild bee population in agricultural and pasture habitats compared to forests; however, despite lacking data, we speculate that forests remain crucial, especially during early spring, for supporting wild bee species. Various studies have highlighted the significance of forests in providing crucial food sources for bees,

particularly during spring and summer when specific trees and shrubs bloom (Bartomeus et al., 2011; Sobieraj-Betlińska et al., 2022; Eckerter et al., 2022). This was an aspect that I did not consider until I began analyzing my results. Forest conservation has been demonstrated to maximize pollination services, emphasizing the need for healthy forest ecosystems to support bee populations (Rivers-Moore et al., 2020; Odanaka & Rehan, 2020). This shows that future studies should commence earlier in spring to capture forest-dependent bees, revealing the impact of seasonal variation and their role in supporting early wild bee colonies (Fujiwara & Washitani, 2017). We speculate these findings suggest that wild bees thriving in these fields might rely on the presence of adjacent forests for their survival and sustainability. This shows the significance of maintaining a healthy balance of forests within the Maritime provinces.

Conclusion

Our research on wild bee communities in the Maritime provinces was connected to several fundamental ecological themes. We had aimed to explore how distinct habitats, including agricultural fields, pasturelands, and forests, can support diverse and thriving wild bee populations. This investigation laid the foundation for understanding the potential role of these habitats in attracting wild bees with the promise of abundant floral resources. Our research primarily focused on documenting the presence of wild bees in various habitats. While this preliminary work did not directly assess their habitat preferences or performance, it established baseline data for future studies to delve into these aspects. Such investigations are essential for gaining a comprehensive understanding of wild bee ecology and for guiding effective conservation

strategies. The concept of habitat disturbance also played a role in this study. By examining various habitat types, including agriculture, pasture, and forest, we aimed to gain a comprehensive understanding of wild bee species abundance and species richness within each of these habitats. This approach enabled us to formulate initial insights into how habitat loss might influence wild bee populations. The insights gathered from this study can serve as a foundational framework for understanding wild bee populations in similar habitats but across different geographical locations. This knowledge will be crucial for tailoring conservation efforts to suit the needs of various bee species and, ultimately, for maintaining healthy and diverse bee populations in changing landscapes.

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Appendix



Figure S1.1 The wild bee trap setup in the field. The setup of the site involved placing the blue vane trap in the middle, four cups on either side, and one cup in front of the blue vane running perpendicular to the road. The cup traps were either blue, yellow, or white in colour.

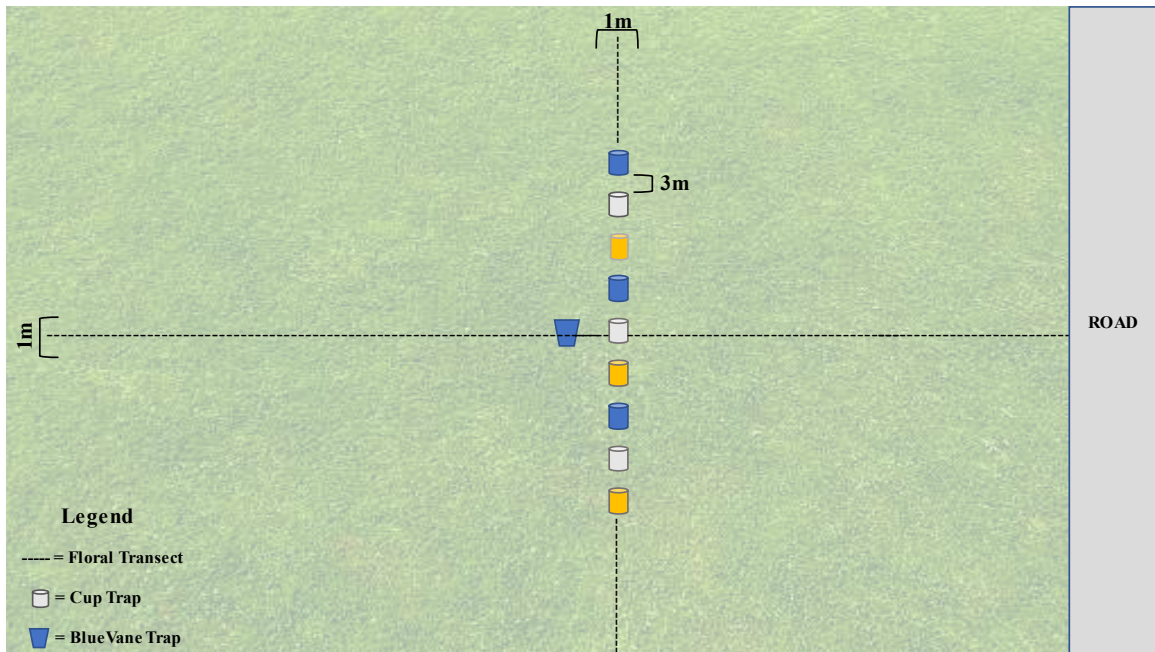


Figure S1.2 The set-up of traps in the field. The cup traps were either blue, yellow, or white in colour and ran parallel to the road. The cup traps were 3 metres apart from each other. The blue vane trap was always placed right beside the middle cup trap (trap #5). The length of one transect was 50m (25m on each side of the blue vane trap).

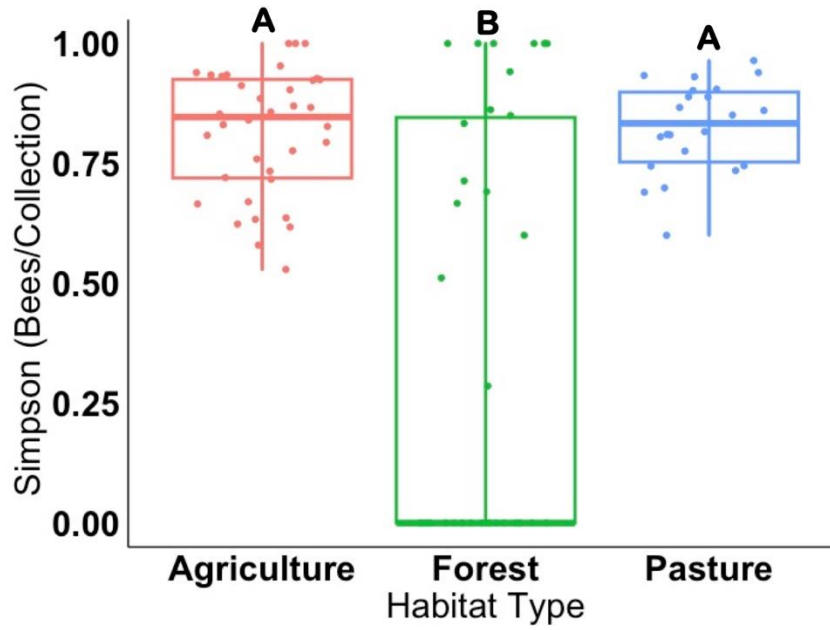


Figure S1.3 Wild bee Simpson diversity index difference between the three habitat types. The pattern shows that Simpson diversity is significantly higher in agriculture and pasture sites compared to forest sites. Bars sharing the same letter are not significantly different at $\alpha = 0.05$, however bars that have different letters are significantly different from each other.

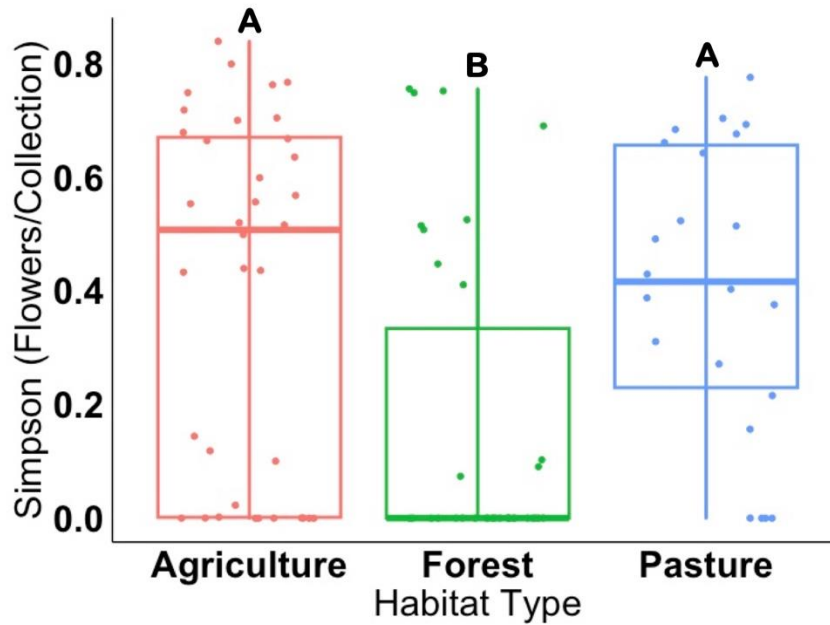


Figure S1.4 Floral Simpson diversity index difference between the three habitat types.

The pattern shows that Simpson diversity is significantly higher in agriculture and pasture sites compared to forest sites. Bars sharing the same letter are not significantly different at $\alpha = 0.05$, however bars that have different letters are significantly different from each other.

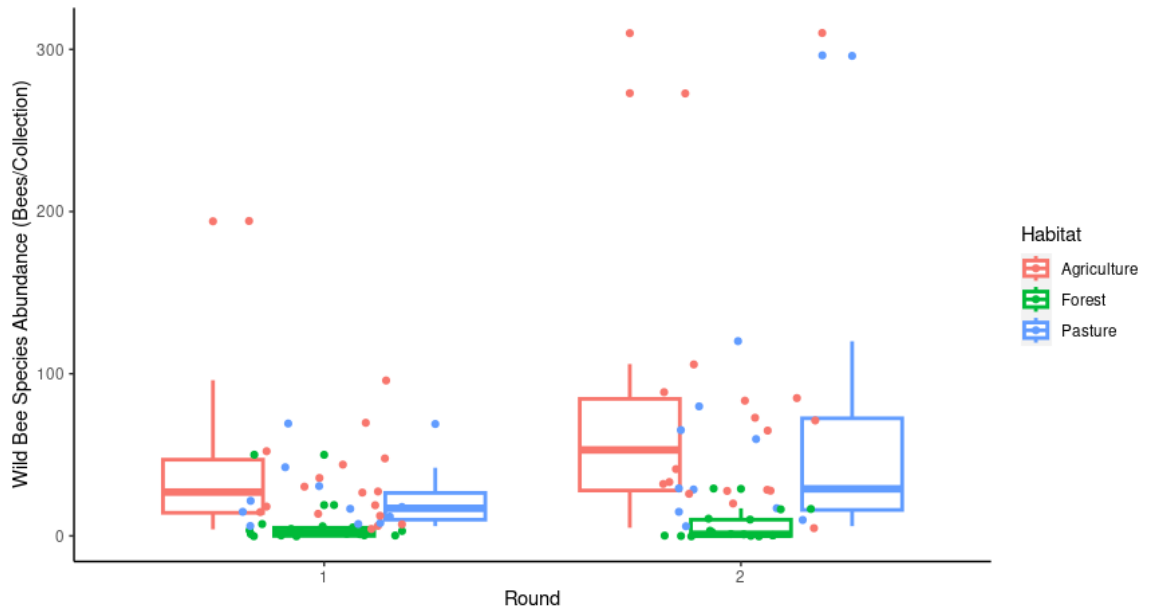


Figure S1.5 Variations in the wild bee species abundance among the two sampling periods. Sampling period 1 refers to May/June 2022 and sampling period 2 refers to July/August 2022. It reveals that wild bee abundance was higher in sampling period 2 for each habitat, agriculture, forest and pasture.

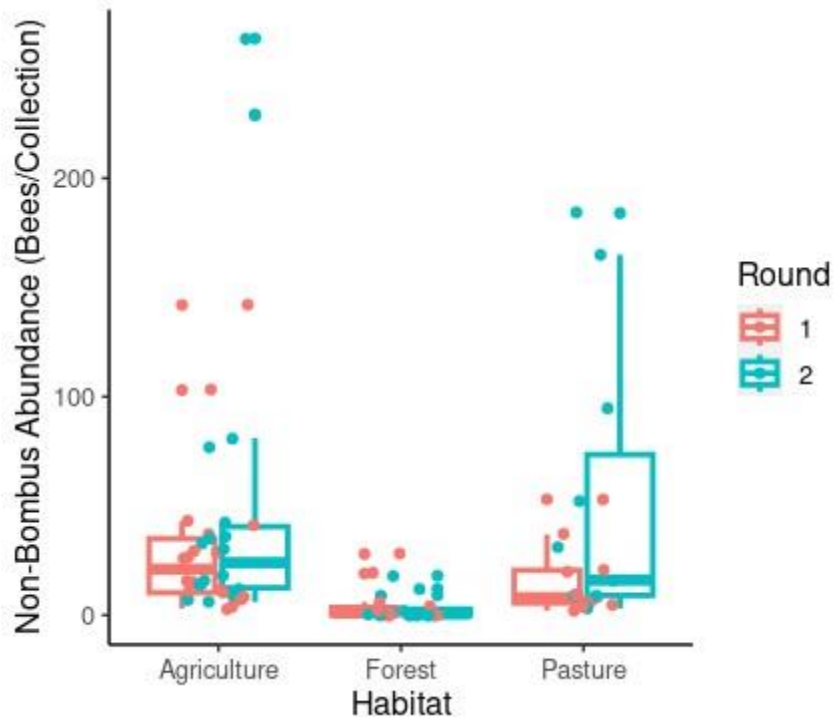


Figure S1.6 Variations in the non-*bombus* abundance among three habitats. Sampling period 1 refers to May/June 2022 and sampling period 2 refers to July/August 2022. It reveals that non-*bombus* abundance was higher in sampling period 2 for agriculture and pasture. However, in the forested habitat, the species abundance was roughly the same.

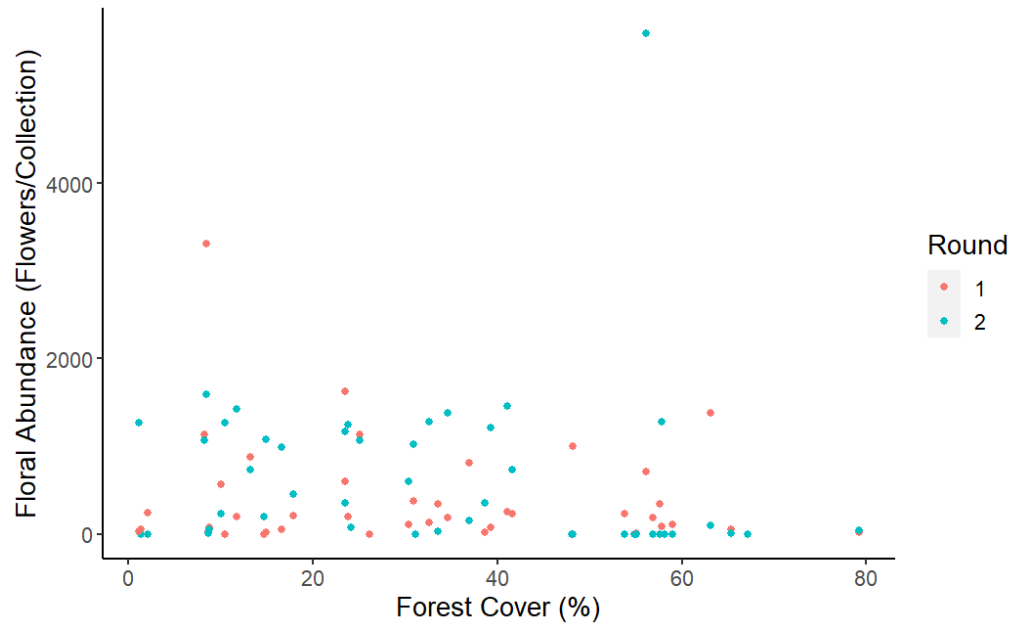


Figure S1.7 The interaction between regional percent forest cover and floral abundance between sampling period 1 and sampling period 2 for all 47 sampled sites. Sampling period 1 represents May/June 2022 and sampling period 2 represents July/August 2022. Regional percent forest cover represents the 1km radius surrounding each local site.

Table S1.8 The distribution of wild bees across agriculture, pasture and forest sites. Each row is species specific and includes the nesting type of that species.

Species	Agriculture	Forest	Pasture	Grand Total	Nesting Requirement
<i>Agapostemon virescens</i>	403	6	144	553	soil
<i>Andrena ovatula</i>	1	0	0	1	soil
<i>Andrena algida</i>	0	0	1	1	soil
<i>Andrena ceanothi</i>	2	0	0	2	soil
<i>Andrena erythronii</i>	4	0	0	4	soil
<i>Andrena frigida</i>	2	0	0	2	soil
<i>Andrena gelriae</i>	1	0	1	2	soil
<i>Andrena milwaukeensis</i>	0	0	1	1	soil
<i>Andrena nasonii</i>	1	0	0	1	soil
<i>Andrena ovatula</i>	1	0	0	1	soil
<i>Andrena perarmata</i>	1	0	0	1	soil
<i>Andrena persimulata</i>	2	0	0	2	soil
<i>Andrena rufosignata</i>	4	0	0	4	soil
<i>Andrena sp 1</i>	35	1	11	47	soil
<i>Andrena sp 10</i>	1	0	0	1	soil
<i>Andrena sp 11</i>	2	0	1	3	soil
<i>Andrena sp 12</i>	2	0	0	2	soil
<i>Andrena sp 13</i>	4	0	0	4	soil

<i>Andrena sp 14</i>	1	0	0	1	soil
<i>Andrena sp 15</i>	2	0	0	2	soil
<i>Andrena sp 16</i>	4	0	0	4	soil
<i>Andrena sp 2</i>	6	2	0	8	soil
<i>Andrena sp 3</i>	17	0	1	18	soil
<i>Andrena sp 4</i>	4	0	2	6	soil
<i>Andrena sp 5</i>	3	0	1	4	soil
<i>Andrena sp 6</i>	3	0	0	3	soil
<i>Andrena sp 7</i>	2	0	0	2	soil
<i>Andrena sp 8</i>	2	0	0	2	soil
<i>Andrena sp 9</i>	2	0	0	2	soil
<i>Anthophora bomboides</i>	0	0	1	1	clay bank
<i>Anthophora terminalis</i>	4	0	1	5	wood
<i>Augochlora pura</i>	6	0	3	9	wood
<i>Augochlorella aurata</i>	5	0	0	5	soil
<i>Bombus bimaculatus</i>	2	0	0	2	cavity
<i>Bombus borealis</i>	165	14	39	218	cavity
<i>Bombus citrinus</i>	2	0	0	2	cavity
<i>Bombus fervidus</i>	3	0	1	4	cavity
<i>Bombus frigidus</i>	1	0	0	1	cavity
<i>Bombus impatiens</i>	127	14	114	255	cavity
<i>Bombus perplexus</i>	255	21	95	371	cavity

<i>Bombus rufocinctus</i>	38	6	33	77	cavity
<i>Bombus sandersoni</i>	148	10	67	225	cavity
<i>Bombus ternarius</i>	95	21	49	165	cavity
<i>Bombus terricola</i>	3	0	2	5	cavity
<i>Bombus vagans</i>	6	1	0	7	cavity
<i>Calliopsis andreniformis</i>	3	0	0	3	soil
<i>Certina calcarata</i>	1	0	0	1	stem
<i>Certina dupla</i>	10	1	1	12	stem
<i>Certina sp 1</i>	3	1	1	5	stem
<i>Certina sp 2</i>	1	0	0	1	stem
<i>Chelostoma rapunculi</i>	3	0	0	3	cavity
<i>Coelioxys sodalis</i>	1	0	0	1	parasitic
<i>Colletes inaequalis</i>	1	0	0	1	soil
<i>Epeoloides pilosula</i>	0	1	0	1	Parasitic
<i>Halictus confusus</i>	3	0	0	3	soil
<i>Halictus ligatus</i>	13	1	16	30	soil
<i>Halictus rubicundus</i>	0	0	1	1	soil
<i>Hoplitis producta</i>	18	0	8	26	stem
<i>Hoplitis producta/spoliata</i>	3	1	3	7	stem/cavity
<i>Hoplitis spoliata</i>	1	0	0	1	cavity
<i>Hylaeus affinis</i>	1	0	0	1	hole
<i>Hylaeus basalis</i>	1	0	1	2	stem

<i>Lasioglossum acuminatum</i>	3	0	2	5	soil
<i>Lasioglossum athabascense</i>	8	0	8	16	soil
<i>Lasioglossum coriaceum</i>	11	0	4	15	wood
<i>Lasioglossum cressonii</i>	2	0	0	2	wood
<i>Lasioglossum ephialtum/subviridatum/saga</i> <i>x</i>	0	1	0	1	soil/wood
<i>Lasioglossum leucozonium</i>	75	15	45	135	soil
<i>Lasioglossum sp 1</i>	6	2	2	10	soil/wood
<i>Lasioglossum sp 10</i>	9	0	3	12	soil/wood
<i>Lasioglossum sp 11</i>	4	0	0	4	soil/wood
<i>Lasioglossum sp 2</i>	2	0	0	2	soil/wood
<i>Lasioglossum sp 3</i>	16	1	7	24	soil/wood
<i>Lasioglossum sp 4</i>	5	1	6	12	soil/wood
<i>Lasioglossum sp 7</i>	19	1	4	24	soil/wood
<i>Lasioglossum sp 8</i>	2	0	0	2	soil/wood
<i>Lasioglossum sp 9</i>	5	3	1	9	soil/wood
<i>Lasioglossum versans</i>	64	17	22	103	soil
<i>Lasioglossum zonulum</i>	271	35	224	530	soil
<i>Megachile gemula</i>	17	0	1	18	hole
<i>Megachile inermis</i>	11	1	3	15	hole
<i>Megachile latimanus</i>	1	0	0	1	soil

<i>Megachile melanophaea</i>	1	0	2	3	soil
<i>Megachile relativa</i>	8	0	1	9	hole
<i>Megachile rotundata</i>	9	1	4	14	cavity
<i>Megachile sp1</i>	1	0	0	1	Unknown
<i>Melissodes desponsus</i>	26	3	5	34	soil
<i>Melissodes druriellus</i>	27	0	8	35	soil
<i>Melissodes illata</i>	2	1	1	4	soil
<i>Melissodes sp 1</i>	28	3	12	43	soil
<i>Melissodes sp 2</i>	10	0	0	10	soil
<i>Melissodes sp 3</i>	0	0	1	1	soil
<i>Melissodes sp/wheeleri</i>	3	0	0	3	soil
<i>Melissodes wheeleri</i>	1	0	0	1	soil
<i>Nomada sp 1</i>	5	1	0	6	parasitic
<i>Nomada sp 2</i>	4	0	1	5	parasitic
<i>Nomada sp 3</i>	3	0	6	9	parasitic
<i>Nomada sp 4</i>	3	1	0	4	parasitic
<i>Nomada sp 5</i>	2	0	0	2	parasitic
<i>Nomada sp 6</i>	1	0	0	1	parasitic
<i>Osmia atriventris</i>	3	0	0	3	hole
<i>Osmia bucephala</i>	1	0	0	1	hole
<i>Osmia inspergens</i>	2	0	0	2	cavity
<i>Osmia proxima</i>	1	0	0	1	cavity

<i>Osmia pumila</i>	1	0	0	1	hole
<i>Osmia sp 1</i>	1	2	1	4	cavity
<i>Osmia sp 2</i>	0	1	1	2	cavity
<i>Osmia sp 3</i>	1	1	0	2	cavity
<i>Osmia sp. aff. albiventris</i>	1	0	0	1	cavity
<i>Osmia tersula</i>	2	0	0	2	hole
<i>Sphecodes ranunculi</i>	1	0	0	1	parasitic

Table S1.9 The distribution of floral resources across agriculture, pasture and forest sites.

Each row is species specific.

Flower	Agriculture	Forest	Pasture	Grand Total
<i>Achillea millefolium</i>	0	0	9	9
<i>Anthemis cotula</i>	66	0	0	66
<i>Arctium lappa</i>	286	0	0	286
<i>Barbarea vulgaris</i>	58	0	0	58
<i>Brassica nigra</i>	385	0	9	394
<i>Capsella bursa-pastoris</i>	2	0	0	2
<i>Cardamine dentata</i>	4	0	0	4
<i>Cardamine pratensis</i>	1	0	0	1
<i>Ceanothus americanus</i>	6	0	0	6
<i>Centaurea nigra</i>	346	0	160	506
<i>Cerastium fontanum</i>	35	0	0	35
<i>Cerastium glomeratum</i>	5821	0	0	5821
<i>Chenopodium album</i>	369	0	0	369
<i>Cirsium arvense</i>	7	0	0	7
<i>Clintonia borealis</i>	0	1	0	1
<i>Cornus canadensis</i>	0	209	0	209
<i>Cornus florida</i>	15	0	0	15
<i>Cornus sericea</i>	85	0	0	85
<i>Daucus carota</i>	644	0	55	699

<i>Daucus pusillus</i>	0	0	1	1
<i>Duchesnea indica</i>	0	0	3	3
<i>Epilobium angustifolium</i>	4	0	0	4
<i>Epilobium ciliatum</i>	12	0	0	12
<i>Epilobium halleanum</i>	2	0	0	2
<i>Epilobium tetragonum L</i>	40	0	0	40
<i>Erigeron strigosus</i>	471	16	3	490
<i>Erysimum cheiranthoides</i>	1	0	0	1
<i>Eupatorium maculatum</i>	7	0	0	7
<i>Eurybia divaricata</i>	30	0	0	30
<i>Euthamia caroliniana</i>	0	0	5	5
<i>Euthamia graminifolia</i>	153	0	0	153
<i>Fagopyrum esculentum</i>	0	0	15	15
<i>Fragaria vesca</i>	310	107	18	435
<i>Galium sp</i>	9044	4	1005	10053
<i>Galium mollugo</i>	296	0	0	296
<i>Galium odoratum</i>	490	0	0	490
<i>Geum canadense</i>	22	0	0	22
<i>Glechoma hederacea</i>	69	0	0	69
<i>Hieracium lachenalii</i>	0	76	0	76
<i>Hypericum mutilum</i>	200	0	0	200
<i>Hypericum perforatum</i>	321	5	33	359

<i>Impatiens capensis</i>	5	0	0	5
<i>Lespedeza cuneata</i>	5	0	0	5
<i>Leucanthemum vulgare</i>	1144	14	88	1246
<i>Lotus corniculatus</i>	0	0	383	383
<i>Lupinus polyphyllus</i>	1	0	0	1
<i>Lysimachia punctata</i>	0	0	45	45
<i>Maianthemum canadense</i>	0	102	0	102
<i>Maianthemum racemosum</i>	0	235	0	235
<i>Maianthemum stellatum</i>	0	150	0	150
<i>Malva moschata</i>	0	0	9	9
<i>Mitchella repens</i>	0	10	0	10
<i>Myosotis scorpioides</i>	0	0	920	920
<i>Myosotis sylvatica</i>	0	94	0	94
<i>Oenothera biennis</i>	23	0	2	25
<i>Oenothera perennis</i>	0	0	1	1
<i>Oxalis corniculata</i>	0	2	0	2
<i>Oxalis stricta</i>	326	0	0	326
<i>Pastinaca sativa</i>	0	0	1	1
<i>Persicaria lapathifolia</i>	0	0	85	85
<i>Prunella vulgaris</i>	0	0	104	104
<i>Ranunculus acris</i>	169	11	486	666

<i>Rosa rugosa</i>	10	0	15	25
<i>Rubus argutus</i>	2	0	0	2
<i>Rubus caesius</i>	0	80	0	80
<i>Rubus pubescens</i>	0	24	0	24
<i>Rudbeckia triloba</i>	77	3	0	80
<i>Rumex crispus</i>	32	0	18	50
<i>Sisyrinchium angustifolium</i>	1	3	0	4
<i>Solanum sp.</i>	200	0	0	200
<i>Solidago sp.</i>	609	8	310	927
<i>Sonchus oleraceus</i>	0	0	165	165
<i>Spiraea tomentosa</i>	0	0	2	2
<i>Stellaria graminea</i>	742	0	670	1412
<i>Stellaria media</i>	5	0	627	632
<i>Stellaria palustris</i>	0	0	38	38
<i>Taraxacum officinale</i>	6117	7	3415	9539
<i>Thymus citriodorus</i>	50	0	0	50
<i>Thymus vulgaris</i>	50	0	0	50
<i>Tragopogon pratensis</i>	2	0	0	2
<i>Trientalis borealis</i>	0	1598	0	1598
<i>Trifolium aureum</i>	749	0	301	1050
<i>Trifolium campestre</i>	40	0	0	40

<i>Trifolium pratense</i>	2781	4	1548	4333
<i>Trifolium repens</i>	3624	0	2450	6074
<i>Valeriana Officinalis</i>	0	0	30	30
<i>Verbascum thapsus</i>	11	0	0	11
<i>Veronica chamaedrys</i>	415	0	0	415
<i>Veronica longifolia</i>	0	0	30	30
<i>Veronica officinalis</i>	2	0	0	2
<i>Vicia cracca</i>	2241	13	680	2934
<i>Viola arvensis</i>	261	0	0	261
<i>Viola sororia</i>	16	0	1111	1127

S1.10: Summary of the ANOVA model for the effect of regional percent forest habitat on each type of habitat. The table presents p-values, f-values, and degrees of freedom which show that forested sites are surrounded by more forests and field sites are surrounded by more fields.

Variable	Factor	p-value	F-value	df	Result
Percent Forest Cover	Forest - Agriculture	0.003	8.4	(2, 89)	Significant
	Pasture - Agriculture	0.7	8.4	(2, 89)	Non – Significant
	Pasture - Forest	0.001	8.4	(2, 89)	Significant

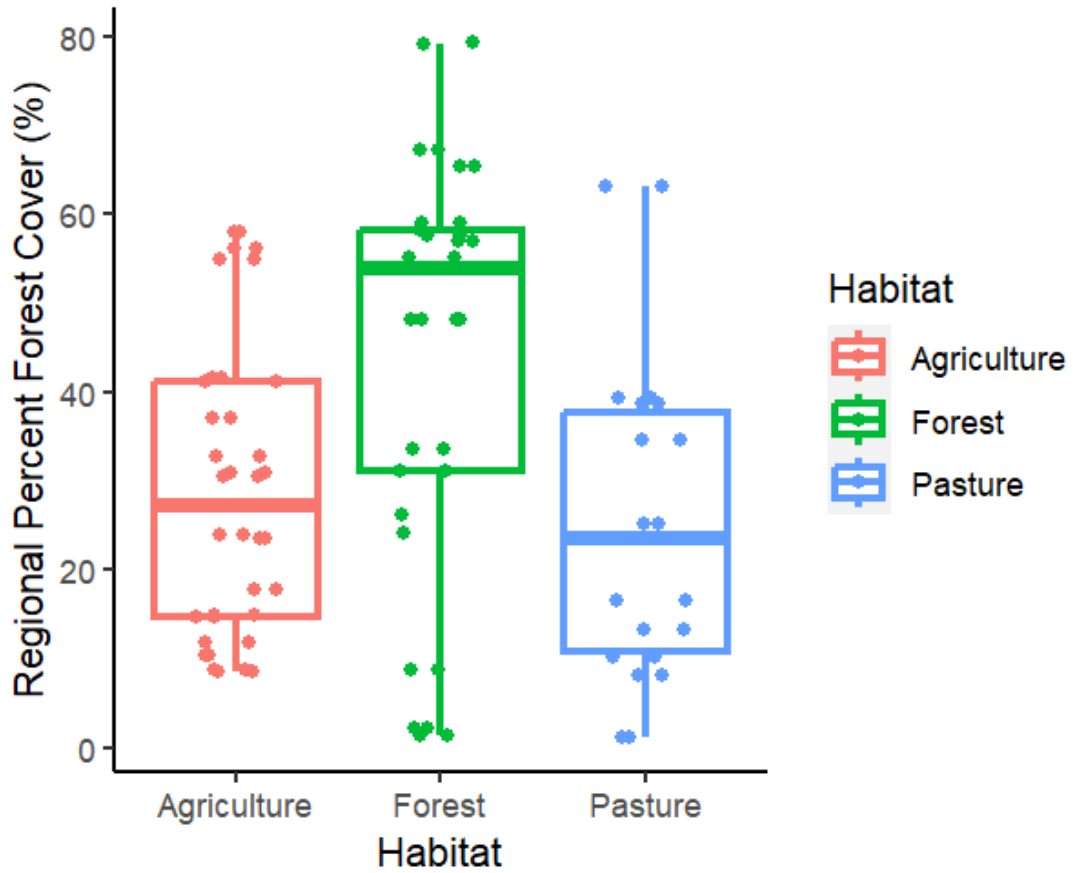


Figure S1.11 The effect of regional percent forest cover on each habitat. It reveals that our forested sites were surrounded by more forests and our field sites were surrounded by more fields.

Curriculum Vitae

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Ahmed, A., J. Vickruck, S. Heard. The impact of habitat alteration and floral resources on wild bee communities in the Maritime provinces, Canada. Joint meeting Canadian Society for Ecology and Evolution and Canadian Botanical Association. June 13, 2023.