Pollinator Communities Important to Agriculture in the Bay of Fundy Dykelands of Nova Scotia

By

Evan Riley McNamara

A Thesis Submitted to
Saint Mary's University, Halifax, Nova Scotia
in Partial Fulfillment of the Requirements for
the Degree of Master of Science in Applied Science.

April 2024, Halifax, Nova Scotia

© Evan McNamara, 2024

Approved: Dr. Jeremy Lundholm
Supervisor
Saint Mary's University

Approved: Dr. Alana Pindar
Supervisor
Cape Breton University

Approved: Dr. Tony Charles
Supervisory Committee Member
Saint Mary's University

Approved: Dr. Anne Dalziel
Supervisory Committee Member
Saint Mary's University

Approved: Dr. David Awde
External Examiner
Mount Saint Vincent University

Date: April 23, 2024

Pollinator Communities Important to Agriculture in the Bay of Fundy Dykelands of Nova Scotia

By: Evan Riley McNamara

Abstract

In the Bay of Fundy dykelands, efforts are underway to determine the trade-offs of ecosystem services between maintaining man-made dykes and restoring them back to the salt marsh habitat that existed in their place prior to European colonization. Dykes protect agricultural land but are at risk due to sea level rise, and there is a lack of resources to keep them functioning. Salt marsh restoration is being proposed due to their ability to protect coastlines while also providing other benefits such as carbon storage, but prior to this it must be known what impacts restoration could have on other ecosystem services. Pollination is one such service, and I assessed pollinator importance to agriculture and the community composition of the wild pollinators providing this service. To determine pollinator importance to crops, I excluded flowers of apple, tomato, and squash from pollination using mesh bags and compared them to those in which pollination was permitted. I found that pollinators increase both fruit set and weight in apple and tomato, but was unable to get conclusive results in squash. Apple was completely reliant on pollinators for successful fruit production, with tomato benefitting from pollination to a lesser, but still significant, degree. Sweep net and bowl-trapping surveys were conducted to determine the species that visited these crops, and I found that wild ground-nesting bees were the most important pollinators of all crops (72% of all bees collected), being found in higher abundances than even domesticated honey bees. Notably, many of these bee species were also detected in a past study in dyke and salt marsh habitats, with *Agapostemon virescens* and *Lasioglossum leucozonium* being amongst the most abundant species. Given the importance of wild pollinators found in this study, pollinator conservation measures should be undertaken within agroecosystems to ensure the continued delivery of this ecosystem service to farmers, while allowing for salt marsh restoration on a case-by-case basis.

Date: April 23, 2024

Acknowledgements

There are many people to thank that have helped me through the long and often difficult process of producing this thesis. First and foremost, I would like to thank my supervisors, Dr. Jeremy Lundholm and Dr. Alana Pindar. Your belief in me, support, and patience with guiding me through this journey is greatly appreciated. I have learned so much from both of you, and I appreciate all you have taught me. I'll also take this opportunity to thank Dr. Colleen Barber, who provided her lab space for me to conduct my bee ID in, and treated me as one of her own students while in this space, essentially becoming an unofficial supervisor at times.

I would also like to thank my committee members, Dr. Anne Dalziel and Dr. Tony Charles at SMU, and Dr. David Awde, my external examiner from MSVU, for taking the time out of their busy schedules to look over my thesis. Your insight and thoughts helped to mould this thesis into something even better, and I greatly appreciate having a second set of eyes to look over my work and provide me with lots of useful thoughts and insight.

Thanks to Terrell Roulston, Hughstin Grimshaw-Surrette, and Owen Yoshida for their help as my field assistants and with some of the bee cleaning and identification process. Without your help, the long field days would have been even longer, and the music choices may not have been as good. Terrell and Hughstin's help in cleaning and some initial ID during the summer helped to cut down tremendously on the work I would continue solo.

I am so grateful for the farmers who allowed me to conduct work on their land and on their crops: Jen and David Greenberg at Abundant Acres, Kevin and Jennifer Graham at Oakview Farm, Courtney and Adam Webster at Olde Furrow Farm, and Josh Oulton and Patricia Bishop at Taproot Farm. Your kindness and generosity in welcoming me onto your farms is so appreciated, especially at a time when many would be hesitant to do so because of concerns surrounding COVID at the time.

Big thanks to my family, friends, lab mates, and fellow ResNet HQPs for all your support throughout these last few years. Whether you know it or not, your presence in my life during this time helped me immensely. Ranging from words of encouragement, sharing laughs, or socializing over coffee or drinks, and much more, day-in and day-out you were there for me, and gave me a break from my work when I needed it. Special shout out to my parents, who have been my biggest supporters throughout this degree.

Finally, it would feel wrong to not highlight the fact that thousands of insects unknowingly gave their lives for this project, and there would be no data to build this project upon without them. They made the ultimate sacrifice in the name of science, and will forever be dedicated to the betterment of future generations of pollinators.

Table of Contents

List of Figures

List of Tables

Chapter 1: General Introduction

1.1. INTRODUCTION

a. The Ecosystem Services Concept

The modern idea of a framework to give a valuation of the natural capital provided by ecosystems dates back to the 1970s and has evolved into a robust tool that can now be used to communicate the benefits of conservation and environmental management practices (Daily and Matson, 2008; De Groot et al., 2002; Gómez-Baggethun et al., 2010; Westman, 1977). Defined by the Millennium Ecosystem Assessment (MA) (2003) as the benefits humans gain from ecosystems, ecosystem services are crucially important to human well-being, with four main categories identified: provisioning, cultural, regulating, and supporting services. These categories encompass a wide array of services provided to humans, from natural resources gain, to nonmaterial benefits, to the regulation of natural processes, and even those necessary to provide all other services, respectively (MA, 2003). The benefits ecosystem services provide are essential for the maintenance of Earth's biosphere, and thus human society itself is dependent on ecosystem services provided by nature (De Groot et al., 2002).

The use of ecosystem-service based approaches to habitat and land management is advantageous in that it seeks to improve the decision-making process by taking into account both demand for services and ecosystem needs (Elliff and Kikuchi, 2015). Using this approach allows us to measure these demands in a variety of different ways (Elliff and Kikuchi, 2015). Defining ecosystem services and their values to humans can allow us to make more informed decisions on habitat and land management for the benefit of both nature and humanity (MA, 2003). For example, knowledge of the value of ecosystem services in agricultural settings can be utilised to

optimise production of land while also maintaining long-term sustainability that will allow these ecosystem services to continue to enhance production from the land (Ghaley et al., 2014). Valuation of ecosystem services can also be a valuable tool in the assessment of environmental damages, not just for policymakers but in helping businesses understand the importance of avoiding environmental degradation caused by their actions (Bherwani et al., 2020). For these reasons, it is important to incorporate ecosystem services and their value into planning for continued sustainable development, especially in urban areas as these places are a key crossroads in the interaction of humans and nature (Niemelä et al., 2010). However, while ecosystem service valuation can be an important tool for ecosystem-based management and decision-making, it is not without its issues which should be addressed.

A problem with the traditional ecosystem services approach is that it is inherently anthropocentric, looking to measure the benefits ecosystems can give to humans (La Notte et al., 2019). Thus, often certain ecosystem services are exploited to benefit humans (Wallace, 2007). There is also the added difficulty of valuing ecosystem services, such as cultural ecosystem services, that have no direct material benefits (Small et al., 2017). Pursuit of particular ecosystem services in one area can often come at a cost for another area and its own ecosystem services (Pascual et al., 2017). There is also much debate over the application of ecosystem-service based management to conserve biodiversity due to the apparent differences in the end goals of land management for biodiversity conservation versus ecosystem services, however one need not choose only one or the other when making management decisions (Reyers et al., 2012). In fact, biodiversity is often closely intertwined with ecosystem services, and it can even be considered an ecosystem service itself (Mace et al., 2012).

Making note of and addressing anthropocentrism, the difficulty of valuing services with no monetary benefits, and the potential unintended consequences of an ecosystem-service based approach to conservation is important for the sustainable development and incorporation of biodiversity into the ecosystem services framework. Careful evaluation of trade-offs in rare situations where only one of biodiversity conservation or ecosystem services can be chosen is needed to make the best decisions on a case-by-case basis. However, in situations where both biodiversity and ecosystem services stand to benefit, there can be powerful collaborations between stakeholders pursuing each of these end goals (Reyers et al., 2012). When managing multiple ecosystem services in which trade-offs may occur, Bennett et al. (2009) recommends quantifying each service and their relationships, identifying drivers and interactions between services, and finally the managing these relationships, to improve ecosystem resilience and benefits. Ecological restoration is an important process in the face of anthropogenic forces altering the earth, and restoration of ecosystem services should be included in this due to the benefits it brings to humanity (Montoya et al., 2012).

Given the value of ecosystem services to human society, their loss is a point of concern for many. The global loss of value in ecosystem services due to land use change is estimated at anywhere from $4.3-$20.2 trillion USD ($5.8-$27.2 trillion CAD) each year (Costanza et al., 2014). Recognition of this value is useful to highlight the importance of ecosystem services, and monetary valuation is effective in communication of this (Costanza et al., 2014; Ghaley et al., 2014). Animal pollination is an example of an important ecosystem service at risk (Kremen and Chaplin-Kramer, 2007; MA, 2003; Potts et al., 2010).

b. Pollination as an Ecosystem Service

Pollination is the transfer of pollen between the male and female parts of plants, and is essential to reproduction in many plant species (U.S. Forest Service, n.d.). This pollen transfer can be done via self-pollination or cross-pollination. In self-pollinating plants, as the name implies, the individual plant transmits pollen between the male and female parts to fertilize itself (U.S. Forest Service, n.d.). Cross-pollination occurs when pollen is transferred between two plants, via a third-party vector such as wind or animals, and can increase genetic variation, seed numbers, and seed quality compared to self-pollination (Crespel and Mouchotte, 2017). Animals which facilitate the transfer of pollen between plants are known as pollinators, which include insects such as bees and hoverflies, or vertebrates such as hummingbirds and bats (Kevan and Baker, 1983; Winfree et al., 2011). Pollinators provide a valuable economic service to humans and are critical to the proper functioning of many ecosystems worldwide. The monetary value of pollination to global agriculture was estimated at approximately €153 billion annually in 2005 (~$339.8 billion CAD in 2024), which accounted for approximately 9.5% of human food production value (Gallai et al., 2009). Many plant-pollinator interactions have co-evolved for millions of years (Hu et al., 2008), with approximately 85% of flowering plant species globally, and 78% in temperate regions, relying on pollinators for reproduction (Ollerton et al., 2011). Thus, disruption of this ecological interaction could put some plant populations at risk of extinction (Lennartsson, 2002; Klein et al., 2007).

Despite the high demand for pollination as an ecosystem service, it has been observed that the supply of pollinators is often too low to meet this demand (Schulp et al., 2014). This is because of the declines pollinators have been facing due to climate change, habitat destruction

13

and fragmentation, pesticide use, and more in recent years (Potts et al., 2010; Vanbergen, 2013). Insect pollinators in particular have been noted to be in decline (Vanbergen, 2013). There is concern that the loss of pollinators could have an impact on other ecosystem services (Christmann, 2019), but the major impact is predicted to be on agricultural crop production, as much of our food is reliant on pollination services (Klein et al., 2007).

c. Plant-Pollinator Interactions

The story of pollinators cannot be told without also telling the story of flowering plants, the angiosperms, which first emerged in the fossil record in the Jurassic period (Soltis et al., 2008; Cui et al., 2022). Angiosperm diversity then expanded in the Cretaceous (Friis et al., 2006). Rapid evolutionary radiation gave rise to the ancestors of more than 97% of modern angiosperm species (Friis et al., 2006; Soltis et al., 2008). It is also during the Cretaceous that a radiation in pollinating insect diversity is seen, including the first bees in the fossil record (Grimaldi, 1999; Poinar and Danforth, 2006). The arrival and subsequent diversification of bees coincides with the evolutionary radiation of early angiosperms, indicating that early bees may have helped facilitate the diversification and subsequent domination of angiosperms in plant communities (Danforth et al., 2006; Friis et al., 2006; Hu et al., 2008; Cardinal and Danforth, 2013). Bees have since co-evolved alongside angiosperms to become the most important pollinating insects globally (Kevan and Baker, 1983; Hu et al., 2008). The interactions between plants and their animal pollinators, and in particular bees, remain some of the most important mutualistic interactions in the modern natural world (Sargent and Ackerly, 2008; Hegland et al., 2009).

In modern-day ecosystems, plant-pollinator interactions are often important determinants of community structure (Heithaus, 1974; Sargent and Ackerly, 2008). It is often the frequency of these interactions that determines their strength or importance (Vázquez et al., 2012). Pollination can shape the structure of plant communities as it drives competition between plant species within a community (Sargent and Ackerly, 2008). Specialization of pollinators for certain plant taxa, and vice versa, is an evolutionary result of this effort to decrease competition and has been noted amongst both plant and pollinator species globally (Fontaine et al., 2005; Fründ et al., 2010; Blüthgen and Klein, 2011; Fantinato et al., 2017). Specialization means that a plant may be specialized to be pollinated by one or a few particular pollinator species, and likewise a pollinator species may be specialized in the pollination of a particular plant species. This specialization of one often occurs in the presence of diverse assemblages of the other, whether that be pollinator or pollinator-reliant plants (Blüthgen and Klein, 2011).

The importance of having diversity in pollinator communities is expressed by the positive correlation between increased pollinator diversity and increased plant diversity (Fründ et al., 2010). Angiosperm reproductive success increases with the presence of diverse communities of pollinators (Albrecht et al., 2012), and pollinator visitation can greatly increase fruit set and yield of many wild plant species (Klein et al., 2003; Klein et al., 2007; Holzschuh et al., 2012; Garibaldi et al., 2013; Hünicken et al, 2020). Increased diversity of pollinator communities is also associated with increased fruit set in agricultural crops (Hoehn et al., 2008; Mallinger and Gratton, 2015). Diversity can also give rise to specialization that may further help pollination of certain plant species (Armbruster, 2016). Pollinator declines are thus concerning because of the likely decreases in fruit set and yield in numerous plant species that would follow.

There are concerns about the resiliency of plant-pollinator interactions in the rapidly changing modern environment (Burkle and Alarcón, 2011). Threats to plant-pollinator interactions are primarily anthropogenically driven, including climate change, pesticide use, and habitat destruction or fragmentation (Potts et al., 2010). Plant-pollinator interactions have gone through previous disruptions in Earth's history, the largest of which was the K-T mass extinction event that occurred approximately 66 million years ago (Rehan et al., 2013). Diversity of both flowering plants and their pollinators did rebound, though the disruption was on a timescale of millions of years (Rehan et al., 2013). In the face of concerns over the future of animal pollination, it is important to understand the potential effects a disruption in pollination services on this timescale could have on human systems, such as agriculture (Aizen et al., 2009; Burkle and Alarcón, 2011).

d. Insect Pollinators and the Buzz About Bees

Though vertebrate pollinators such as hummingbirds and bats make important contributions to their ecosystems, insect pollinators outnumber them greatly and are the most important group of pollinators globally (Winfree et al., 2011). Amongst insects, Orders Coleoptera (beetles), Diptera (true flies), and Lepidoptera (butterflies and moths), contain large numbers of pollinators (Kevan and Baker, 1983). However, Order Hymenoptera is the most important taxonomic group of pollinating insects (Kevan and Baker, 1983) and includes eusocial and social insects like ants and wasps that provide pollination services, as well as the bees (Kevan and Baker, 1983).

Rader et al. (2015) found that non-bee pollinators accounted for as much as 38% of flower visits globally. While other pollinating insects are not as specialized for this function as

bees are, and thus carry and deposit less pollen on flowers, they make up for this with a high visitation frequency (Rader et al., 2015). Orders Coleoptera (beetles), Diptera (true flies), and Lepidoptera (butterflies and moths), contain large numbers of pollinators, and non-bee Hymenopterans such as ants and wasps also provide pollination services, with other insect orders containing smaller numbers of pollinators (Kevan and Baker., 1983). Among these groups, butterflies within order Lepidoptera and hoverflies within order Diptera contain some of the more important taxa for pollination (Courtney et al., 1982; Doyle et al, 2020). Butterflies are perhaps the next most well-known and specialized group of pollinators, with a proboscis specialized for nectar uptake from flowers, though some argue that this structure can lead to incidents of accidental nectar robbery when the butterfly visits flowers not specialized for butterfly pollination and does not come in contact with the stamen or stigma (Courtney et al, 1982; Inouye, 1980). Though they are not frequent flower visitors, they are still important in an ecological sense by transferring pollen over large distances that other pollinators are unable to traverse (Courtney et al, 1982). Order Diptera constitutes the second-largest group of insect pollinators (after bees), and hoverflies make up most of the flower visits within the order (Doyle et al 2020; Rader et al, 2015). Hoverflies could become important pollinators in the future in the face of declines in bee populations and may even be used as a managed species if need be (Doyle et al 2020).

Bees are the most important insect pollinators, being specialized for this role more so than any other organisms (Kevan and Baker, 1983; Danforth et al., 2006). They belong to the superfamily Apoidea within the order Hymenoptera, comprising seven families which contain over 20500 species identified to date (Ascher and Pickering, 2022; Kevan and Baker, 1983). Bees have evolved alongside flowering plants for millions of years, allowing angiosperms to

become the most diverse and dominant types of plants globally (Kevan and Baker, 1983; Hu et al., 2008). Bees are the chief pollinators of most globally important, pollination-dependent crops (Klein et al., 2007).

Just a small snapshot of global bee diversity is found in Nova Scotia, with over 200 bee species identified in Nova Scotia to date (Sheffield, 2006). While many people typically think of hive-nesting honey bees when bees are mentioned, the reality is that few bee species exhibit this nesting biology besides honey bees (Packer et al., 2007). Most bee species globally are ground-nesters, and Nova Scotia certainly is no exception to this trend (Sheffield et al., 2003). Some of the ground-nesting genera in Nova Scotia include *Andrena*, *Bombus*, and the family Halictidae which includes *Lasioglossum* and *Halictus* species, some of the most numerous species in the province (Sheffield et al., 2003). Nesting in wood cavities is done by genera such as *Ceratina* and *Osmia* bees in the province (Sheffield et al., 2003; Packer et al., 2007). There are bees across some of these Nova Scotian genera that are parasitic as well, for example *Lasioglossum* and *Bombus* include some parasitic species, as well as wholly parasitic genera such as *Specodes* and *Nomada* (Sheffield et al., 2003).

Bees and other pollinators have made headlines, both in the news media and scientific literature, for their dramatic population declines in recent years (Potts et al., 2010; Weston, 2023). It is because of these population declines that there are concerns about the loss of the important ecosystem service of pollination, which could devastate both human society and ecosystems around the world (Smith et al., 2022). Due to these potential consequences, there is now great interest in ensuring the health of pollinator populations so that this ecosystem service can continue into the future (Hall and Martins, 2020).

e. The Debate Over Honey Bee Conservation

Though it is wild bees that are most in need of conservation measures, another bee species not native to North America often receives more attention from the public when discussing the plight of pollinators, often at the detriment of these wild bees (Smith and Saunders, 2016; Colla and MacIvor, 2017; Mathiasson and Rehan, 2020). The European honey bee (*Apis mellifera*), which has been domesticated and introduced to many ecosystems by humans, is the most frequent flower visitor worldwide, and is an important pollinator of both crops and the surrounding natural ecosystems (Winfree et al., 2011; Hung et al, 2018). Being so abundant and widespread, it is perhaps the most well-known pollinator and receives a disproportionate amount of media attention (Smith and Saunders, 2016). Honey bees thus represent a 'flagship' or 'charismatic' species for pollinator conservation, that is, one that can raise media awareness of the plight of pollinators (Ducarme et al., 2013; Penn et al., 2019). This status can be beneficial in bringing attention to pollinator declines, as invertebrate conservation efforts often struggle to find species that can gather research funding and public attention, with none being included amongst a public survey of the most charismatic species (Barua et al., 2012; Albert et al., 2018). However, all this focus solely on the honey bee can bring with it some drawbacks.

Despite its usefulness as a 'charismatic species', some scientists believe that the honey bee should not be the target of pollinator conservation efforts outside of its native range in Eurasia (Iwasaki and Hogendoorn, 2021). Given the prominence of honey bees amongst the general public, conservation efforts towards this species outside of its native range can fuel misunderstanding of pollinators and undermine conservation of wild bee species (Colla and MacIvor, 2017; Colla, 2022). There is also the ongoing debate within the scientific community

as to whether the honey bee represents an invasive species outside of its native range (Moritz et al., 2005). Managed honey bees can often disrupt pre-existing plant-pollinator interactions, reducing biodiversity (Valido et al., 2019). In some cases, the presence of introduced honey bees within an ecosystem can lead to competition that alters foraging behavior of wild bees, potentially leading to lower reproductive success amongst wild bumble bees (Thomson, 2004; Hung et al., 2019). This can result in lowered visitation by wild bees, thus lowering the pollination of native flowers (Page and Williams, 2022).

While honey bees can be detrimental in some ways, they are a valuable pollinator to agriculture, enabling the production of many crop species (National Research Council, 2007). Due to their favorable biology, honey bees have become the most common pollinator of agricultural crops (National Research Council, 2007). Honey bees can also aid in pollination of natural ecosystems due to their generalist foraging habits (Hung et al., 2018). Honey production from beekeeping is also valuable, with annual sales of honey in Canada totalling to $253.5 million CAD in 2022 (Statistics Canada, 2022). While honey bees are important to world agriculture, there is evidence that wild pollinators can successfully fill the crop pollination niche within agroecosystems (Nabors et al., 2018).

Regardless of where one stands on the issue of honey bee conservation, too much reliance on this one species could ultimately be a hinderance to agriculture, as domestic honey bee populations are not increasing at a rate fast enough to keep up with the current demand for their pollination services (Aizen and Harder, 2009; Mashilingi et al., 2022). Honey bee colonies have also been struggling recently due to a variety of factors, ranging from the parasitic *Varroa destructor* mites to Colony Collapse Disorder (Ellis et al., 2010; Smith et al., 2013). Given concerns about honey bee declines, looking to wild bees native to North America may help fill

20

pollination gaps. Wild bees have been found to be just as efficient pollinators of crops as honey

bees (Park et al., 2016). Even in ecosystems dominated by non-native *A. mellifera*, pollination

services can be provided by wild pollinators with a minimal decline in plant seed production

after honey bee removal. (Nabors et al., 2018). Thus, it is time to begin looking towards wild

pollinators for the delivery of crop pollination services (Mashilingi et al., 2022).

f. Major Issues Facing Pollinators

Humans are driving species declines and extinctions globally, and insects are certainly no

exception to this trend (Díaz et al., 2019; Goulsen, 2019; Wagner, 2020). Declines in insect

populations have been noted in multiple studies across the globe (Biesmeijer et al., 2006;

Hallman et al., 2017; Møller, 2020; Wagner, 2020). Hallman et al. (2017) found that flying

insect biomass had declined dramatically, by over 76%, over a period of only 27 years. These

declines in insect populations also mean a reduction in the ecosystem services they can provide,

including pollination (van der Sluijs, 2020).

Widespread declines in populations of pollinators are being recorded globally (Lever et

al., 2014; Potts et al., 2010). One reason for their decline is pesticide use, which is associated

with lower species richness among bee and butterfly species at a regional level (Brittain et al.,

2010). Neonicotinoid insecticides are of particular concern due to their widespread use and

effects as a neurotoxin on insect pollinators (van der Sluijs et al., 2013). Neonicotinoids can also

act synergistically with pathogens such as *Nosema* fungi to weaken bee colonies (Alaux et al.,

2010). Main et al. (2020) found that many other pesticides are being accumulated in large

numbers of wild bees and butterflies, with many ground-nesting taxa being identified as at-risk

to pesticide exposure due to high numbers of these samples being found to contain pesticides.

The three most common non-neonicotinoid pesticides identified in this study were metolachlor,

tebuconazole, and atrazine, with a total of 16 being identified. While only two were considered

'highly toxic,' chronic exposure to the others could still lead to negative sublethal effects (Main

et al., 2020).

Other reasons for declines in pollinator populations include introduction of foreign

species, climate change, and habitat loss and fragmentation (Potts et al, 2010). Invasive species

including pathogens, plants, and even other, non-native pollinators are having negative impacts

on native bees (Mathiasson and Rehan, 2020; Morales et al., 2013; Vilcinskas, 2019). In

particular, wild bumble bees (*Bombus*) are facing competition and extirpation from other,

invasive pollinator species (Morales et al., 2013), which may also be potential transmitters of

pathogens (Vilcinskas, 2019). There is evidence that invasive plant species can negatively affect

specialist pollinators who are losing their primary food sources (Mathiasson and Rehan, 2020),

while generalist foragers are often positively impacted by introductions of flowering plants due

to the increased food availability (Drossart et al., 2017; Potts et al., 2010). In combination with

climate change, invasive species can greatly alter ecological communities and the pollinator-

plant interactions that occur within them (Schweiger et al., 2010).

Climate change drives pollination decline by altering temporal and spatial ranges of many

species, while also exacerbating other drivers of decline, such as habitat loss (Settele et al.,

2016). Habitat loss caused by humans is a major cause of declines in biodiversity worldwide

(Foley et al., 2005), and pollinators are no exception. Habitat loss and fragmentation is arguably

the largest factor in pollinator decline globally (Brown and Paxton, 2009; Richards, 2001). The

negative effects of habitat fragmentation on pollinator populations have been shown to negatively impact plant communities, as decreased fruit sets are found in plants in fragmented areas due to reduced pollination services (Cunningham, 2000).

Declines in pollinators are ultimately detrimental to both natural plant communities and agriculture, and so pollinator conservation is a concern for stakeholders representing both interests. For example, MacLeod et al. (2020) found that many rare wild species of bees were dominant pollinators of key crops in the Northeastern United States. Wild pollinators often provide an important service to fruit farmers, increasing profits with their presence (Pérez-Méndez et al., 2020). The decline of pollinators can also mean the decline of plant species reliant on their services (Biesmeijer et al., 2006). Diverse pollinator communities enhance pollination services to ecosystems, with higher pollinator diversity associated with better plant reproductive success (Albrecht et al., 2012).

Taking steps to encourage pollinator conservation can help to slow or reverse pollinator declines. Increased reporting of pollinator declines is helpful in enacting policy change, as it increases public awareness of this issue (Althaus et al., 2021). For wild pollinators, it is often beneficial to have areas of natural habitat interspersed within agricultural land, which can also increase visitation to crops (Joshi et al., 2016; Kremen et al., 2004). Pesticide use should be discouraged on pollinator-dependant crops, when possible, as pollination services are more valuable for agricultural yield than pesticide application (Catarino et al., 2019). Enacting pollinator conservation practices within the agricultural sector, which is reliant on pollination services, can be a key to pollinator conservation.

g. The Bay of Fundy Dykelands Landscape

There is a need for identification of trade-offs when managing ecosystems for their services in Canada (NSERC ResNet, 2019a). NSERC ResNet was established to help with sustainable land management in six landscapes across Canada (NSERC ResNet, 2019a). Within each landscape, researchers are examining multiple ecosystem services to further our understanding and assist in the modelling of these services to aid stakeholder decision-making (NSERC ResNet, 2019a). This thesis is part of this effort, and I will look into pollination services in the Bay of Fundy dykelands in Nova Scotia.

This study takes place on farms within the Bay of Fundy dykelands landscape in and around the Annapolis Valley in Nova Scotia (**Figure 1.1**). This area is the agricultural heart of the province, and is also the location of many current and former coastal salt marsh habitats (Gordon Jr. et al., 1985; Devanney and Reinhardt, 2011). A salt marsh is defined by the Government of Nova Scotia (2019) as a wetland which is regularly flooded tidally, or otherwise influenced by salt water, making the water and soil either saline or brackish. Dating back to Acadian settlement of Nova Scotia in the 1700s, dykes were used to convert salt marsh to agricultural land (Wynn, 1979; Sherren, 2016). It is because of this that the farmland in the Annapolis Valley region is often referred to as 'dykelands' (Sherren, 2016). There are 241 km of dykes in Nova Scotia, creating and protecting an estimated 16139 ha of agricultural land from salt water (van Proosdij et al., 2018). However, in the face of sea level rise associated with climate change, there has been much debate over whether the dykes should stay or dykelands be restored to their former salt marsh habitat, as the Nova Scotia Department of Agriculture (NSDA) does not have the resources to continue maintenance of all dykes in the province

24

(Sherren et al., 2016; van Proosdij et al., 2018). A deeper understanding of potential effects on ecosystem services like pollination in this interconnected landscape of cropland, dykes, and salt marshes is needed prior to salt marsh restoration (NSERC ResNet, 2019b).

Understanding the landscape this study takes place in is important, as it is known that location can have an impact on ecological communities including pollinators (Edwards et al., 2019). Pollinator populations that visit crops may meet their resource requirements via a variety of different habitats across the broader landscape (Cole et al., 2017). Encouraging diverse habitats to allow pollinators to meet their needs can help enhance the resources pollinators need for survival and the ecosystem service they provide (Cole et al., 2017; O.Brien and Arathi, 2021). The Bay of Fundy dykelands landscape is a complex system, with multiple ecosystem services at work simultaneously to ultimately deliver benefits to both natural and human communities (Sherren et al., 2021). Given that this landscape includes the agricultural center of the province of Nova Scotia, farmers represent an important local stakeholder group (Devanney and Reinhardt, 2011). Many important crops grown in this area are reliant on pollination services for successful harvest (Klein et al., 2007; Devanney and Reinhardt, 2011). Given that it is already known surrounding habitats can influence pollinator assemblages on farms (Joshi et al., 2016), I aim to determine how pollinator communities on dykes and in salt marshes compare to those on farms so that I can assess the potential impacts of modifying surrounding habitats through salt marsh restoration (Carvalheiro et al., 2010).

h. Pollination of Crop Species
h.i. Pollination of Apple

Apple (*Malus domestica*) is one of the most important fruit crops grown globally, and is harvested on all continents except for Antarctica (FAO, 2023). Apple is also one of the two most important fruit crops to Nova Scotian agriculture (Devanney and Reinhardt, 2011; Ramírez and Davenport, 2013). Commercial apple growth favors varieties which typically flower early in the growing season in temperate climates, including Nova Scotia (Gottschalk and van Nocker, 2013). Pollinators are strongly needed for apple crop production (Klein et al., 2007); while self-pollination is possible in apple trees, it occurs much less than cross-pollination (Ramírez and Davenport, 2013). Even in cases where self-pollination does occur, it yields a much lower fruit set and weights than cross-pollinated apple (De Witte et al., 1996; Olhnuud et al., 2022). Pollinizers such as crabapple (*Malus floribunda*) are commonly planted in commercial orchards to help facilitate cross-pollination of apple trees, as apples benefit from pollination between different cultivars (Delaplane and Mayer, 2000; Ramírez and Davenport, 2013).

The domesticated honey bee (*Apis mellifera*) is the most abundant and important pollinator of apple crops globally (Ramírez and Davenport, 2013), but are not the most efficient pollinators of apple flowers (Delaplane and Mayer, 2000). Thus, other bees and insect pollinators are important for apple pollination as well (Ramírez and Davenport, 2013). Gardner and Ascher (2006) found that the most numerous and diverse native bee visitors to apples were those belonging to the genus *Andrena* in apple orchards in New York state, which are also found in Nova Scotia. Another Nova Scotian bee genera important for apple pollination is *Osmia*, with management of some bee species within this genus being considered for apple pollination (Sheffield, 2006; Sheffield et al., 2008).

26

h.ii. Pollination of Tomato

Tomato (*Solanum lycopersicum*) is another crop commonly grown in Nova Scotia (Devanney and Reinhardt, 2011). Tomato was used as the mid-season flowering species in this thesis, with flowering occurring over a longer period of time than other crops. Tomatoes are capable of being grown outside, but are also a common greenhouse crop, and one the three most important horticulture crops (Dorias et al. 2002). Under greenhouse conditions, pollinators may still be used both passively and actively (Morandin et al., 2001). Tomatoes are less reliant on pollinators than apple and squash, being self-compatible (Rick, 1983). The crop does still benefit from cross-pollination that can be provided by pollinators and relies on pollinators to some extent (Klein et al., 2007).

Tomatoes rely on a special method of pollination called buzz pollination that can only be provided by certain groups of bees (De Luca and Vallejo-Marín, 2013). Buzz pollination occurs when bees use specific frequencies of vibrations during their collection of pollen from flowers, with the energy from these vibrations helping to release pollen from the anthers onto the pollinators, which fertilizes plants upon visitation to another flower (De Luca and Vallejo-Marín, 2013; Vallejo-Marín, 2018). It is because of this unique requirement for successful pollination that wild species of bees can be better pollinators of tomato than honey bees, *Apis mellifera,* which is incapable of buzz pollination (Asada and Ono, 1996; Franceschinelli et al., 2013; Pritchard and Vallejo-Marín, 2020). Bumble bees (genus *Bombus*) are specialized to provide this type of pollination through their natural behavior, and thus make excellent pollinators of tomato crops (Asada and Ono, 1996; Nazer et al., 2003; Franceschinelli et al., 2013). About half of all

27

bee species are capable of buzz pollination, including large carpenter bees (Genus *Xylocopa*) and small sweat bees (Family Halictidae) (Pritchard and Vallejo-Marín, 2020).

h.iii. Pollination of Squash

Squash (*Cucurbita* spp.) is entirely reliant on animal pollination for successful crop production (Klein et al. 2007). Self-pollination across multiple generations in squash plants negatively impacts production, resulting in lowered fruit weight, size, and seed production due to inbreeding (Cardoso, 2004). There are five species within the genus *Cucurbita* which are harvested commercially, with crop production centering on North America and the countries surrounding the Mediterranean Sea (Paris, 1996). The primary species I studied was *C. pepo*, the summer squash. This crop will represent the latest-flowering crop in this thesis, with flowering occurring from mid-summer to early fall (Cornell University, 2006).

Squash depends on fewer pollinator species than apples and tomatoes (Stoner, 2020). Bees belonging to the genera *Peponapis* and *Xenoglossa* display a high degree of specialization towards pollination of squash plants, a foraging behavior known as oligolecty, and because of this they are appropriately known as 'squash bees' (Michelbacher et al., 1964; Ritchie et al., 2016). Bumble bees are another important wild pollinator of squash in Northeastern North America (Stoner, 2020).

i. Objectives

There are few previous studies on pollination services to agriculture in the Bay of Fundy dykelands landscape (but see Roulston, 2021 and Sheffield et al., 2013); this thesis intends to fill in some of this knowledge gap. Pollinator surveys have been conducted in Bay of Fundy salt marsh and dyke habitats by Roulston (2021). Comparing wild pollinator communities between those habitats and cropland is crucial for furthering our understanding of how pollinator communities are partitioned across the broader landscape, and how the presence or absence of these habitats near farms may impact the delivery of pollination services. The pollinator survey I conducted directly on farms was thus needed to determine which wild bee species are also visiting crops. While there have been past surveys of pollinators in apple orchards in the Annapolis Valley (Sheffield et al., 2013), that study did not have a focus on the proximity to salt marsh and dyke habitat, and there have been no previous pollinator surveys done in Nova Scotia on tomato and squash crops.

The combined objectives of my thesis chapters are to determine the species compositions of the pollinator assemblages visiting apple, tomato, and squash crops, and how important to crop yields these assemblages are in the Bay of Fundy dykelands. By looking at the taxonomic composition of pollinator assemblages, I can determine how many of the visitors in these crops are wild pollinators. Combining these results with those of the pollinator exclusion study can show the importance of wild pollinators to agriculture in this region of Nova Scotia. I then compared the species found in this study to past studies by Roulston (2021) and Sheffield et al. (2013) to help draw comparisons with some of the habitats that may occur around these farms, and determine how pollination services to farms may be affected by changes to these habitats,

such as salt marsh restoration. Based on past studies done in Nova Scotia, I expected to see diverse wild pollinator communities on farmland (Sheffield et al., 2013; Walker et al., 2021). I also expect to see that wild pollinators increase crop yields, as all crops observed here are at least moderately reliant on pollination services (Klein et al. 2007). Past pollinator exclusion studies on apple and tomato have also found increased yields from pollination, with wild pollinators noted to be better at providing this ecosystem service than introduced domestic honey bees (Delaplane and Mayer, 2000; Franceschinelli et al., 2013; Mallinger and Gratton, 2015).

j. Study Sites

Farms which made use of fewer or less damaging pesticides, including organic farms, were selected to minimize the potential impacts pesticide use could have on nearby insect populations, including pollinators (Holzschuh et al, 2008; Brittain et al, 2010). Farms also needed to be within two kilometers of salt marsh or dyke habitats to allow for a comparison with Roulston (2021); this distance was chosen as it is around the typical flight distance for many bees (Greenleaf et al., 2007; Kuhn-Neto et al., 2009; Kendall et al., 2022). Applicable farms in the region were contacted with information about the study and of those, four responding expressing interest in participating and so were selected as sampling locations. These farms were Abundant Acres Farm, Oakview Farm, Olde Furrow Farm, and Taproot Farms (**Figure 1.1**). The farms selected all grow a variety of crops which require pollination services making them ideal candidates for this study. All farmers were made aware of the likelihood of small crop losses due to the methods I would use, most notably for the pollinator exclusion portion of this study, and fully approved all research activities before proceeding.

Abundant Acres is located in Centre Burlington, Nova Scotia (**Figure 1.1**). It is situated along the Cogmagun River, and the only farm in this study to be located outside of the Annapolis Valley. The Abundant Acres property is 95 acres, of which approximately 30 acres was the site of a salt marsh restoration project, where a dyke was breached for the purposes of restoring artificial land to its former salt marsh habitat (J. Greenberg, pers. comm., October 24, 2023). Oakview Farm is a 30-acre farm located just outside of Kingsport, Nova Scotia (Graham, 2017) (**Figure 1.1**). It is across a rural highway from the extensive Kingsport salt marsh. Olde Furrow Farm is a 100-acre family farm located near Port Williams, Nova Scotia (Olde Furrow Farm, n.d.) (**Figure 1.1**). It is located furthest upstream from the Minas Basin of any of the sites used for this study, but is still near to the tidal Cornwallis River, which is extensively dyked (Olde Furrow Farm, n.d.). However, the nearby Belcher salt marsh restoration occurred a short distance upstream, and so may have an influence on the pollinator community at this farm. TapRoot Farms is located near Starr's Point, Nova Scotia (**Figure 1.1**). It is the largest of the farm operations used as a study site, with about 280 acres of farming area (TapRoot Farms, 2019).
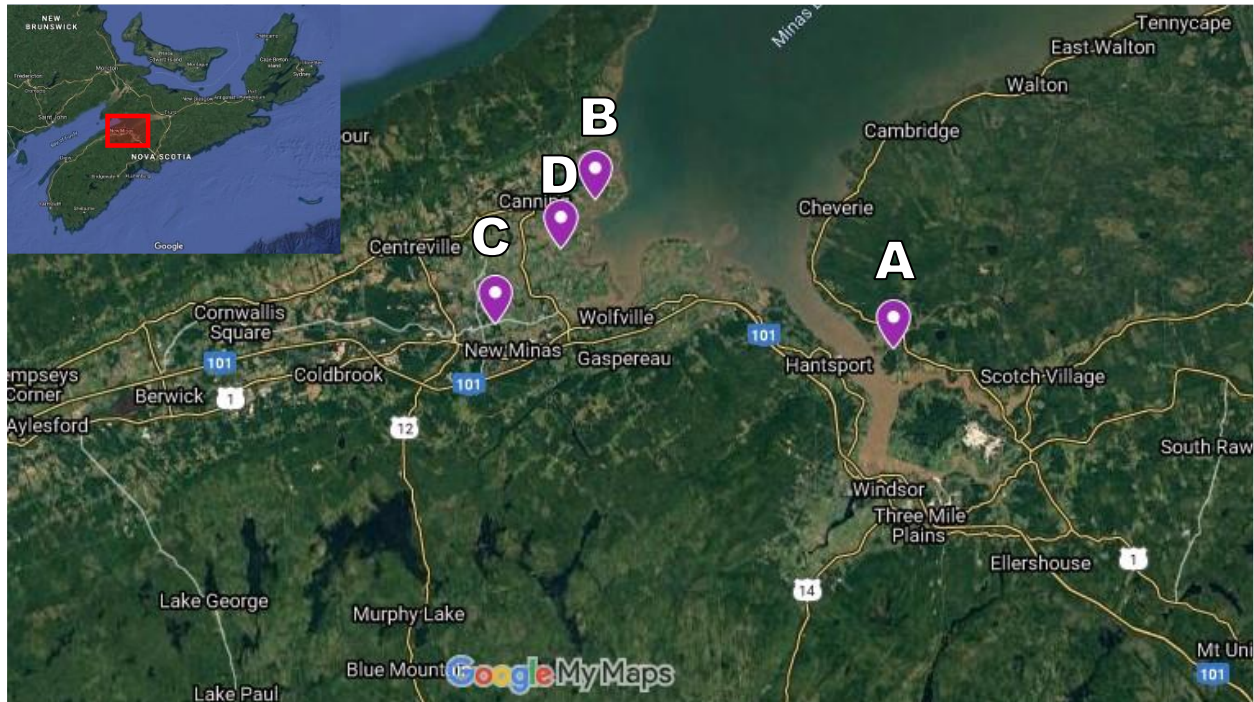
Figure 1.1. Location of farms used as sampling sites in Kings and Hants Counties, Nova Scotia. Sampling sites were used for both fruit exclusion experiment and pollinator surveys. A – Abundant Acres Farm. B – Oakview Farm. C – Olde Furrow Farm. D – Taproot Farms. Imagery from Google maps.

An initial shortlist of candidate crops was created using the list of crops outlined in Klein et al. (2007) as showing some degree of reliance on insect pollination to increase their production. Once farms had been selected, farmers were contacted to determine what they were growing. Crops selected for this experiment were apple, tomato, and squash. These crops were ultimately selected due to their reliance on pollination, the fact that all farms being sampled were growing these species, and their differing flowering times, allowing for an assessment of how pollinator communities may change over the course of a growing season (Kimoto et al., 2012). Apple is the earliest-flowering crop, and squash the latest, with tomato flowering occurring in the middle of the growing season. Both pollinator surveying and pollinator exclusion occurred in these crops during the 2021 growing season.

Chapter 2: Agricultural Pollinator Communities in the Bay of Fundy Dykelands of Nova Scotia, Canada

2.1. INTRODUCTION

a. The Needs of Wild Pollinator Communities

Diverse pollinator communities also have diverse resource requirements. Landscapes with a variety of different habitats are thus more likely to give rise to diverse ecological communities, including pollinator communities, as they can offer a wider variety of resources to organisms (Coutinho et al., 2021). Across a single landscape, species compositions can vary greatly between habitats with as little as 500-1000 m of separation (Torné-Noguera et al., 2014). For bees, the primary habitat requirements are space for both foraging and nesting within close proximity, as the flight range of many bee species is limited, especially of smaller species (Potts et al., 2005; Greenleaf et al., 2007). Close habitat proximity ensures that bees can access the resources they need while minimizing energy expended while flying (Greenleaf et al., 2007).

Mass flowering of crops can lead to an overabundance of nectar resources for bees at some times during the growing seasons, but a deficit in available food at other times (Timberlake et al., 2019). Provisioning of suitable foraging habitat for pollinators within agroecosystems ensures that floral resources are available throughout the growing season, encouraging bee guilds that emerge at different times (Guezen and Forrest, 2021). Suitable amounts of foraging habitat could be as little as 2% of flower-rich habitat per 100 ha of farmland (Dicks et al., 2015). Flowering species richness is important to consider for generalist pollinators, as they will often forage to maximize species richness within their diet (Jha and Kremen, 2012). Directly on farms, practices such as organic farming can ensure food availability during times that it would

typically be scarce from conventional monoculture farming (Austin et al., 2019). Diverging from conventional agricultural practices can also be beneficial for pollinator nesting habitat.

Suitable nesting habitat provides bees with both shelter and a space for reproduction and subsequent rearing of young. Most bee species prefer to nest below ground, with the majority of these ground-nesters preferring little to no vegetation cover and sandy to sandy loam soil for their nesting habitat; higher quality habitat is often just as valuable as the quantity available (Potts et al., 2005; Harmon-Threatt, 2020). The contrasting low amount of vegetation needed for nesting compared to the higher amounts of vegetation needed for foraging by many bee species highlights the need for vastly different resources to be available to bees near to each other (Potts et al., 2005). Disturbance events can also affect the nesting habitats of bees, for example, wildfires can increase suitable habitat for cavity-nesting species (Simanonok and Burkle, 2019). An understanding of the nesting material and habitat needs used by cavity nesters allows for better artificial nests to be built to aid in their conservation while minimizing nest parasites (Eeraerts et al., 2022). Hard infrastructure such as paved roads can have a negative impact on bee nesting habitat and should be avoided if pollinator conservation is to be pursued (Jha and Kremen, 2012).

Landscape composition can have a significant effect on pollinator community composition (Potts et al., 2005; Andersson et al., 2013; Coutinho et al., 2021). Understanding the community compositions of pollinator species in a landscape allows us to determine their habitat needs. Consideration of both foraging and nesting needs of pollinator communities is important for successful pollinator conservation (Potts et al., 2005). Encouragement of wild pollinator habitat is associated with better pollination of agricultural crops, returning the investment farmers may make when establishing this habitat on their land (Blaauw and Isaacs, 2014).

Increasing wild pollinator habitat can also increase other ecosystem services beneficial to farmers, such as biological pest control (Wratten et al., 2012). Making space for pollinator habitat can thus allow for pollinator communities and ecosystem services beneficial to farmers to flourish simultaneously.

b. The Benefits of Wild Pollinators to Nova Scotia

Wild bees are important pollinators of croplands (Mallinger and Gratton, 2015; Franceschinelli et al, 2013). Exclusion studies have found that even on farms that allowed honey bee pollination, if wild bumble bees were unable to pollinate, profits were up to two times lower (Pérez-Méndez et al., 2020). Diverse wild pollinator populations are associated with high fruit set in apple orchards, while honey bee presence or absence was found to have little to no effect (Mallinger and Gratton, 2015). In fact, it has been shown that wild bees are better pollinators of some crops than domesticated honey bees (Delaplane and Mayer, 2000; Franceschinelli et al., 2013). Some wild bees are specialist pollinators for certain plant species, as opposed to the generalist natures of honey bees, making them important for the plant-pollinator networks of these ecosystems (Hung et al., 2018; Larsson, 2005). Wild bee populations also provide a sort of insurance policy to ensure pollination in the face of honey bee die-offs from Colony Collapse disorder (Winfree et al., 2007).

Interspecific interactions between wild bees and honey bees have also been shown to increase pollination by the latter in some crops (Greenleaf and Kremen, 2006). Thus, even in agroecosystems where farmers will be using honey bees for the bulk of their crop pollination, management practices which encourage wild bees can bring economic benefits. Given the

35

oftentimes thin profit margins present in the agricultural industry, the pollination service wild bees provide could be used to offset some of the costs farmers may spend on importing honey bees (Pérez-Méndez et al., 2020).

There are many species of bees found in agroecosystems in Nova Scotia that could be useful pollinators of commercial crops (Sheffield et al., 2013). Bees native to Nova Scotia are known to be important in the pollination of the two most economically important fruit crops in the province, apples and blueberries (Devanney and Reinhardt, 2011; Sheffield et al., 2013; Walker et al., 2021). The diverse assemblage of bee species in Nova Scotia certainly provides many opportunities for farmers to enact pollinator management practices on a case-by-case basis. Habitat provisioning is one of the best practices and has been shown to rapidly increase numbers and diversity of pollinators (Killewald et al., 2023). For example, cavity-nesters can be provided with trap nests, also termed 'bee hotels,' in apple orchards, increasing the viability of some native species as commercial pollinators (Sheffield et al., 2008; MacIvor, 2017). However, a further understanding of the pollinators present in Nova Scotian agroecosystems and the crops they pollinate is needed before these policies can be successfully implemented.

My thesis intends to fill a research gap by identifying the insect pollinators of crop species in the Bay of Fundy dykelands agroecosystem and determine if pollinator diversity is similar to that found in saltmarsh and dyke habitats around the cropland (Roulston, 2021). I also conducted the first measurements of changes in pollinator diversity and abundances over time in Nova Scotia. Since bee species have differing flight periods, the make-up of pollinator communities can change over the timespan of a single growing season (Kimoto et al., 2012). By looking at crops with different flowering periods, I can determine how the pollinator communities in the Bay of Fundy dykelands change over the course of a single growing season.

Understanding how natural communities change over time is oftentimes just as important as understanding how location can affect community composition (Oleson et al., 2008; Bramon Mora et al., 2020).

c. Objectives & Hypotheses

The objective of this thesis chapter is to determine which pollinators visit three major pollinator-reliant crops (apple, tomato, and squash) in the Bay of Fundy dykelands of Nova Scotia. I quantified the diversity (number of species) and abundance (total numbers of all pollinators) of wild pollinators visiting each crop, to determine which groups are the most important pollinators of each crop species. I also draw comparisons with previous pollinator surveys done in Nova Scotia, including Roulston's (2021) study in salt marshes and dykes in the Bay of Fundy dykelands. I hope to determine the degree to which salt marsh and dyke habitats support the same pollinator species as the crop fields, to evaluate the potential of these adjacent habitats to support pollination services to croplands. This is of great interest due to ongoing salt marsh restorations in the region (Singh et al., 2007).

I expected to see high abundances of wild bees across all crop species and expect that bumble bees will be some of the most numerous pollinators of tomato plants (Franceschinelli et al., 2013). The genera *Andrena* is known to contain important native pollinators of apple orchards in Northeastern North American, so I expected these bees will be abundant amongst the apple crops (Park et al., 2016; Nooten et al., 2020). In apple, I also expected to see the highest numbers of introduced honey bees, given their commercial use as pollinators of this crop (Ramírez and Davenport, 2013).

2.2. METHODS

a. Introduction to Pollinator Surveying Methods

For pollinator surveys, a combination of bowl trapping and sweep netting was used within each of the three crops (apple, tomato, and squash) at each of the four sites described previously. The use of multiple methods can give a more complete picture of the diversity within pollinator communities (Wilson et al., 2008). Both methods were chosen due to their standardized use in pollinator collection (Droege, 2010), including in previous studies within Nova Scotia (Sheffield et al., 2013; Walker et al., 2021). They are easy to implement and low cost, requiring minimal materials. Bowl trapping was done for ten non-consecutive days in each crop species in the spring and summer of 2021. In some cases, this meant that bowl trapping ran either slightly before or after the flowering period of a crop species at a particular site. In apple, the surveys were conducted from May 11th-June 1st. In tomato, the surveys were done from June 25th-July 13th, and squash was surveyed from July 29th-August 18th.

b. Bowl Trapping

Bowl trapping was done at every site on every day of pollinator sampling. Three different colours – white, yellow, and blue – of small disposable plastic bowls were used. These colours were chosen as they have been shown to be among the colours most attractive to pollinators (Saunders and Luck, 2012). A total of 24 bowls – eight of each colour - were used each day at each site.

Bowls were laid out amongst plants of the targeted crop species at each site consecutively each morning, typically being placed at the first site as early as 8:30 am and placed at the last site no later than 11:00 am, depending on travel time between sites. At each site, bowls were laid out in a grid pattern consisting of four parallel transects of six bowls each (**Figure 2.1**). Each transect was ~5 meters from each other. Within the transects, the bowls were also placed ~3 meters from each other. The bowls were laid out so that the different coloured bowls were alternating, meaning that each transect had two bowls of each colour. Bowls were filled approximately two-thirds of the way full with a mixture of water and a small amount of Dawn-brand dish soap, to help break surface tension.
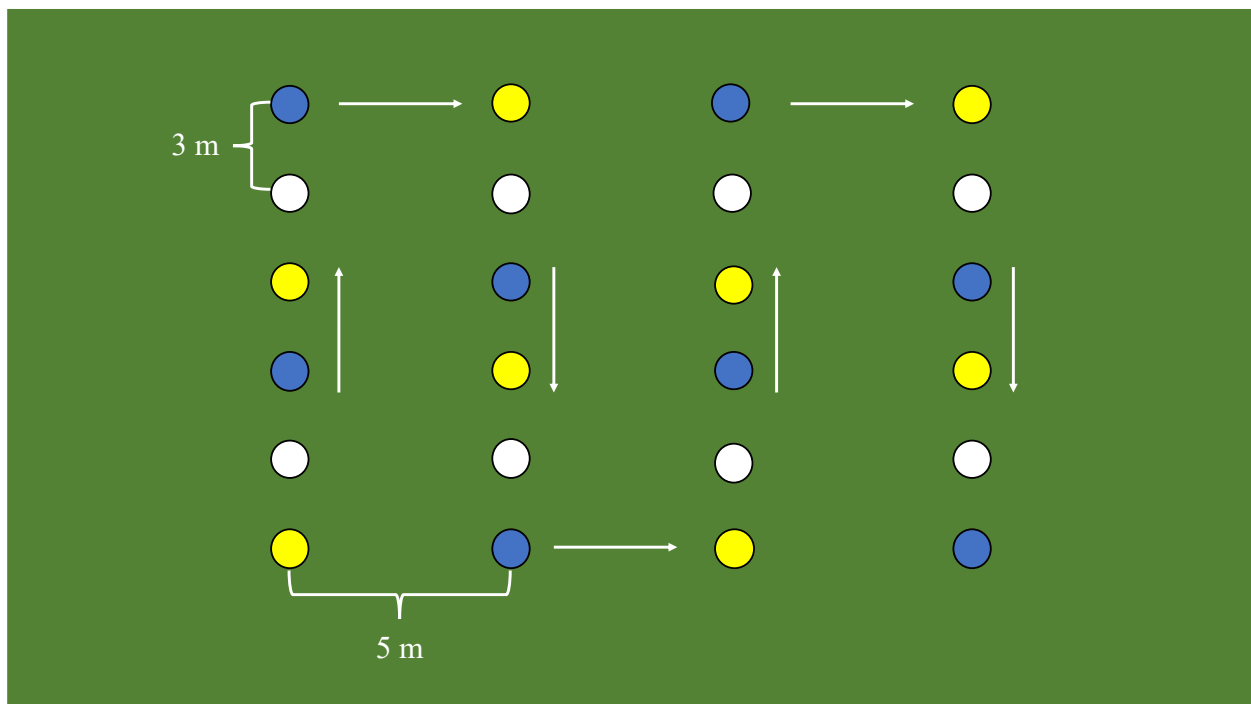
Figure 2.1. Schematic layout of bowl traps within crops at each site. It is important to note that while bowl colours always alternated within transects so that no two of the same were next to each other, the order of the colours did not always exactly follow the order presented here. Arrows indicate order bowls were placed and picked up in. Diagram is not to scale.

Bowls were placed at ground level for ~6 hours at each site after being laid out and filled. The time of finishing at each site in the morning was recorded to determine when the pick-up time in the afternoon would be. Pick-up of bowls between sites was thus done in the same order as the laying out of bowls in the morning. At each site, bowls were emptied of their pollinator catches by pouring their contents into a strainer. Three strainers – one for each colour – were used to avoid confusion. The catches for each colour of bowl at each site were combined together in each strainer. This gave us a total sample size of 120 over the ten day sampling period in each crop – 30 at each of the four sites, as the bowls were pooled into the three colours everyday for each site. After all the bowls at a site had been picked up and drained, the pollinators that were now in the strainers were placed into plastic Ziploc bags labelled with the crop, site, date, and the bowl colour. These bags were then filled with enough 95% ethanol or 70% isopropyl alcohol to fully submerge all specimens and then sealed for preservation while they were being transported back to the lab for analysis.

c. Sweep Netting

Targeted sweep netting of crop species was done for each crop on the same days as bowl trapping. Weather conditions required for sweep netting were temperatures above 15º Celsius (a slight raise from the 10º Celsius used in Walker et al. (2021), as few pollinators were observed as temperatures approached 10º), with no precipitation and low wind, similar to the conditions previously identified by Drummond (2002) and Walker et al. (2021). As much of the sampling took place during the late spring or summer, this raise in temperature for sampling was easily accommodated. Flowering individuals of the targeted species were also required for sweep

netting. Because of these requirements, there were fewer days of sweep netting than bowl trapping. Logistical concerns prevented extra days from being made up in cases of crops with flowering periods that extended beyond sampling times.

Sweep netting was done by two individuals at the same time, typically during the middle of the day, in between drop-off and pick-up of the bowl traps at a specific site. This was done by each individual establishing a non-overlapping area of approximately two meters in diameter within the flowering crop, measured in the field by using the reach of each person using their arm span combined with the sweep net. Only flowers that could be reached through the use of the sweep net by standing in a single spot at the middle of this circle would be observed for these surveys. Once this was done, sweep netting commenced. Targeted sweep netting was used for this survey, meaning only pollinators that were seen visiting flowers of the targeted crop species within the established sampling area were caught. Each person sampled for 15 minutes, for a combined sampling effort of 30 minutes for each day on each site, the same as used by Drummond (2002) and Walker et al. (2021). Any pollinator found visiting a flower during this time period was caught and placed in a vial, following the methods outlined in Droege (2010).

Once netting was finished, all the collected pollinators in vials from both surveyors were placed into one large plastic Ziploc freezer bag labelled with the crop, site, date, and method (to distinguish from bowl-trapped individuals). At the end of the day, these samples were placed into a freezer overnight to humanely euthanize the pollinators. The following morning, the pollinators were then taken out of all their vials and combined into a smaller Ziploc bag labelled with the crop, site, date, and the fact that they were caught while sweep netting. Enough 95% ethanol or 70% isopropyl alcohol to submerge all specimens was then poured into the bag for preservation until they could be identified.

d. Pollinator Identification

Prior to identification, captured pollinators needed to be cleaned, pinned, and labelled. Cleaning was done by first removing all individuals from a bag and placing them into a mixture of water and dish soap. It is at this stage that any insects identified as non-pollinators were set aside to be disposed of. Following this, the remaining pollinators were then rinsed in a bath of tap water, and then dried by laying them out individually on paper towel. After a short period of drying, pollinators were pinned individually, except in the case of some smaller Coleoptera which were attached to a strip of paper together and the paper was pinned, and then given a small paper label containing information such as a unique number identifier, date of capture, capture method, and site and crop it was captured within. This information all corresponded with a digital database containing this same information on all of the specimens, that would also be used during the identification process (Droege, 2010).

Identification of pollinators was done using a number of keys, a list of which can be found in **Table 2.1**, alongside Discover Life (Ascher and Pickering, 2022). Non-bee pollinators were identified to Order, with notes being made on those within the Order Hymenoptera to further specify what was captured. Bees were identified directly to their genus and species, except in cases where specimens were damaged or otherwise unidentifiable. Pollinator specimens were identified using a dissecting microscope. Once identified, the taxonomic information for that specimen was added to the database. All specimens are currently housed in the Cape Breton University insect collection.

Table 2.1. List of keys used as references during pollinator identification (excluding Discover Life).

Author and Year	Title
Gibbs, 2011	Revision of the metallic Lasioglossum (Dialictus) of Eastern North America (Hymenoptera: Halictidae: Halictini)
Mitchell, 1960	Bees of the Eastern United States. I.
Mitchell, 1962	Bees of the Eastern United States. II.
Packer et al, 2007	The Bee Genera of Eastern Canada
Rehan and Sheffield, 2011	Morphological and molecular delineation of a new species in the *Ceratina dupla* species-group (Hymenoptera: Apidae: Xylocopinae) of eastern North America.
Sheffield et al, 2011	Leafcutter and Mason Bees of the Genus *Megachile* Latrielle (Hymenoptera: Megachilidae) in Canada and Alaska.

e. Data Analysis

Statistical analysis and presentation of data collected was performed using a combination of Microsoft Excel and RStudio Integrated Development Environment for R statistical software (R Core Team, 2022; RStudio, 2022). In Excel, abundances of all pollinators, including non-bees, was done first, before the data was narrowed to include only bees. Pie charts were made showing the proportion of bees and non-bees out of the total catches in each crop surveyed in this study.

After the data was sorted to include only captured bees, the total abundances and species richness of bees by crop and by site were presented. Nesting biology of bee species was then determined using a variety of sources, listed in **Appendix B**. The breakdown of the nesting biology of each individual species found in this study was placed in **Table 6.1** in **Appendix B**. The proportions of each type of bee nesting biology were then presented in the form of pie charts, first including the hive-nesting European honey bee (*Apis mellifera*), then without, to be able to focus solely on the nesting biology of wild bee species. Following this, the five most

common species in each crop were noted and placed in a table. If *A. mellifera* was amongst the most common species, it was noted, and the next most common species was included.

Rank-abundance plots for pollinator species were then made using Excel, for each site visited in this study. This was done to determine the similarity of pollinator community composition between different sites. If the slope and tail lengths of these plots are similar, then further statistical analysis could be conducted, as it is indicative of no irregularities at a particular site, such as a lack of or overabundance of 'rare' (only one catch or few catches) species in comparison to the other sites.

Further statistical analysis was then done using R and RStudio statistical software (R Core Team, 2022; RStudio, 2022). Non-metric multidimensional scaling (NMDS) was done to visualize the ordination and show the similarities and differences in bee community composition between different crops and sites. The NMDS was done in R using the 'MASS,' 'readxl,' and 'vegan' packages. Three dimensions were used to give a stress value, showing ordination fit. Three dimensions was chosen as it gave the best balance between a lower number of dimensions, and a low stress value. For this analysis, each 'method' of capturing the pollinators was used as a single sample unit, or row, on each site everyday, with each different colour of bowl traps being considered a different 'method,' alongside the sweep netting data.

Rarefaction curves were produced in R (using the 'MASS,' 'readxl,' and 'vegan' packages) to ensure an adequate amount of sampling effort was performed which accurately portrayed the species composition of bee communities within apple, tomato, and squash. One curve was first produced and plotted for the study as a whole. After this, individual curves for each site were plotted together. Slopes of the rarefaction curves would ideally appear to follow the same pattern, indicating that at no site too little or too much time was spent sampling. The

ideal rarefaction curve would be starting to plateau, but still slightly positive, indicating that further sampling effort may reveal a few new, rare, species, but with most of the species in the environment already accounted for.

2.3. RESULTS

A grand total of 4403 pollinators were caught during the course of this study (**Table 2.2**). Of this, a total of 3235 were identified as bees, accounting for approximately 73.5% of pollinator catches. The highest proportion of bee catches out of total pollinator catches was found in apple, with close to 90% of pollinator catches being bees, whereas the lowest was in squash, with only approximately 53% of pollinator catches identified as bees. Of the catches in the tomato crop, approximately 70% of pollinators were bees (**Figure 2.2**).

Of the non-bee pollinators (n = 1168), most were beetles (Order Coleoptera, 623/1168), with the majority in squash (352/1168). Other Hymenopterans besides bees, mostly wasps, were the next-largest group of pollinators (417/1168), relatively evenly distributed between each crop. Dipterans (113/1168), including hoverflies, were found across all crops, again relatively evenly distributed between each one. Only 11 out of 1168 non-bee pollinators were Lepidopterans such as butterflies and moths, with none found amongst apple.

Table 2.2. Total abundances of all pollinators (n = 3 crops, n = 4 farms), including non-bees, caught in each crop and at each study site. SD = standard deviation.

	Pollinator Abundances					
	Crop					
Farm	**Apple**	**Tomato**	**Squash**	**TOTAL**	**Mean**	**SD**
Abundant Acres	495	275	201	971	323.67	152.92
Oakview	865	365	245	1475	491.67	328.84
Olde Furrow	128	509	206	843	281.00	201.27
Taproot	250	357	507	1114	371.33	129.10
TOTAL	1738	1506	1159	**4403**		
Mean	434.5	376.5	289.75			
SD	325.05	97.25	146.16			
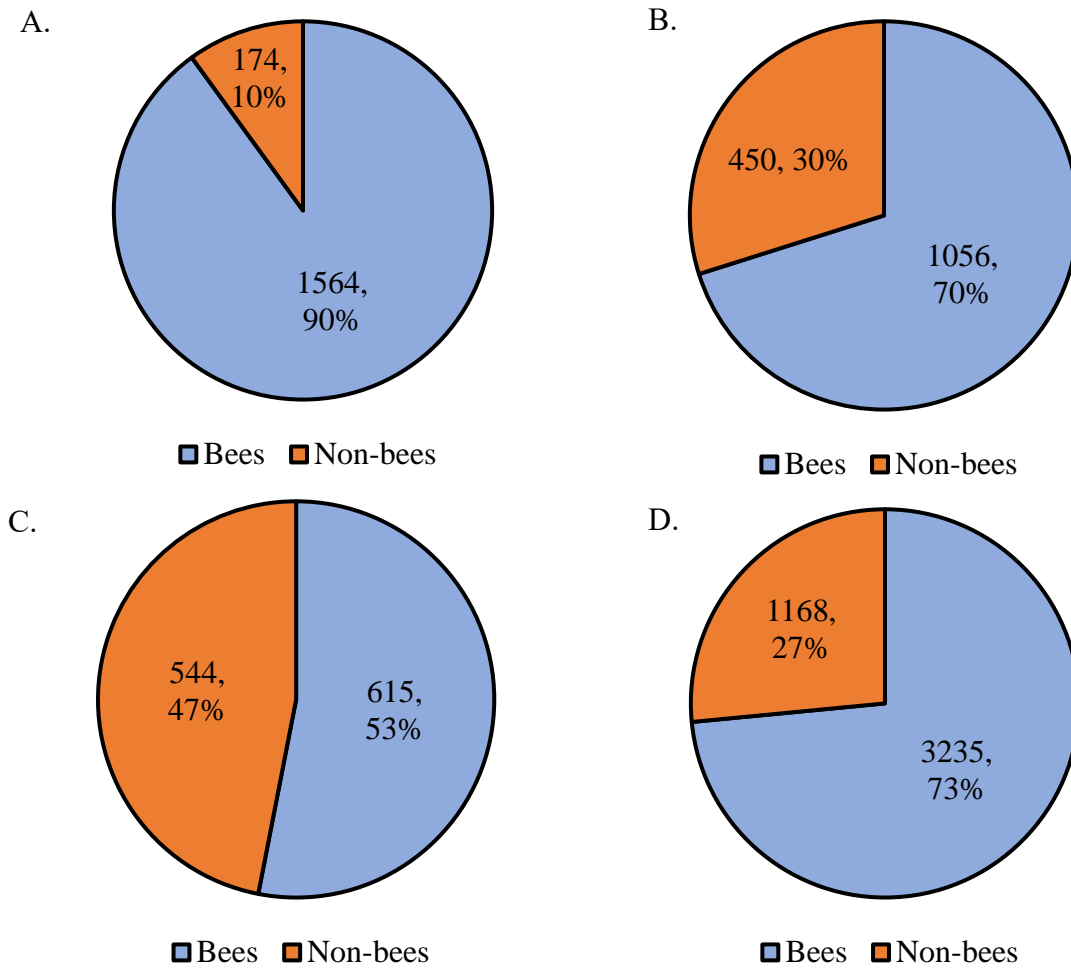
Figure 2.2. Proportion of pollinators identified as either bees or other groups of pollinators in each crop surveyed. From the top, left to right: A. Apple, B. tomato, C. squash, and D. all crops studied combined.

3099 out of the 3235 bees caught were identified to the species level. The remainder were unidentifiable due to issues such as mould. The abundances and species richness across different sites and crops are located in **Tables 2.3 and 2.4**. A total of 157 bee species were collected across all sites throughout the course of this study. A complete list of the abundances of all bee species identified, alongside their nesting biology, can be found in **Appendix B**.

The numbers of pollinators decreased later into the growing season, with the earliest-flowering crop, apple, having the most pollinators caught, and squash, the latest-flowering crop, having the fewest (**Table 2.3**). A notable exception to this trend was observed at Olde Furrow Farm, where I can see the fewest catches at this site was in apple (**Table 2.3**). Olde Furrow Farm also saw the highest number of bee catches in tomato of any farm. Taproot Farm was also an exception to this trend, with the lowest numbers of pollinators being found in apple, though it was not as dramatic of a difference as observed at Olde Furrow Farm. Overall, at Taproot Farm, the numbers of pollinators seemed to remain relatively steady throughout the growing season, as can be seen in the much smaller variance in number of catches as compared to the other farms (**Table 2.3**).

Oakview Farm saw the highest numbers of bees throughout this study, though most of those bees were caught in apple. The numbers caught in tomato and squash at this site dropped off dramatically in comparison, with Oakview even seeing the lowest numbers of bees caught at any site in tomato. Olde Furrow Farm saw the lowest numbers of bees caught at any site, as well as having the lowest numbers of bees caught in apple, thought this site did see the highest number of bees being caught in their tomato crop. The highest numbers of bees caught in squash was at Taproot Farm, with the lowest being at Abundant Acres.

The highest number of unique bee species found at a site was at Oakview Farm, with the highest number being found in a single crop also in the apple crop at this site (**Table 2.4**). This site also saw the highest number of bee species found in squash. The fewest species overall were found at Olde Furrow Farm, although this site did see the highest number of bee species caught in the tomato crop. The tomato crop did exhibit the lowest variance between the three crops in

this study, indicating little difference in the mean number of bees found at each site during the flowering of this crop.

Much like what was observed with pollinator abundances, the total numbers of pollinator species declined over the course of the growing season, with apple seeing the most species, squash the least, and tomato as an intermediate. This high number of species observed early in the growing season may be attributed to bees from the genus *Andrena* and parasitic *Nomada* being observed in high numbers during this this time (**Appendix B**). No other genera caught in this study experienced such a dramatic difference in the number of catches between different crops as *Andrena*.

Table 2.3. Total abundances of identified bees caught in each crop and at each study site (n = 3 crops, n = 4 farms. SD = standard deviation.

	Bee Abundances					
	Crop					
Farm	**Apple**	**Tomato**	**Squash**	**TOTAL**	**Mean**	**SD**
Abundant Acres	414	194	79	687	229.00	170.22
Oakview	763	148	126	1037	345.67	361.59
Olde Furrow	94	409	120	623	207.67	174.84
Taproot	216	267	269	752	250.67	30.04
TOTAL	1487	1018	594	**3099**		
Mean	371.75	254.50	148.50			
SD	292.27	114.06	83.00			

Table 2.4. Total species richness of bees in each crop and in each site (n = 3 crops, n = 4 farms). SD = standard deviation.

| | **Species Richness** | | | | | |
| | **Crop** | | | | | |
Farm	**Apple**	**Tomato**	**Squash**	**TOTAL**	**Mean**	**SD**
Abundant Acres	56	34	14	76	34.67	21.01
Oakview	86	40	36	113	54	27.78
Olde Furrow	29	45	20	69	31.33	12.66
Taproot	48	36	24	74	36	12
TOTAL	108	85	56	**157**		
Mean	54.75	38.75	23.50			
SD	23.71	4.86	9.29			

Looking at nesting biology, the European honey bee (*Apis mellifera*) was the only hive nester in this study and made up a notable minority of the bees caught in apple and squash, accounting for ~14% and ~33% of total catches, respectively (**Figure 2.3**). Honey bees did visit the tomato as a much smaller proportion of the community (~5% of total catches) than in the other two crops. The honey bee was the top pollinator of both apple and squash, and it was still among the most common pollinators of tomato (**Table 2.5**). Overall, the honey bee made up approximately 15% of all bee catches in this study. However, given my goal of studying wild bees, further analysis of nesting biology is focused on these wild species.

The majority of wild bees caught (even when honey bees are taken into account) were ground-nesting bees (Figure 3.3). These were the most abundant type of pollinator in all crops, accounting for ~75% of wild bees in apple, ~94% in tomato, and ~93% in squash (**Figure 2.4**). Ground nesters include most of the Families Halictidae, the so-called 'sweat bees,' and Andrenidae, as well as the genus *Bombus*, alongside others. Cavity nesters were found in very small numbers in the tomato and squash crops (approximately 3% of wild bees in each of these

crops), but made up a larger proportion of catches in apple compared to the other two crops, accounting for approximately 19% of wild bees caught in apple (**Figure 2.4**). Cavity nesters included many *Ceratina* species that were found in much higher numbers in apple than in any other crop (**Appendix B**). Parasitic species, like those belonging to the genera *Sphecodes* and *Nomada*, and the *Bombus* species *B. ashtoni* and *B. citrinus*, as noted in **Appendix B**, made up a small amount of the catches in all crops. Approximately 6% of catches in apple were parasitic bees, ~3% in tomato, and ~4% in squash.
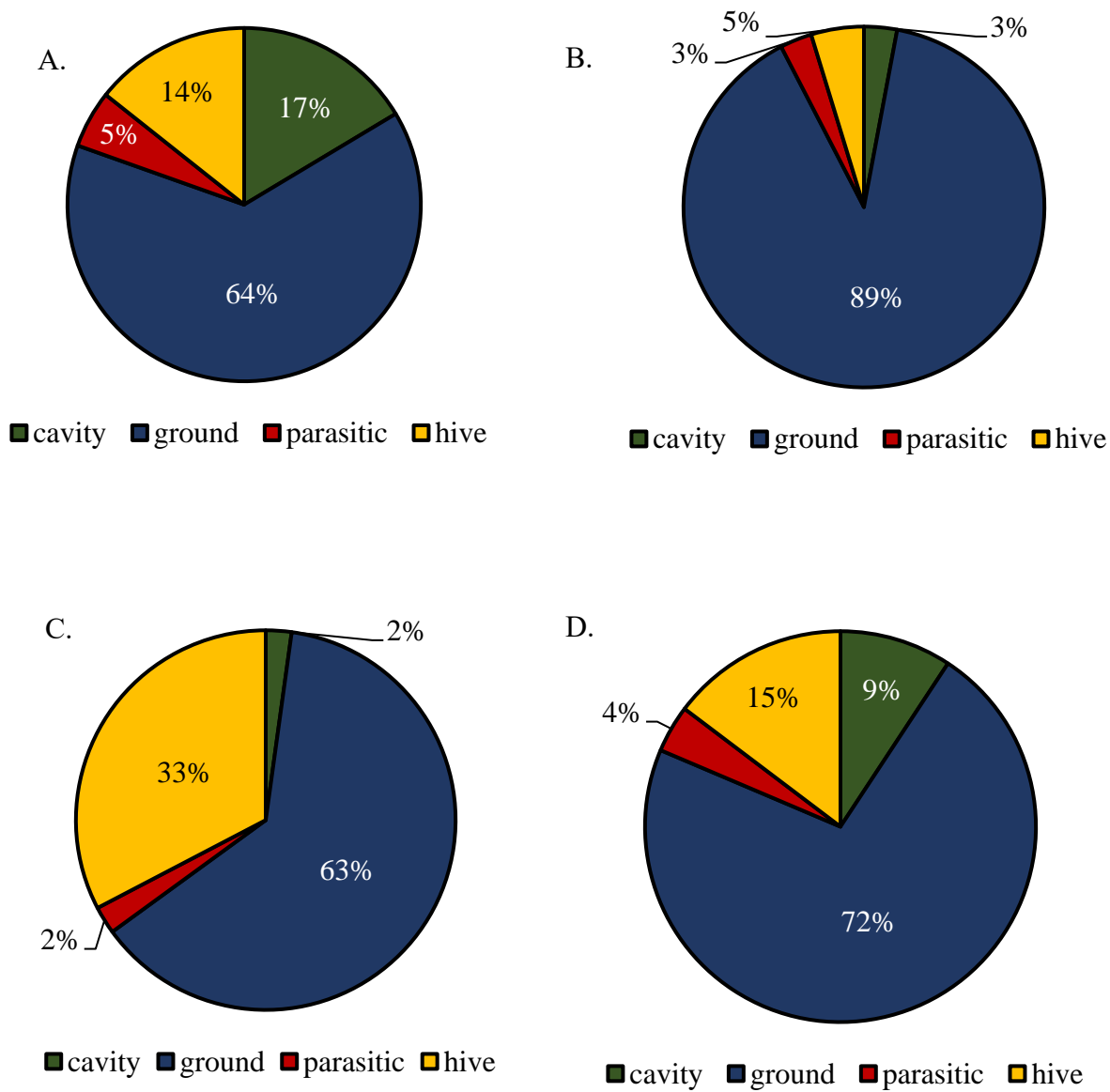
Figure 2.3. Nesting biology of bees caught as a proportion of total bees caught for each crop, as well as the study as a whole. These figures includes Apis mellifera catches, shown here as the only hive-nesting species. From the top, left to right: A. Apple (n = 1487), B. tomato (n = 1018), C. squash (n = 594), and D. all crops studied combined (n = 3099).
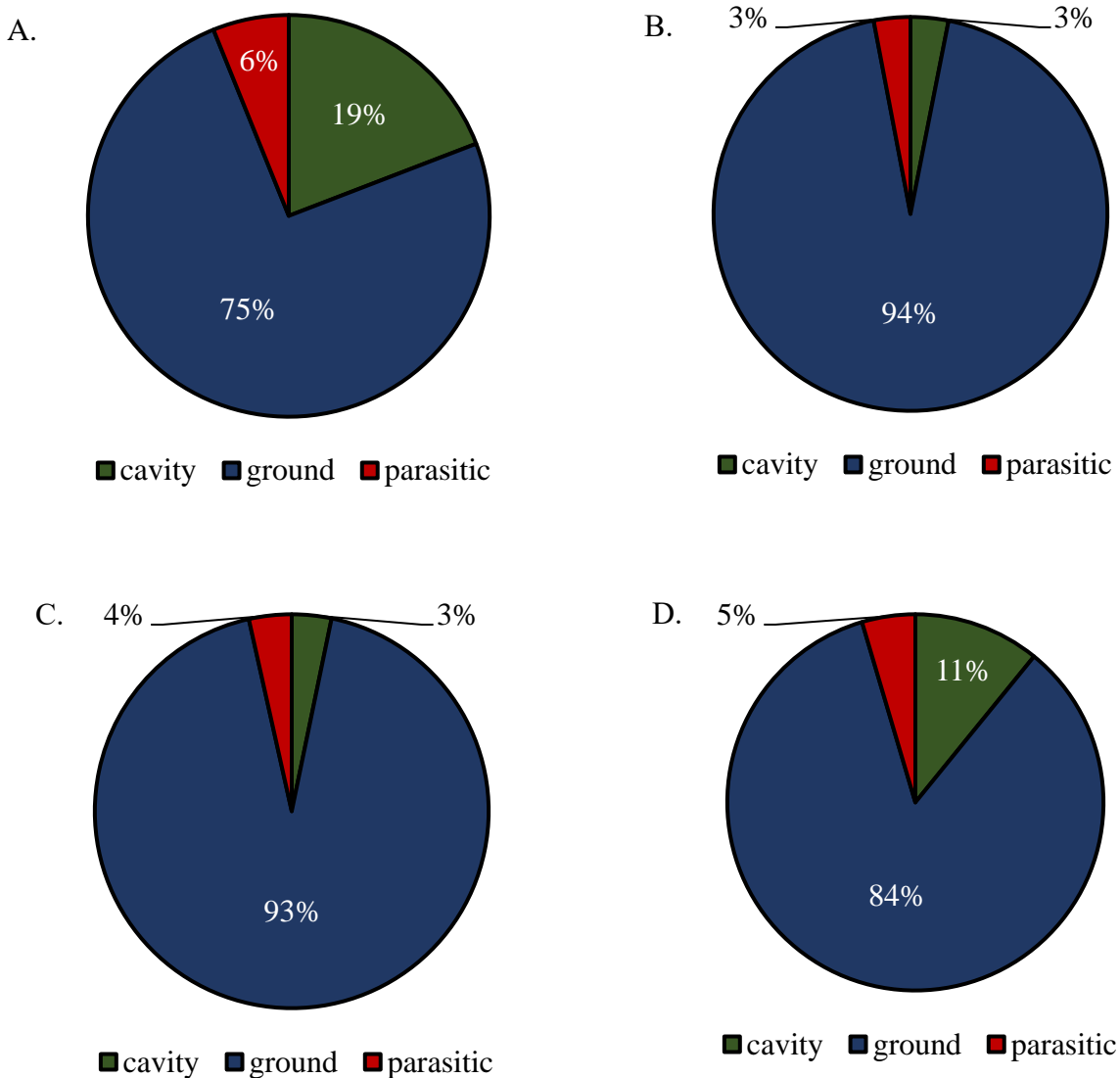
Figure 2.4. Nesting biology of wild bees (Apis mellifera excluded) as a proportion of total wild bees caught for each crop, as well as the study as a whole. From the top, left to right: A. Apple (n = 1274), B. tomato (n = 967), C. squash (n = 400), and D. all crops studied combined (n = 2641).

The family Halictidae were often the most common bee species found in this study (**Table 2.5**), with the only native bees amongst the top pollinators of a crop not from this family being *Ceratina mikmaqi* and *C. calcarata* in apple, and *Bombus impatiens* in squash. All of the most common pollinators of tomato were Halictids. *Lasioglossum* species were amongst the

most common pollinators for every crop looked at in this study. In tomato, *Agapostemon virescens* and two *Lasioglossum* species were notable in being even more common pollinators than *Apis mellifera*.

When looking at individual species and genera found by Roulston (2021), most that were found across both studies were found both on dykes and in salt marsh (**Table 2.6** and **Appendix B**). All of the top species (**Tables 2.5** and **2.6**) were found across both studies. Two native species in each habitat were found to be amongst the most common species both in this study and by Roulston (2021), as can be seen in **Table 2.6**. *Lasioglossum zonulum*, a top pollinator of both squash and tomato, was one of the most common species in salt marshes (**Tables 2.5** and **2.6**). *Halictus ligatus*, found commonly in both salt marsh and dyke habitats, was a top pollinator of apple (**Tables 2.5** and **2.6**). *Melissodes druriellis* was found commonly in both habitats by Roulston (2021) but was not found often on farms (**Table 2.6**).

Most of the cavity-nesting species were much more abundant amongst apple than tomato or squash. This trend is apparent when looking at *Ceratina* and *Osmia* species. However, some cavity-nesting genera were more common in other crops, though these were typically genera in which much lower numbers overall were found. These genera included *Hylaeus* and *Megachile* bees. Ground-nesting *Andrena* were also found in extremely high abundance in apple, with numbers dropping off in the other crops. These *Andrena* provided a lot of the species diversity found in apple that were not present in tomato and squash. With the *Andrena* came high numbers of parasitic *Nomada* as well, which were not present in as high abundance in the other crops. Among other ground-nesting bees, some *Lasioglossum* species like *L. pilosum*, *L. sagax*, and *L. versans*, and fellow Halictid *Halictus ligatus* were also much more abundant in apple than in other crops (**Appendix B**).

In tomato, the most notable species showing much higher numbers than in other crops was the ground-nesting *Agapostemon virescens*. This crop also showed notably lower numbers of *Apis mellifera* compared to squash and apple. *Lasioglossum* species found in much higher abundance in tomato than other crops included *L. cressonii* and *L. leucozonium*. Tomato was also the only crop in which *Perdita* bees were caught during this study, and all but 2 *Calliopsis* observations were within this crop too. *Hylaeus* bees were found in higher numbers in tomato, with none found in apple despite being a cavity nester, though some were found in squash too (**Appendix B**).

Very few common bee species were found in higher abundances in squash compared to apple and tomato. These species would be the bumble bee *Bombus impatiens* and sweat bee *Lasioglossum zonulum*, both ground nesters, though the latter did have a high number of catches in tomato too. *Lasioglossum leucozonium* was also found in high numbers here as well, even higher than *L. zonulum*, just not as high as the numbers found in tomato. Squash was, however, the only crop in which *Melissodes* bees were caught, of which two species were observed (**Appendix B**).

Table 2.5. The five most common bee species caught in each crop, ranked in descending order from more common to less common. The European honey bee, Apis mellifera, was among the five most common catches in each crop, but is highlighted as it is non-native and domesticated, and thus will be excluded from discussion in this part of the study, with the 6th most common wild bee species being included instead.

	Highest Number of Catches (Descending Order)		
Rank	**Apple**	**Tomato**	**Squash**
1	*Apis mellifera*	*Agapostemon virescens*	*Apis mellifera*
2	*Ceratina mikmaqi*	*Lasioglossum cressonii*	*Bombus impatiens*
3	*Lasioglossum versans*	*Lasioglossum leucozonium*	*Lasioglossum leucozonium*
4	*Ceratina calcarata*	*Apis mellifera*	*Lasioglossum zonulum*
5	*Halictus ligatus*	*Lasioglossum zonulum*	*Lasioglossum pilosum*
6	*Lasioglossum pilosum*	*Lasioglossum versans*	*Halictus confusus*

Table 2.6. The most common bee species found in both habitats surveyed by Roulston (2021), with coloration to compare with this study, represented by the rightmost column. Names highlighted in green indicate those which were amongst the top species found in both studies. Yellow indicates Apis mellifera, the non-native European honey bee.

	Highest Number of Catches (Descending Order)		
Rank	**Dyke**	**Salt Marsh**	**On Farms**
1	*Lasioglossum leucozonium*	*Halictus ligatus*	*Apis mellifera*
2	*Agapostemon virescens*	*Agapostemon virescens*	*Agapostemon virescens*
3	*Melissodes druriellis*	*Melissodes druriellis*	*Lasioglossum leucozonium*
4	*Halictus ligatus*	*Lasioglossum zonulum*	*Lassioglossum cressonii*
5	*Augochlorella aurata*	*Lasioglossum leucozonium*	*Lasioglossum versans*

Rank-abundance plots of numbers of pollinator species by site are presented in **Figure 2.5** below. All sites displayed similar slopes, which is indicative of similar pollinator communities. Tail lengths were similar for all sites, indicating no under- or overabundance of 'rare' species at any one site. The only site with only noticeable difference from the others was Oakview Farm, and this difference is due to the higher number of species found at this site relative to other sites. The slope of the plot still follows a similar pattern to what I can see at the other sites, and the tail is around the same length relative to the number of observations. Given that no sites exhibit any dramatic differences, further statistical analysis on pooled data across both sites and crops could be conducted.
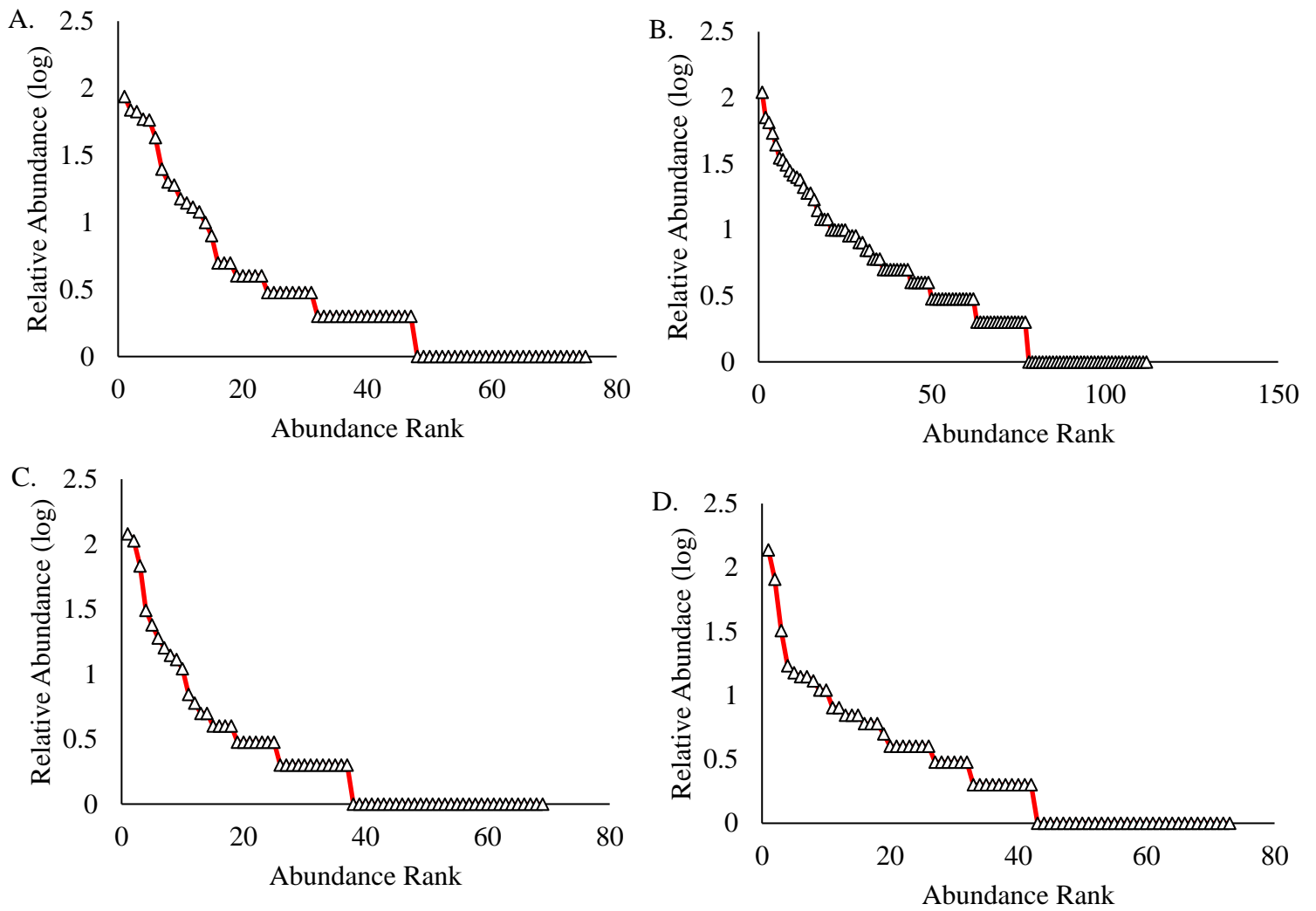
Figure 2.5. Rank-Abundance plots of pollinator species for each of the study sites, calculated using the log of their actual abundances. From the top, left to right: A. Abundant Acres Farm, B. Oakview Farm, C. Olde Furrow Farm, and D. Taproots Farm.

NMDS plots were produced using 3 dimensions to visualize differences in community composition between sites and crops, giving a stress value of 0.1301725, indicative of a relatively fair ordination fit. Here, the positions of the points for different sites are all intertwined amongst each other, and no notable differences can be observed between sites, indicating that the pollinator community composition is quite similar at each of the sites (**Figures 2.6A** and **2.6B**).

This can also be seen in **Figures 2.7A** and **2.7B**, with the names of the top pollinators overlaid to show which species commonly occurred in the presence of or without other top species. On all 3 axes, the only pollinator species that deviates far from the cluster near the middle of both plots is *Ceratina mikmaqi*, though some other species deviate in one plot only, for example *Bombus impatiens* (**Figure 2.7A**).

Much like in the site ordination, the points for crop observations are quite intertwined as well (**Figures 2.8** and **2.9**). However, differences between the crops are more apparent than between sites, indicating that crop species, or perhaps time of year, may be a stronger determinant of pollinator communities in this region (**Figure 2.8**). While the species names overlaid are in the same positions as in **Figures 2.6** and **2.7**, and so most are clustered again near the middle of the plot, the relationships between the top bee species and the crops are more apparent due to the previously noted differences between crops in the ordination. In **Figures 2.8** and **2.9**, I can see that the location of all 3 *Andrena* species, as well as *C. mikmaqi*, is associated with the apple plots, matching what was noted above about these species' presence within this crop. *B. impatiens* matches the locations of the squash plots that were located towards the bottom of the plot in **Figure 2.9A**, separate from the rest of the squash plots, indicating a different species profile from the rest of the squash plots, likely driven by the presence of *B. impatiens*. I can also see that *Agapostemon virescens* is more closely associated with tomato plots, most clearly visible in **Figure 2.9B**, matching my results noted in **Table 2.5** above.

Table 2.7. Abbreviations and the bee species they correspond to, used for NMDS plotting. Only species with greater than 30 individuals caught during the whole study are included (n=21).

Abbreviation	Full species name
A.br	*Andrena bradleyi*
A.cr	*Andrena cressonii*
A.du	*Andrena dunningi*
A.vi	*Agapostemon virescens*
A.me	*Apis mellifera*
B.im	*Bombus impatiens*
C.ca	*Ceratina calcarata*
C.mi	*Ceratina mikmaqi*
H.co	*Halictus confusus*
H.li	*Halictus ligatus*
H.ru	*Halictus rubicundus*
L.cr	*Lasioglossum cressonii*
L.la	*Lasioglossum laevissimum*
L.lc	*Lasioglossum leucocomum*
L.lz	*Lasioglossum leucozonium*
L.pe	*Lasioglossum perpunctatum*
L.pi	*Lasioglossum pilosum*
L.sa	*Lasioglossum sagax*
L.ve	*Lasioglossum versans*
L.zo	*Lasioglossum zonulum*
L.ze	*Lasioglossum zephyrum*

A.

B.

Figure 2.6. A (left) and **B** (right). NMDS ordination showing similarities and differences in pollinator community composition between sites sampled in the Bay of Fundy dykelands in the summer of 2021.

A.

B.

Figure 2.7 A (left) and **B** (right). NMDS ordination showing similarities and differences in pollinator community composition between sites sampled in the Bay of Fundy dykelands in the summer of 2021, with abbreviations for species that had abundances greater than 30 (n=21 species) over the course of the whole study overlaid and their coordinates multiplied by a factor of 2, for readability purposes. The species which correspond to the abbreviations presented here can be found in **Table 2.7**

Figure 2.8. A (left) and **B** (right). NMDS ordination showing similarities and differences in pollinator community composition between the different crops sampled in the Bay of Fundy dykelands in the summer of 2021.
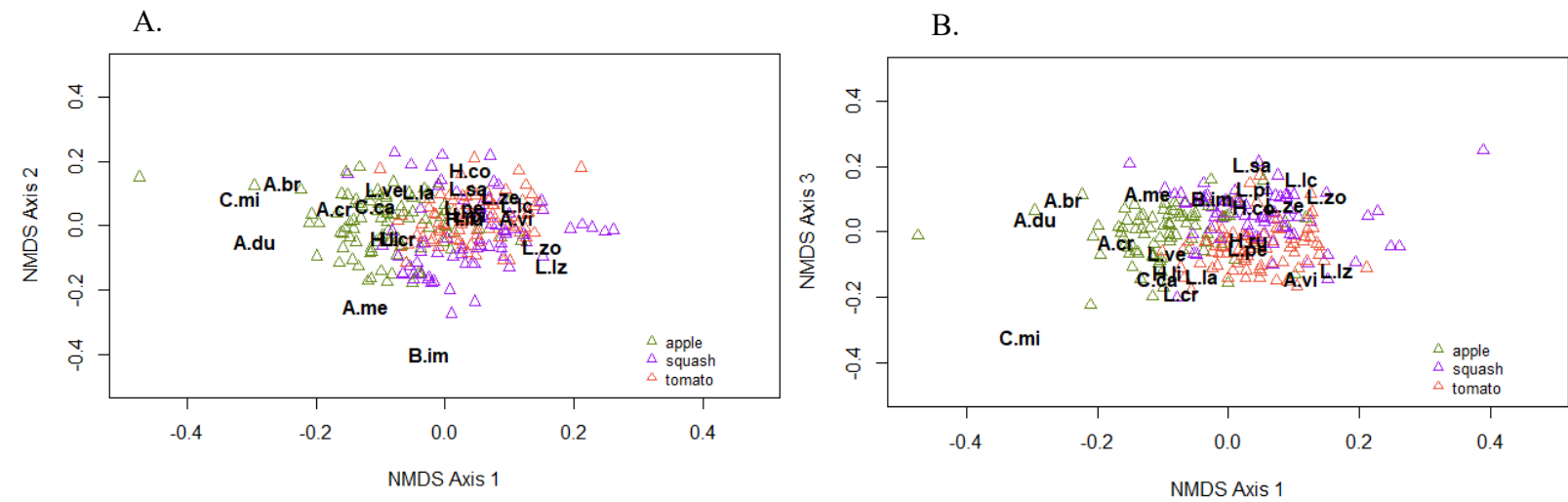
Figure 2.9. A (left) and **B** (right). NMDS ordination showing similarities and differences in pollinator community composition between different crops sampled in the Bay of Fundy dykelands in the summer of 2021, with abbreviations for species that had abundances greater than 30 (n=21 species) over the course of the whole study overlaid and their coordinates changed by a factor of 2, for readability purposes. The species which correspond to the abbreviations presented here can be found in **Table 2.7.**

Rarefaction performed on the pollinator data was used to create rarefaction curves first for all sites in the study (**Figure 2.10**), indicating the total number of species to be discovered in this environment is plateauing. However, the slope is still positive indicating that further sampling effort could reveal some new species within the Bay of Fundy dykelands environment. **Figure 2.11** shows individual rarefaction curves for each site from the study. The slopes of the curves generated all follow the same general pattern, indicating sufficient similarity between sites. The curves for three of the sites in particular are in fact all almost the same, with the only exception being Oakview Farm. The curve from this site still follows the same general pattern, however, indicating sufficient sampling effort, with the reason it is higher than the others being due to higher numbers of species and total catches at this site.
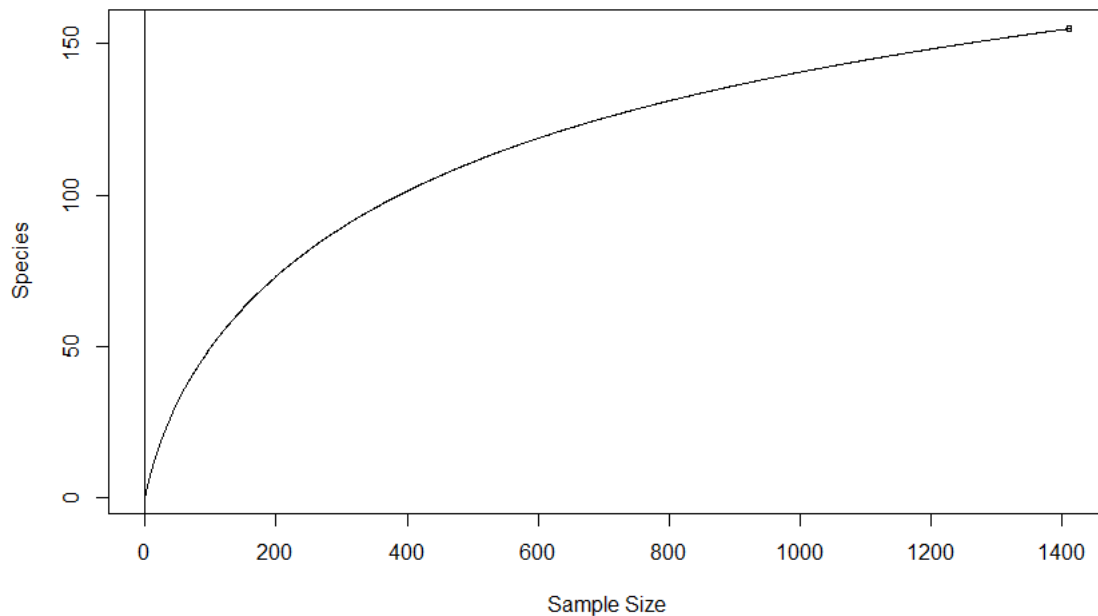
Figure 2.10. Rarefaction curve generated for the entire study, with all sites combined.
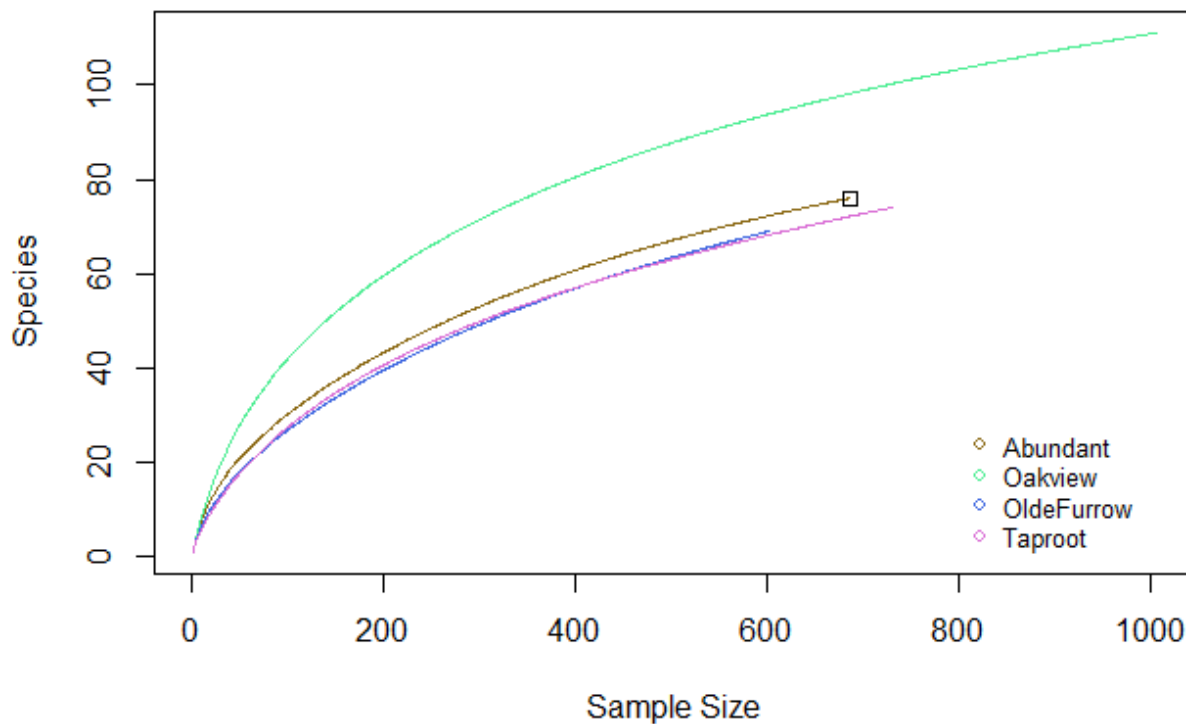
Figure 2.11. Rarefaction curves generated for each individual site in the study.

2.4 DISCUSSION

a. Overview of Results from Pollinator Survey

My results indicate that wild pollinators are both abundant and diverse within crops grown in the

Bay of Fundy dykelands landscape. Ground-nesters were the most common visitor in all crops,

both in terms of diversity and overall abundance. This result aligns with expectations, given that

most Nova Scotian bee species are ground nesters, and previous studies which have shown the

domination of ground-nesters in agroecosystems (Sheffield et al., 2003; Ahrenfeldt et al., 2019;

Rondeau et al., 2022). Many of these ground-nesters were from the Halictid genera of *Halictus*

and *Lasioglossum*, with species from *Lasioglossum* being top pollinators of all crops surveyed in this study. Given that these genera are among the most common bees in Canada, this is an expected result (Packer et al., 2007). Parasitic bees from the genus *Sphecodes* were another Halictid genus found throughout the entirety of the growing season, though in relatively small numbers in all crops. When looking at individual crops, some differences in the abundances of certain Halictid species can be noted, with *Lasioglossum sagax*, *L. versans*, and *Halictus ligatus* found more commonly amongst apple, *Agapostemon virescens*, *L. cressonii*, and *L. leucozonium* more common amongst tomato, and *L. zonulum* was more common amongst squash. Together, this data suggest that bee communities change greatly over the course of a single growing season in Nova Scotia.

The mining bee genus *Andrena* was well-represented within the apple crop, both in terms of number of species and abundance, aligning with past research that had found bees of this genus to be an important native pollinator in apple orchards (Park et al., 2016; Nooten et al., 2020). There were high numbers of *Nomada* in the apple in comparison to other crops; *Nomada* bees are a known nest parasite of *Andrena* bees (Packer et al., 2007). *Andrena* numbers dropped off quite heavily in the tomato and squash crops that flowered later in the season. As *Andrena* species are often amongst the earliest bees to emerge in the spring, with their flight period taking place early in the growing season, my data matches findings in other North American locations (Stephen, 1966; Johnson, 1981; Neff and Simpson, 1997). I can predict from this that *Andrena* is likely an important pollinator of other crops grown in the region that flower early into the growing season.

Apple was the crop which showed the highest abundances of cavity-nesting bees, as predicted based on past studies from the region (Sheffield et al., 2008). I expected to see a higher

proportion of cavity-nesting bees in apple given these past findings, but found just shy of one-fifth of the bees were cavity nesters during my survey. Many of these cavity-nesters in apple were from the genus *Ceratina*, with the highest numbers of *Osmia* also being found in apple. Two out of the five most common species in apple were *Ceratina* species, including the most common wild species. With past studies confirming their importance to the other major fruit crop in Nova Scotia, blueberries, it is likely that this genus is quite important to the Nova Scotia fruit farming industry as a whole, and conservation of *Ceratina* in provincial agroecosystems should thus be a priority (Nooten et al., 2020).

In tomato, the first observations from the genus *Hylaeus* occurred, the only cavity-nesting genus not found in apple. This genus was noted by Packer et al. (2007) to be found more commonly in the summer, hence why it appeared in tomato and squash, and not the early-flowering apple. Other bee genera first found in tomatoes include *Calliopsis* and *Perdita* of the family Andrenidae, the latter of which was found exclusively in this crop. Interestingly, *Perdita octomaculata*, the only species of the genus found in Nova Scotia, has been noted in previous research from northeastern North America to be a late-flying species, with the flight period typically being from August to October (Eickwort, 1977). Given my tomato survey occurred in July, this could be an indication that climate change has altered the phenology of this species since Eickwort (1997), as has been found in other bee species, though this would represent an advancement much greater than has been recorded in previous studies (Bartomeus et al., 2011; Pawlikowski et al., 2020).

Perhaps the most unexpected result in tomatoes was the lack of bumble bees (Genus *Bombus*). Given previous studies have shown the importance of buzz pollination to tomato plants, which can only be performed by bumble bees, I expected them to be among the most

numerous pollinators of tomatoes (Franceschinelli et al., 2013). It should be noted that there were anecdotal observations by the author of large numbers of bumble bees visiting tomato flowers after the surveying period had ended within this crop. Since tomato plants have a longer flowering period than the other crops in this study, it is possible that the time I chose to observe the tomato plants (late June-early July), when their flowering had just begun, was simply too early in the season for bumble bee visitation. *Bombus* queens are known to emerge and forage early in the growing season in northeastern North America, however, there seems to be a lack of published research on the flight phenology of bumble bee workers (Lanterman et al., 2019). It has been suggested that the flight phenology of bumble bee species could be changing due to climate change, though this would mean it is getting earlier in the season as temperatures increase, which fails to explain my results (Pawlikowski et al., 2020).

My results from squash show that it contained the highest proportion of non-bee pollinators relative to the other crops from this study. Non-bee pollinators are capable of being important pollinators of some crop species, and this may be the case with squash grown in Nova Scotia (Rader et al., 2020). In terms of bee pollinators, squash was the only crop in which a bumble bee, *Bombus impatiens*, was a top pollinator. It should be noted that *B. impatiens* may not actually be truly native to Nova Scotia, and instead may have arrived in the province in an eastward migration from New Brunswick (Sheffield et al., 2003). The only other notable result in squash is the inclusion of the only records of the two *Melissodes* species found in this study.

Looking at comparisons with honey bees, in all crop species the number of wild bees outnumbered honey bees. They made up the highest proportion of bee species in squash, and the lowest in tomato. This result in tomatoes may be because honey bees are poorly adapted to tomato pollination, being incapable of the buzz pollination they require, and thus honey bees

may be unable to access food resources from tomato flowers (Rocha et al., 2023). Given the high numbers of wild bees in this study, even on farms where honey bee hives are directly brought in for pollination, or those which are adjacent to farms which use honey bees, it may be safe to say that wild bees may be more important pollinators of apple, tomato and squash in Nova Scotia, as in other locations (Mallinger and Gratton, 2015). Rented honey bee hives can inflate the numbers of honey bees perceived to be needed for crop pollination, driving up costs to farmers unnecessarily (Park et al., 2016; Pérez-Méndez et al., 2020).

b. Comparison to Previous Nova Scotia Pollinator Surveys

A previous survey done in apple orchards in the Annapolis Valley of Nova Scotia allows for a direct comparison to my results in the apple crop (Sheffield, 2006; Sheffield et al., 2013). A similar number of species was found in total in this study as was found in the Sheffield study, with 157 bee species being found in my study, compared to 146 in Sheffield et al. (2013). However, a more appropriate comparison may be between my results in apple with the orchard results of Sheffield et al. (2013), where I found 108 species, whereas the Sheffield study yielded 56 and 78 species in apple orchards surrounded by farmland and isolated from other farmland, respectively. Interestingly, my results found that on the farms with less commercialized apple production (Abundant Acres and Olde Furrow), I found fewer bee species, whereas Sheffield et al. (2013) found more bee species at the level of human management decreased. My site with the highest bee diversity, Oakview, was also surrounded by farmland, contradicting the findings of Sheffield et al. (2013), though the activity on the farm itself was comparable to these other two sites. This could indicate that it is a combination of both the environments around these farms

and the activities which occur directly on them that have the greatest impact on pollinator diversity amongst these crops.

A recent study done in the Bay of Fundy dykelands is Roulston (2021), who looked at pollinator abundances in salt marshes and on dykes in the region. Comparing my results with Roulston (2021) will help to determine similarities and differences between pollinator communities on farmland and in salt marsh and dykes, habitats that are commonly near farms in the Bay of Fundy dykelands landscape. Understanding how pollinators use the natural or man-made habitats around farmland is crucial in enacting positive pollinator management practices across agroecosystems (Gillespie et al., 2022). Compared to Roulston (2021), this study contained both more in total and a higher proportion of ground nesters and fewer cavity nesters, compared to both salt marsh and dyke habitats (**Appendix A**). The higher proportion of ground nesters in my study compared to salt marshes makes sense, given their regular inundation with tidal waters, however this is a surprising result when comparing to dykes, given the good nesting substrate and foraging habitat they can provide for these taxa due to their similarities to old field habitats identified by Sheffield et al. (2013) to be good pollinator habitat. In terms of proportions of taxa, the most similar between this study and Rouslton's (2021) was with parasitic bee taxa (**Appendix A**).

Most of the species that were found exclusively in one habitat were primarily those in the family Megachilidae, found mostly on dykes, but most of those species were not found on farmland (Roulston, 2021). Roulston's study unexpectedly contained more *Megachile* bees than this one in both habitats, given what was thought to be the better suitability of nesting habitat for this genus on farmland than in salt marshes (Sheffield et al., 2011). An expected result is a higher number of honey bees in my study than Roulston's (2021), due to many of the farms using

or being in close proximity to domestic honey bee hives. Honey bees were not amongst the most common catches by Roulston (2021) in either habitat (**Table 3.6**). *Lasioglossum* was the most common genus of bees in both studies, with slightly more being caught by Roulston (2021) on dykes. This seemed to be the trend with commonly found bee genera across both studies – slightly higher numbers in dyke compared to salt marsh, as can also be seen when comparing numbers of *Agapostemon*, *Augochlorella, Bombus*, *Calliopsis*, *Ceratina,* and *Perdita*. Most of these, except for *Ceratina*, are ground-nesting genera (Packer et al., 2007). The only exception to this trend was *Halictus*, a ground-nesting sweat bee genera found more commonly in salt marsh, with *Halictus ligatus* being amongst the most common catches in this habitat (**Table 3.6**). Very few *Andrena* were found by Roulston (2021), though this is likely because of the early flight period of *Andrena* observed within this study on farmland, prior to when Roulston's sampling took place (Stephen, 1966; Johnson, 1981; Neff and Simpson, 1997). Additional sampling earlier in the growing season on dyke and salt marsh would need to be done to get the full picture of pollinator diversity and abundances in these habitats.

Roulston (2021) noted no significant difference in pollinator communities on dykes and in salt marshes, so it is difficult to come to a definitive conclusion as to which habitat is better to have near farms. However, there did seem to be notably higher numbers of *Ceratina* and other cavity-nesters on dykes, so perhaps on farms growing apple and other early-flowering crops reliant on these bees for pollination, it may be more beneficial to have more dyke habitat nearby. This may also be beneficial in encouraging some ground-nesting species as well, as dykes can provide better nesting substrate for these species than salt marshes, evident by the slightly higher numbers of ground-nesting genera found on dykes noted above (Roulston, 2021). But an argument to the contrary can also be made, with restoring tidal wetlands possibly favored

because of the various other ecosystem services they can bring, evidently at the cost of little to no loss in bee numbers and diversity (Barbier et al., 2011; Rendón et al., 2019; Roulston, 2021). It does seem that when looking just at bees, dykes may edge out salt marshes as being better habitat for farmers to have nearby, but when looking at the bigger picture and including other ecosystem services, salt marsh habitats may instead end up being preferred. This highlights the need for the choice between salt marsh restoration or retaining the dykes to be done on a case-by-case basis, depending on what is best for the local stakeholders that will be most impacted by these decisions. Managed realignment could strike an effective balance between the stakeholder needs of both salt marsh and dyke habitat, as there is still an intact dyke, it has just been moved inland to allow for the development of salt marsh on the foreshore (Sherren et al., 2021). Certainly, more research needs to be done into how many of the bees were actually nesting versus simply foraging in these habitats, as well as directly within the crops, in order to resolve the inconclusiveness of this comparison.

c. Implications for Pollinator Conservation and Future Research

A diverse assemblages of wild bees occur in cropland in the Bay of Fundy dykeland region, and they are important pollinators of crop species. Assemblages of species within a pollinator community can change greatly over time, even in the same location. Conservation efforts to preserve these wild bee communities will ensure the ecosystem service they provide can continue to be supplied to the Nova Scotian agricultural sector. These efforts include the provisioning of appropriate foraging and nesting habitat, alongside other pollinator-friendly management practices.

In farmland, conservation efforts should be undertaken to preserve habitat for ground-nesting bee species. Flower strips and hedgerows are frequently used in wild pollinator conservation within agricultural lands, but they have been found to only provide foraging habitat, oftentimes failing to provide appropriate nesting habitat for ground nesters (Sardiñas et al., 2016). More intensely managed farmland has been found to result in smaller-sized *Agapostemon virescens*, which could have negative implications for overwintering survival (Nooten and Rehan, 2022). Soil tillage has been found to have negative consequences of ground-nesting wild bees that pollinate squash (Ullmann et al., 2016). Using less intense farming methods, such as reducing tillage where possible, is thus an effective way to conserve nesting habitat for ground-nesting bees.

Alongside ground-nesters, my study has shown the importance of some cavity-nesters like *Ceratina* to crops such as apples, so conservation of these species is also important. Nest boxes, also called trap nests and 'bee hotels,' could be a useful tool in incorporating citizen science with conservation of wild cavity-nesting bees (MacIvor, 2017). However, there is evidence that these may provide better nesting habitat for other insects besides cavity-nesting bees, and so further research is needed to determine appropriate nesting structures for cavity-nesting bees (MacIvor and Packer, 2015). Many of these insects found were non-bee pollinators, though, and so they may still have their use in agroecosystems (MacIvor and Packer, 2015).

One common, cheap, and effective method used by farmers and others to support pollinator populations is the planting of native wildflowers to provide foraging resources (Ganser et al., 2020; Kordbacheh et al., 2020). Floral strips can quickly increase the numbers of bees in agricultural areas (Killewald et al., 2023). In many cases in agroecosystems, there will be a lot of flowering resources for pollinators when crops flower, however gaps between crop flowering

periods can leave pollinators with limited food availability (Timberlake et al., 2019). Farmers should consider the flowering phenology of the crops they grow to determine gaps in floral resource availability to pollinators and try to plant wildflowers that will flower during these times of limited forage to address potential 'hunger gaps' that may occur when their crops are not flowering (Timberlake et al., 2019). Dykes, due to their similarity to old field habitats which may contain many flowering species that exhibit phenological differences from nearby natural and agricultural landscapes due to the presence of non-native wildflowers, could be a habitat which helps with addressing this issue by providing foraging habitat during times of floral scarcity (Reeb et al., 2020).

Though my study was successful in establishing a greater knowledge of the pollinator communities amongst crops in the Bay of Fundy dykelands, there is still much room for improvement and future studies. A full study covering the entirety of the tomato flowering period should be done, to account for numerous observations of bumble bee visitation after the survey on this crop had ended. A survey looking further into the non-bee pollinators of the crops in this study should be done to get a better idea of the entirety of the pollinator community present. This should especially be done in squash, given the higher abundances of non-bee pollinators found in this crop. Future studies may also choose to incorporate other habitats that may influence pollinator visitation to nearby farmland.

d. Conclusions

In conclusion, this study found diverse pollinator assemblages on farmland in the Bay of Fundy dykelands. Wild pollinators were found in higher numbers in all crops surveyed than introduced

honey bees, showcasing their importance to agriculture in the region. Ground-nesters were the dominant pollinators in all crop species, though some cavity-nesters, notably from the genus *Ceratina*, were found to be abundant in apple. Comparisons with a past survey done in apple by Sheffield et al. (2013) noted quite a few similarities, and comparisons with Roulston's (2021) surveys of salt-marsh and dykeland habitats showed there was a large amount of overlap in bee species found in this study that were observed in both salt marsh and dyke habitats, perhaps indicating that in terms of pollination services to crops, restoration of salt marsh habitat or maintaining dykes should be done on a case-by-case basis. Conservation efforts should be undertaken to encourage wild pollinator populations in agroecosystems both inside and outside of Nova Scotia, which will provide ecosystem service benefits to farmers for generations to come.

Chapter 3: Pollinator Importance to Apple and Tomato Crops Grown in Nova Scotia, Canada

3.1. INTRODUCTION

a. Pollination Services to Farming

Much of the agricultural sector is reliant on the ecosystem service of pollination, so pollinators are important to our food security (Klein et al., 2007; Requier et al., 2023). Approximately 87 of the 115 major crop species grown by humans reliant on pollinators to increase production to some degree, accounting for 35% of human food production by weight (Klein et al., 2007). Though by weight they do not make up the majority of our food production, this is made up for by their nutritional importance to humans. It is estimated that as much as 40% of the nutrients we need is reliant on pollinators, including the majority of nutrients such as Vitamins A and C (Eilers et al., 2011; Ellis et al., 2015). Agriculture in the developing world is also more pollinator-dependent, and so pollinators are important to food security and limiting habitat destruction caused by agriculture in these regions (Aizen et al., 2009). Even meat and dairy production is partially reliant on pollination services, as feed crops such as alfalfa or clover need to be pollinated by animals (National Research Council, 2007). Besides the direct nutritional benefits of consuming food dependent on pollinators, other health benefits of pollinators can include assisting in the pollination of medicinal plants, and mental health benefits associated with green spaces whose vegetation is maintained by pollinators (Garibaldi et al., 2022).

Pollination is an economically valuable ecosystem service, with many studies being performed in an effort to quantify the monetary value of pollination services (Gallai et al., 2009; Porto et al., 2020; Breeze et al., 2016). Estimates on the value of pollination to global agriculture

range from \$267-657 billion USD when adjusting for inflation in March of 2020 (Porto et al., 2020), with Gallai et al. (2009) estimating the value at ~\$210 billion USD, or approximately 9.5% of human food production value. As market value for many fruits are dependant on factors which are driven by pollinator visitation, pollinators are thus directly tied to profits for many farmers (Garratt et al, 2014). Pollinating insects have been shown to increase marketability and shelf life of produce (Klatt et al., 2014; Wietzke et al, 2018). Much of this value is also derived from wild bees, and not just the use of the domesticated honey bees commonplace in agricultural systems (Holzschuh et al., 2012).

Wild pollinators often provide better pollination of crop species than domesticated honey bees, despite the honey bee being the dominant pollinator of crops globally (Delaplane and Mayer, 2000; National Research Council, 2007; Franceschinelli et al., 2013). Profits among fruit farmers were found to be up to two times lower without pollination by wild bees (Pérez-Méndez et al, 2020). Diverse wild pollinator communities have been found to be more strongly associated with higher fruit set, whereas the presence or absence of honey bees had little to no effect (Garibaldi et al., 2013; Mallinger and Gratton, 2015). Wild bee populations should thus be supported by farmers, even if honey bees are to be used, as they can also provide a sort of safety net to ensure pollination in the face of honey bee die-offs from issues like Colony Collapse disorder (Winfree et al, 2007).

b. Pollination in Nova Scotia Agricultural Landscapes

Agriculture is an important sector of the Nova Scotian economy, accounting for approximately 1.8% of the provincial Gross Domestic Product (GDP) in 2008, a value of approximately $544.4 million (Devanney and Reinhardt, 2011). While this contribution to the province's economy may seem small, it brings many non-monetary benefits to rural areas of Nova Scotia. The agricultural industry is a 'cornerstone' industry, as the use of the land to harvest resources allows for other sectors of the economy to grow (Devanney and Reinhardt, 2011). Fruit farms are the most abundant type of farm in Nova Scotia, with Nova Scotia accounting for approximately 11% of fruit farms in Canada, playing a large role on the national scale despite the small size of the province (Devanney and Reinhardt, 2011). The two most important fruit crops grown in Nova Scotia, apples and blueberries, both rely on animal pollination for germination (Boulanger et al, 1967; Devanney and Reinhardt, 2011; Ramírez and Davenport, 2013). Production of apple primarily takes place around the Bay of Fundy, which is considered one of the agricultural centers of the province (Devanney and Reinhardt, 2011).

The domesticated honey bee is the single most important pollinator of apple cultivars, and so often beekeeper-reared stocks are used in apple orchards for pollination (Ramírez and Davenport, 2013), but they are not the most efficient apple pollinator (Delaplane and Mayer, 2000). Other bees and insects were still important pollinators of apples (Ramírez and Davenport, 2013). Besides honey bees, in Nova Scotia, there has been previous research into the rearing of *Osmia lignaria* for the pollination of apple orchards (Sheffield et al., 2008; Sheffield, 2014).

Many other pollinator-reliant crops are grown in Nova Scotia as well (Devanney and Reinhardt, 2011). One example is tomatoes, which are also better pollinated by native species of

bees than honey bees (Devanney and Reinhardt, 2011; Franceschinelli et al, 2013). Other crops reliant on pollinators grown in Nova Scotia include strawberries, cranberries, pears, pumpkins, and squash (Michelbacher et al, 1964; Kevan et al, 1983; Devanney and Reinhardt, 2011; Wietzke et al, 2018; Hünicken et al, 2020).

Nova Scotia has a thriving wine industry, centered in the Annapolis Valley, an example of a crop where, though not directly reliant on animal pollination, can still benefit from their services (Wine Growers of Nova Scotia, 2022). The use of cover crops, crops which are grown not to be directly harvested themselves but are instead planted alongside the actual target crop in order to increase soil health and fertility, is common practice in many vineyards (Tesic et al., 2007; Messiga et al, 2015). Many cover crops, such as soybeans, are dependant on pollination services (Wilson et al, 2018). This relationship with cover crops is also mutually beneficial, as the cover crops can provide an important food source for pollinators and thus brings conservation benefits to pollinators in a landscape that may otherwise be lacking in food resources (Wilson et al, 2018).

It is evident that pollination is important for many crops grown in Nova Scotia and Canada (Rondeau et al. 2022), but there are currently research gaps in pinpointing exactly how reliant some crops grown in the province are on pollinators, such as apple, tomato, and squash. There is also a geographical research gap, as much previous North American research into this subject comes from studies done in the United States, with a lack of Canadian studies (Rondeau et al., 2022). Filling in this research gap is important for effective implementation of pollinator conservation policy, targeting relevant guilds of bees in a region (Rondeau et al., 2022). Exclusion studies on apple and tomato have not yet been performed in Nova Scotia. This study intends to seal this research gap and determine the importance of pollinators to some of the crops

grown in Nova Scotia by directly quantifying the effects of pollinator exclusion on fruit set and weight.

c. Objectives

The objective of this study is to determine the importance of insect pollination to the successful growth of three agricultural crops in Nova Scotia: apple, tomato, and squash. This will be quantified by comparing the fruit set and weight of stems in which pollination is either permitted or disallowed. Based on past studies on various fruit species, I expected to see a greater yield, in terms of both fruit set and weight, amongst stems in which pollination is permitted (Holzschuh et al., 2012; Franceschinelli et al., 2013; Samnegård et al., 2019). I also expected to see some crops show a greater reliance on pollination, based on Klein et al. (2007), and this will be expressed as greater differences between the pollinator-excluded and permitted stems. In particular, I expected to see a large difference between the two treatments in apple, whereas the difference will be less pronounced in tomato and squash, as these have been shown by Klein et al. (2007) to be less reliant on insect pollination.

3.2. METHODS
a. Exclusion Set-Up

To determine the importance of insect pollination to the targeted crop species, a select number of flowering stems were excluded from pollination through the use of breathable fabric bags tied to a branch via drawstring (**Figure 3.1.**). From this point forward, the terminology of 'stems' and

'buds' will be used, and it is important to understand the distinction between the two. A 'stem' refers to the part of the branch beyond the flagging tape, and may include multiple buds or flowers. Stems were typically 5-10 cm in length, as this was the typical size range that the exclusion bags used could cover. A 'bud' is referring to only a single bud that will go on to flower along the stem. A visualization of the differences can be seen in **Figures 3.2** and **3.3**. Ten exclusion bags were placed on stems of each crop at each site just before the beginning of their flowering period. Ten stems of the same crop were also used as controls for this experiment. Stems were marked off using flagging tape, with different colours being used to differentiate between pollination-permitted and excluded stems. The use of bags for pollinator exclusion is a method that has been done in many past studies, including on crop species being analyzed in this study (e.g., Franceschinelli et al., 2013; Garratt et al., 2014 Samnegård et al., 2019).

Figure 3.1. An example of an exclusion bag in use on a flowering apple stem. A non-excluded stem is also present here, marked by orange flagging tape towards the top-right corner of the picture. Image from Terrell Roulston.

Figure 3.2. (left) and **3.3.** (right). These figures show the difference between a 'stem' and a 'bud' for discussion purposes during this experiment. A 'stem' is referring to the part of the plant circled in yellow in both images above, and can include multiple 'buds,' which refers to the part circled in red in both images. An apple tree is shown in **Figure 3.2**, and a tomato plant is shown in **Figure 3.3**.

Three pollinator-dependent crops were chosen for this experiment: apple, tomato, and squash. These crops were chosen due to being fully or partially reliant on animal pollination (Klein et al, 2007; Calderone, 2012) and the differing flowering periods of each, making logistics easier. Apple was the earliest-flowering crop, with flowering taking place from mid-May to early June. Squash was the latest-flowering crop, occurring from late July to late August. Tomato flowering began in late June, and though the stems I selected flowered until mid-July, other tomato stems did continue to flower late into the growing season. The number of flowers covered by exclusion bags was recorded, though it varied between crop species. For squash, only a single flower could be covered by the exclusion bags due to the size of the flowers, and typically only one flower grew on each stem. On tomato and apple plants, oftentimes multiple

flowers could be covered with a single bag, and so the number of flowers covered was recorded, and accordingly control stems marked off would include multiple flowers too. It should be noted that in squash, the majority of stems marked under both pollination conditions died off, perhaps due to the flagging tape used being tied too tight around them. Because of this, results for squash were excluded from presentation, as they were not representative of what was happening within the rest of the crop not included in this experiment.

The plants on which the exclusion bags were placed were monitored throughout the growing season to determine a good time to remove the bags. The bags were removed once flowering had ended, and some fruit growth had been observed. Exclusion bag removal prior to harvest was done so as to prevent the restriction of fruit growth within them, as the bags were typically too small to allow for the fruit to fully grow. This would prevent the size of the bags themselves from interfering in possible fruit growth. This was also done at a time after flowering ended to prevent any of the stems from getting pollinated, as this happening would negate the use of the exclusion bags.

b. Fruit Set and Weight Measurement

Following exclusion bag removal, the stems which had been marked continued to be monitored until closer to harvest time. Once harvest time neared and it appeared that the fruit were close to fully grown, fruit set and weight measurement commenced. Both measurements for a particular crop at a particular site were typically done on the same day. Fruit set was measured first, and was measured by a simple count of the number of successful fruits grown on the marked stems,

regardless of their size following the methods of Garratt et al (2014), followed by the weight recordings of the fruit for each stem.

Weight measurement was done for each stem after the fruit set had been determined. All fruit from a particular marked stem were picked at once. They were then all weighed together, using a scale which rounded to the nearest gram, to determine the total yield from that particular stem.

c. Statistical Analysis

Fruit set and weight data was analysed using a combination of Microsoft Excel and RStudio Integrated Development Environment for R statistical software (R Core Team, 2022; RStudio, 2022). The first analysis done was in Microsoft Excel, to determine the proportion of fruit compared to the initial number of buds, expressed as a percentage of the number of buds that would go on to bear fruit. This data was plotted for visualization purposes, with standard deviation was used to produce error bars. A chi-square test with Yates' correction (to account for the small sample size, n = 4) was performed to determine if there were any significant differences between treatments. This small sample size was due to data unintentionally being pooled at the site level during sampling, as opposed to having individual stems being kept track of. The formula used for showing the proportion of buds that bore was the same as was previously used by Walker et al (2021), and is presented again here:

$$\% Fruit = \left(\frac{N_{fruit}}{N_{buds}} \right) \times 100$$

Analysis of Variance (ANOVA) tests were performed on both weight and fruit set data to test for statistically significant differences between the two pollination conditions using R Studio and R software (R Core Team, 2022; RStudio, 2022). ANOVA was used for both weight and fruit set instead of an alternative test due to the small sample sizes present, again due to the unintentional pooling of data at the site level as opposed to the stem level. First, a variety of linear models were run with pollination condition as a manipulated variable, and some others with site and the interaction between the two as manipulated variables. In cases where a model was chosen that showed both site and treatment, but not their interaction, to have a significant effect, an additive model would be used. This was done as it allowed us to determine variation caused by both site and treatment in cases where the interaction did not have a significant effect on yield. Otherwise, the model selected would be multiplicative, to account for the significant effect of the interaction. Once the model with the best fit (higher adjusted r^2 value) was chosen, an ANOVA was performed. A Tukey pairwise comparison was then done.

3.3. RESULTS

In both apple and tomato, the stems in which pollination was permitted (from this point forward, will be referred to as 'pollinated' stems) saw a higher proportion of fruit production as opposed to those which were excluded from insect pollination (from this point forward, will be referred to as 'excluded' stems) (**Figures 3.4** and **3.5**). In apple (**Figure 3.4**), the total number of successful buds was significantly higher in those pollinated than in the excluded stems ($p = 5.78 \times 10^{-19}$). The pollination of excluded stems in apple was essentially zero, with only two stems successfully producing fruit, though they were severely stunted and already rotting when bags

were removed, preventing measurement of weight. Amongst the pollinated buds, approximately 20% would go on to successfully produce fruit. In tomato (**Figure 3.5**), the pollination success between 'excluded' and 'pollinated' groups was similar. Though the pollinated stems appeared to yield a higher figure than the excluded stems (**Figure 3.5**), this difference was not statistically significant ($p = 0.813193$). The excluded stems did grow a number of successful fruit, unlike in apple, with approximately 80% of buds yielding a tomato amongst the excluded stems. In the pollinated stems, around 100% of buds marked produced fruit, meaning the number of fruit was approximately equal to the number of buds initially marked, although in some cases, more than one fruit grew from a single flower, which explains why the standard deviation strays above 100%.
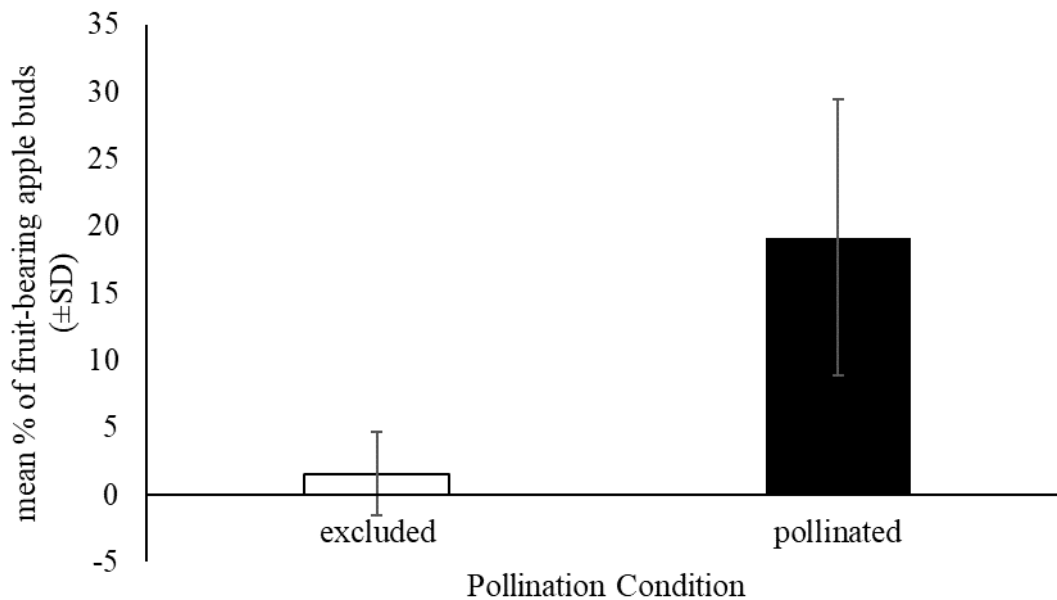
Figure 3.4. The percentage of the apple buds marked in each condition that successfully produced fruit, in all four sites combined. SD = Standard Deviation.
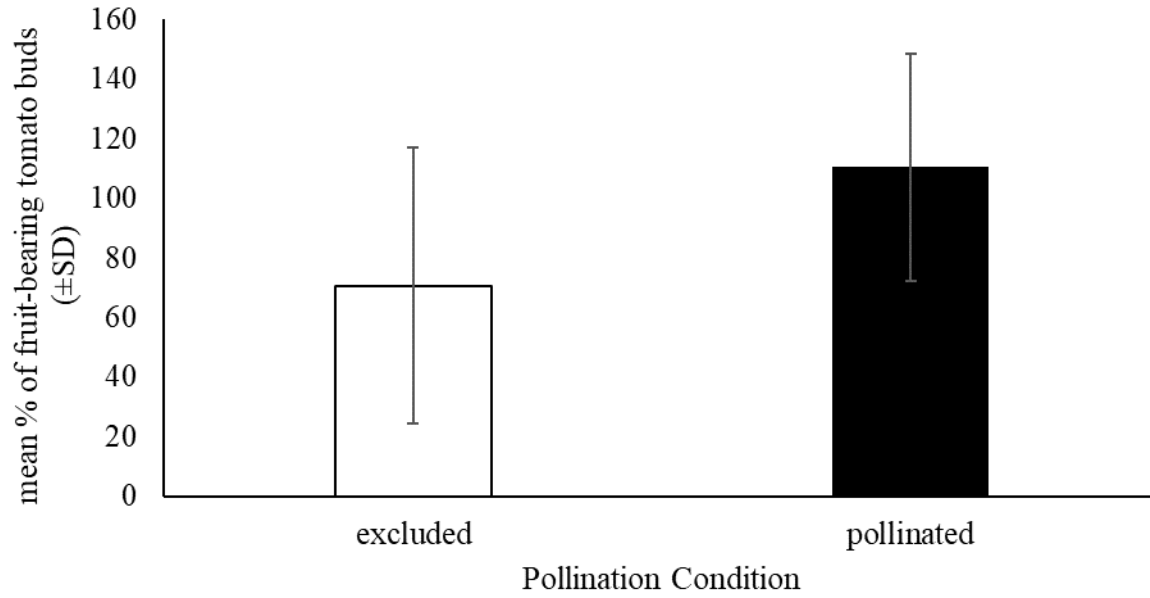
Figure 3.5. The percentage of the tomato buds marked in each condition that successfully produced fruit, in all four sites combined. SD = Standard Deviation.

In apple, there was a significant effect of the treatment (exclusion, pollination) on both weight (df = 1, F-value = 19.3534, Pr(>F) = 3.986×10^{-5}) and fruit set (df = 1, F-value = 21.4822, Pr(>F) = 1.638×10^{-5}), but no effect of site or interaction. The pollinated stems had a significantly higher weight and fruit set than the excluded stems (**Figures 3.6** and **3.7**). In both response variables, the value given for the excluded stems was zero, meaning there were no successful fruit when pollinators were excluded from the apple flowers.
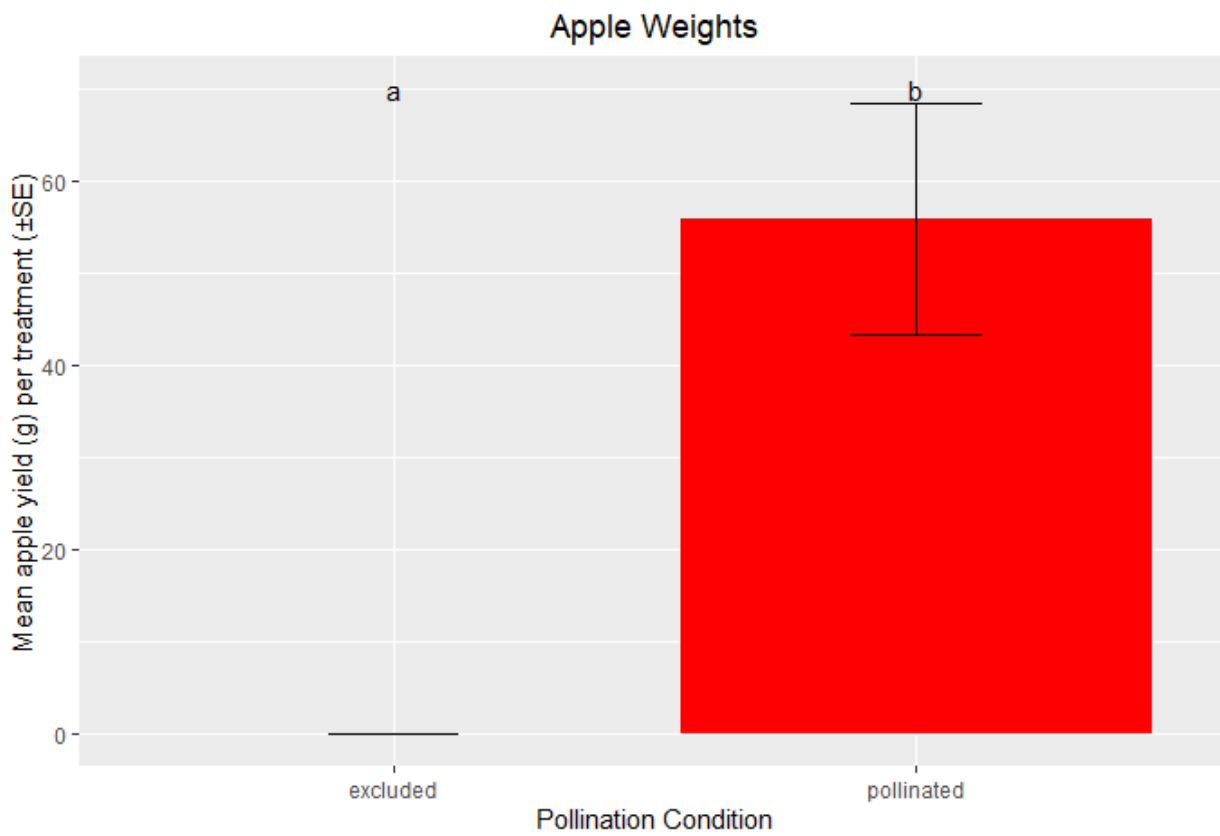
Figure 3.6. Mean weight yielded (in grams) in marked stems in each pollination condition in apple. Statistically significant differences are represented by different letters atop each treatment ($\alpha = 0.05$). SE = Standard Error.
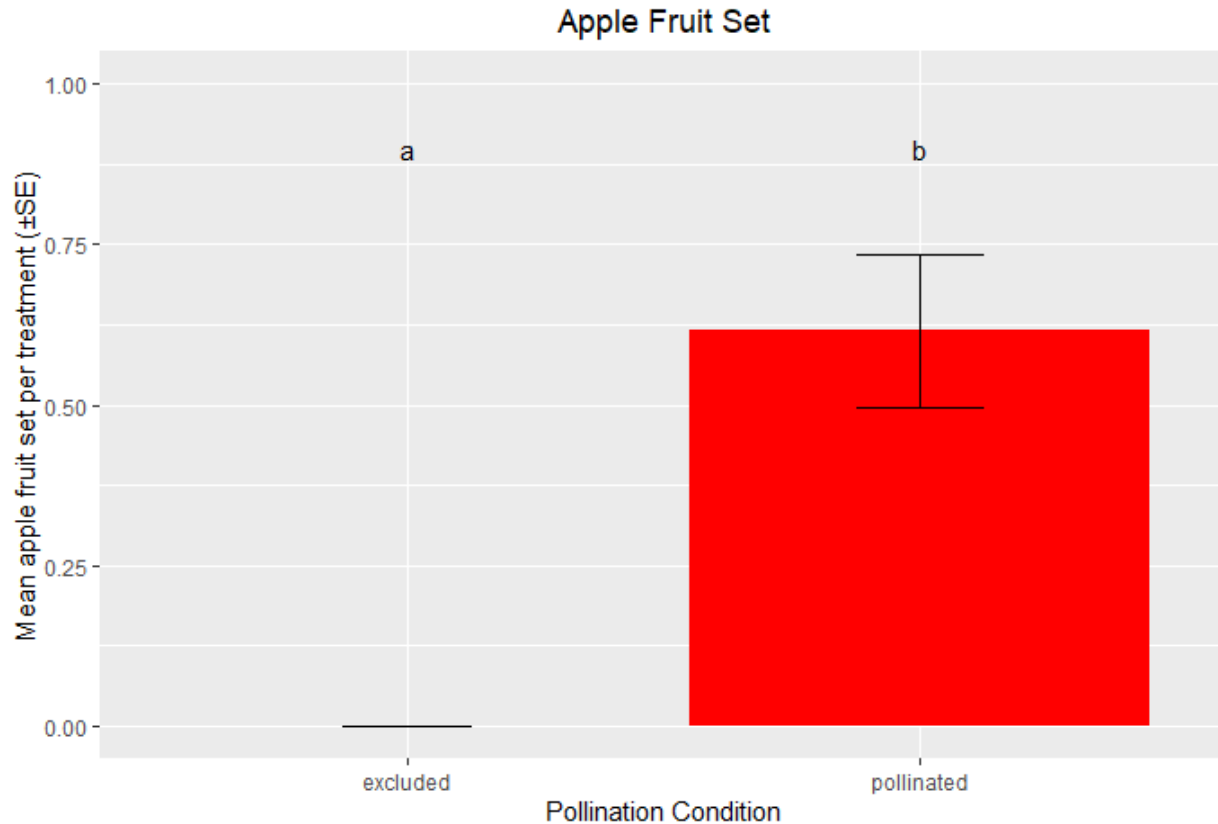
Figure 3.7. Mean fruit set of marked stems in each pollination condition in apple. Statistically significant differences are represented by different letters atop each treatment ($\alpha = 0.05$). SE = Standard Error.

In tomato, an additive model for ANOVA was used for both response variables, as there was no significant interaction between treatment and site for weight or fruit set. For weight, a significant effect of both treatment (df = 1, F-value = 6.9768, Pr(>F) = 0.01018) and site (df = 3, F-value = 14.3121, Pr(>F) = 2.28×10^{-7}) was found. Across all sites, the pollinated stems showed higher weight than in the excluded stems (**Figure 3.8**). The site with the closest weights between each treatment was Taproot, although in all sites with the exception of Oakview, the excluded stems and pollinated stems belonged to the same groupings. Oakview showed higher

weights in both treatments than in the other sites; this is reflected in its grouping being different

from the other sites.
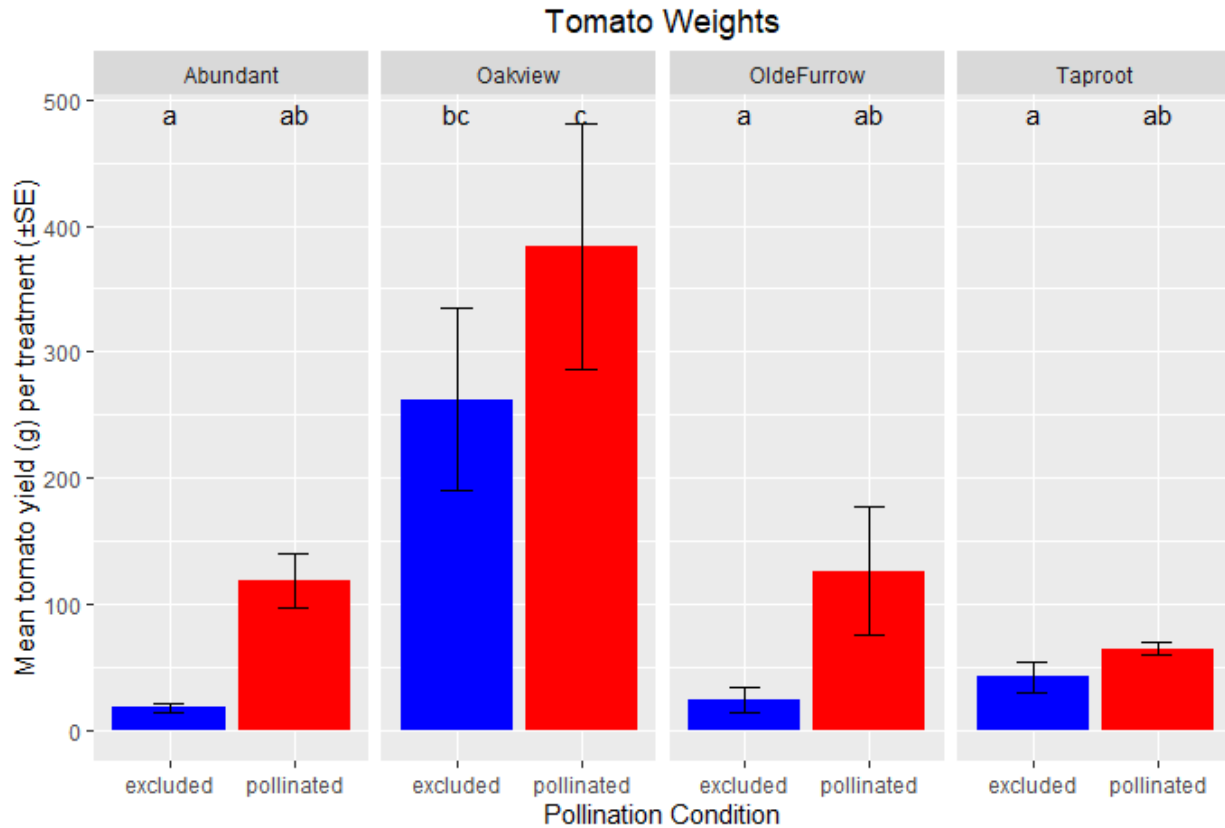
Figure 3.8. Mean weight yielded (in grams) in marked stems in each pollination condition in tomato. Statistically significant differences are represented by different letters atop each treatment ($\alpha = 0.05$). SE = Standard Error.

There was a significant difference in tomato fruit set among treatments (df = 1, F-value = 8.5583, Pr(>F) = 0.004615) and sites (df = 3, F-value = 9.4205, Pr(>F) = 2.556×10^{-5}). For fruit set, Taproot was notably higher than the other sites, with a different grouping in each of the treatments than the other sites. Oakview was the only site in which fruit set was higher amongst excluded buds, and the only time throughout this experiment where one of the response variables was higher in the excluded buds than the pollinated buds. All other sites showed a higher fruit set in the pollinated buds than the excluded stems (**Figure 3.9**).
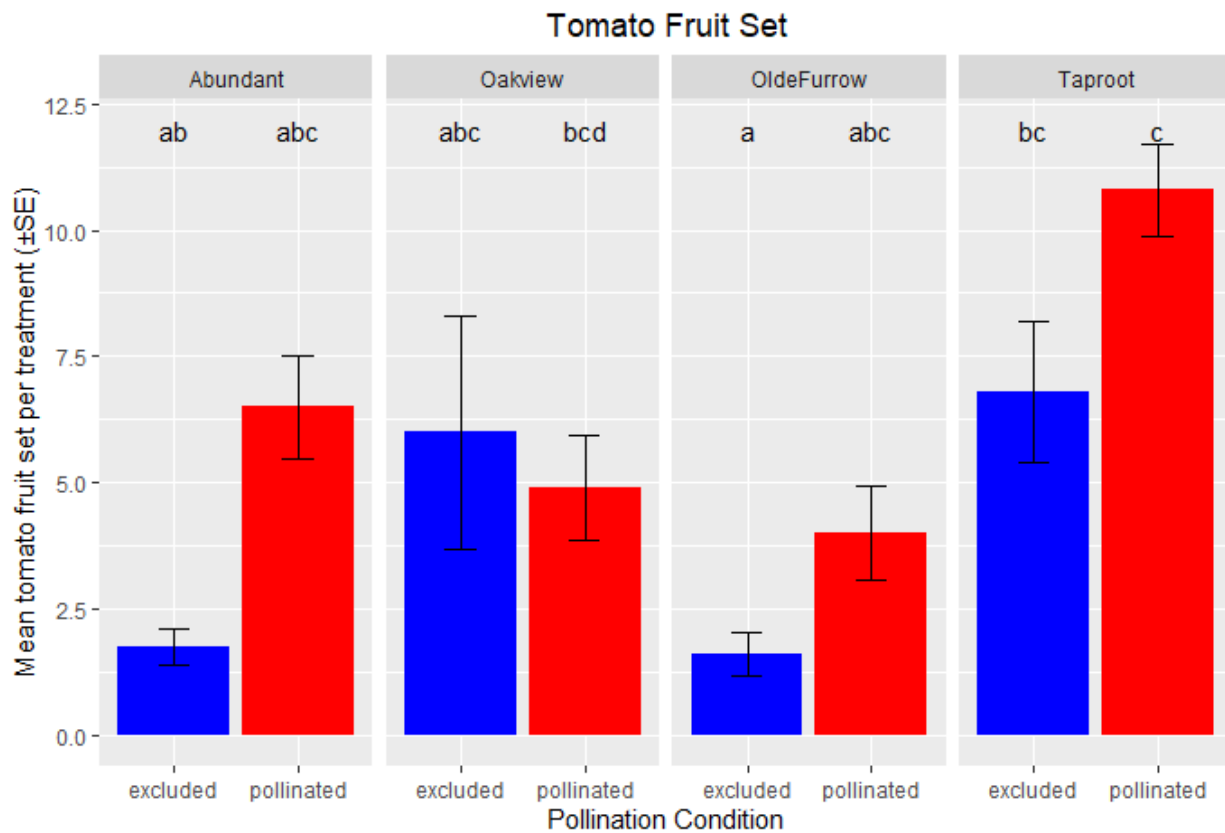
Figure 3.9. Mean fruit set of marked stems in each pollination condition in tomato. Statistically significant differences are represented by different letters atop each treatment (α = 0.05). SE = Standard Error.

3.4. DISCUSSION

a. Overview of Pollinator Exclusion Results

The investigated fruit crops showed both higher fruit set and yield when animal pollination was permitted as opposed to when pollinators were excluded. For both tomato and apple, this is similar to results from previous pollinator exclusion studies (Holzchuh et al., 2012; Franceschinelli et al., 2013; Samnegård et al., 2019) I also found that apple was more dependent

on pollinators for successful fruit production than tomato, which aligns with predictions based on pollination reliance by Klein et al. (2007). While there was a notable difference in tomato fruit set and weight between treatments, with pollinated tomato stems producing more fruit at a higher yield than excluded stems, this difference was less pronounced than the apple data.

In tomatoes, insect pollination did help to increase fruit set and yield, a finding which has been noted in past studies (Franceschinelli et al., 2013). Pollinator exclusion made a lesser difference than in apple, with pollination also shown to have made more of a difference in the tomato weight than the fruit set. It was expected that production of tomatoes could occur without pollinators, as they are capable of self-pollination (Kimura and Sinha, 2008). Tomatoes are also reliant on a special method of pollination known as buzz pollination provided primarily by bumble bees (Cooley and Vallejo-Marín, 2021). This service cannot be provided by domesticated honey bees, with honey bees being poor pollinators of buzz-pollinated crops, in some cases even being considered a pollen thief (Solís-Montero et al., 2015). Even in greenhouses, use of bumble bee colonies for pollination of tomato has been shown to be beneficial (Morandin et al., 2001).

As expected, apples showed a dramatic decline in fruit set and weight when pollinator visitation was prevented, this falls in line with previous studies on this crop (Samnegård et al., 2019). While I did expect a major difference due to this crops' reliance on pollinators (Klein et al., 2007), my results show that apple production on these Nova Scotian farms is completely reliant on pollinators, with no successful fruit being produced without animal pollination, aligning with the past findings of Calderone (2012). This is an alarming result in the face of ongoing pollinator declines (Potts et al., 2010). Honey bees are the most important pollinators of apple in terms of sheer numbers, with the use of domestic honey bee colonies for pollination

commonplace in apple orchards (Ramírez and Davenport, 2013). Indeed, two of the sites in this study imported honey bee colonies for pollination services, with another site likely impacted by honey bees being used by nearby farms.

The marketability and quality of produced fruit was not examined in this study. Many of the tomatoes that came from excluded flowers were not aesthetically pleasing, and so fruit set and weight of these stems alone may not be representative of the actual profitability of these excluded stems. It is not known the degree to which this may have been due to bag removal after fruit growth had already begun, but past studies have shown that pollination can increase fruit marketability (Wietzke et al., 2018). Consumers are 'picky' when it comes to the appearance of the produce that they purchase, and they can perceive abnormally shaped produce as a potential risk to purchase or eat (Loebnitz et al., 2015; Loebnitz and Grunert, 2018). Fruits which are less aesthetically pleasing and have irregularities or imperfections are less likely to be purchased, and so often need to be sold for a lower price (Loebnitz et al., 2015). Thus, more aesthetically pleasing, marketable fruit represents a greater opportunity for profits for farmers, and pollination can be used to ensure a greater amount of fruit produced by farmers meet these demands by the public (Wietzke et al., 2018).

b. Applications to Nova Scotia Agriculture

Based on these results, it is evident that pollinators are important, and in some cases, essential to fruit production in Nova Scotia. Adoption of management practices within the agricultural industry which are beneficial to pollinators should be encouraged because of the benefits this ecosystem service provides to fruit farmers. Pollinator management practices can often be cheap

to implement, with provisioning of pollinator-friendly habitats within agricultural systems a good way to make use of some less viable cropland (Nowakowski and Pywell, 2016). Implementation of pollinator-friendly practices can have benefits to food security, agricultural economics, and human health (Eilers et al., 2011; Garrat et al., 2014).

Healthy pollinator populations in agriculture can increase food security, and Nova Scotia is no exception to this (van der Sluijs and Vaage, 2016). Encouraging crops that are reliant on pollination can be beneficial, as they rely on less area and can bring more profits than non-pollinator dependent crops, translating to an increase in the value of crops per unit of land area (Ashworth et al., 2009). The suitability of Nova Scotia to fruit production reliant on pollination could be seen as an opportunity for growth in the agricultural sector within the province (Devanney and Reinhardt, 2011). Better management of pollination services can thus increase the food security of Nova Scotia while bringing economic benefits to the province.

Pesticide use has been shown to limit crop pollination services, especially by wild bees, which can have negative implications for future crop yields (Stanley et al., 2015). Bees can be a low-cost method to increase crop yields and thus profit margins, outperforming pesticide use in these metrics (Catarino et al., 2019). Therefore, pesticide reduction, or even just using less toxic pesticides, is one step towards better pollination management practices (Biddinger and Rajotte, 2015). Limiting pesticide use can also bring health benefits to humans, as many pesticides have been found to be hazardous to human health (Poudel et al., 2020). Given the price of pesticides, limiting them may also be seen as a cost saving measure, in an industry with tight profit margins (Duffy, 2009). Pesticide use is commonplace in fruit farming, especially in apple orchards in Nova Scotia, but this can also have a negative effect on pollinator populations that are important for this industry (Beaulieu et al., 2008; Brittain et al., 2010). Though in many cases, pesticide use

cannot be eliminated entirely, it should be limited to help encourage healthier pollinator populations that can provide the benefits of additional profits to farmers, including from consumers who may see pesticide-free fruit as 'higher quality' (Harker et al., 2003). Even within this study, apple growers at Taproot and Oakview Farms noted that they used fungicide for 'fire blight,' claiming it near impossible to grow commercially viable apples in Nova Scotia without this, but even a reduction in this could be beneficial to pollinator populations. A balancing act should be conducted on a case-by-case basis to determine the optimal levels of both pesticide use and pollinator management while still maximizing farmer profit (Biddinger and Rajotte, 2015).

Consumers also show a preference for locally grown crops (Bruhn et al., 1992). Purchasing of locally grown crops can stimulate rural economies, so should be encouraged (La Trobe, 2001). Promotion of locally grown Nova Scotia crops which need animal pollination should be a priority to ensure profits for local farmers, reduce greenhouse gas emissions from transportation, and assist in pollinator conservation at the local level (La Trobe, 2001; Striebig et al., 2019).

c. Broader Implications and Future Research

The implication of these findings extends beyond just the province of Nova Scotia. By showing the importance of pollination services to crops here, I hope to encourage adoption of pollinator-friendly practices within not just Nova Scotia, but elsewhere too. Already, it has been shown that many farmers are aware of the importance of pollinators and adopt some form of pollinator management on their farms (Hevia et al., 2020). Fostering further interest in pollinator

conservation by showing their value to farmers is an important step towards pollinator conservation in agricultural systems.

Studies such as mine showing the importance of pollinators to the human food system can be important to highlight the importance of pollinators. Education is an extremely useful tool in conservation biology, and the hope is that this study can be used to better educate both farmers and consumers on the importance of pollinator conservation. People more exposed to and educated on conservation measures are more likely to adopt them (Barata et al., 2017). Focus on local environmental issues, such as what this study has done, can often resonate better in encouraging the public to take an interest in conservation (Ardoin et al., 2020).

While my study does establish the importance of pollinators to tomatoes and apples in Nova Scotia, some knowledge gaps still remain. Future studies should be performed to determine individual Nova Scotian crops' reliance on pollination, allowing us to better understand the importance of pollinators to human food systems. A repeat of this study should also be performed on squash, given the failure to produce results here.

Future studies can also test the effects of pollinator exclusion on other factors related to crop value, such as the quality of produced fruit, the appearance, and the shelf life. Other studies have indicated that pollination can increase some of these qualities in produce, and the likelihood a consumer will buy them (Klatt et al., 2014; Wietzke et al., 2018). Given more consumers are gravitating towards food if it is advertised using terms like 'organic,' research could be done into seeing if advertising pollinator-friendly management practices increase the likelihood of purchasing produce (Demirtas, 2019). This could pave the way for a pollinator-friendly certification that could encourage farmers globally to adopt methods that encourage pollinator conservation.

94

d. Conclusions

This fruit exclusion study has shown the reliance on pollinators of two fruit crops grown in Nova Scotia: apple and tomato. Both fruit set and weight increase in the presence of pollination services. In particular, the importance of pollinators for successful fruit production exceeded expectations in apple, with my results indicating an essentially complete reliance on pollinators. Adoption of pollinator-friendly practices within the province of Nova Scotia, and in the agricultural sector globally, is thus recommended to make the most of this beneficial ecosystem service.

Chapter 4: General Discussion and Conclusions

4.1. DISCUSSION

a. Putting it all Together – The Benefits of Pollinator Conservation to Agriculture

Pollinator visitation increases both fruit set and weight in apples and tomatoes, with these visits coming from a diverse wild pollinator community, even in the presence of domesticated honey bees. In the case of apples, no successful fruit production occurred without pollinators, which highlights the importance of pollinators to apple production in Nova Scotia. Most pollinators in apple were found to be native pollinators, though the numbers of cavity nesters differed from past studies (Sheffield et al., 2008; Sheffield et al., 2013). Overall, my finding of the importance of wild pollinators to apples aligns with past studies (Mallinger and Gratton, 2015; Samnegård et al., 2019). In tomato, the fruit production was less reliant on pollinators, but I still saw higher fruit set and weight amongst stems in which animal pollination was permitted, matching results of past studies on this crop (Franceschinelli et al., 2013). Given that tomatoes showed the highest numbers of wild bees relative to honey bees, I can make the assumption that wild bees are important in increasing the crop value of tomato farming in the Bay of Fundy region of Nova Scotia. This finding is important for filling the knowledge gap on tomato pollination, as little work has previously been done on this crop in Canada (Rondeau et al., 2022).

My pollinator survey was not successful in squash, as the fruit exclusion experiment ultimately failed in this crop. Thralls and Treadwell (2017) have previously noted that despite prolific flower blooms, there can sometimes be much lower fruit production than expected in squash, as plants only produce one sex of flower (Thralls and Treadwell, 2017). It is unknown if this was the cause of the failure in this study, but it is a possibility. Using the methods from this study, but on a larger scale with more stems and plants may help to prevent this issue. I did find a

diverse pollinator community, including non-bees, in my pollinator survey in squash. However, amongst bees, there was less diversity than in the other crops, though successful pollination of squash has been shown to still occur with lower pollinator diversity (Stoner, 2020). Linking my results on the pollinator community in squash in Nova Scotia to actual exclusion results is needed to fully understand the importance of wild pollinator communities and non-native honey bees to squash in this region.

While honey bees do make an important contribution to the pollination of apple, tomato, and squash, my findings indicate that wild bees are likely responsible for most of the pollination services to these crops. In fact, honey bees are likely overrepresented in my results, as more managed honey bee hives are likely being used for crop pollination than are actually required, especially given that wild pollinators can already provide us with this ecosystem service (Park et al., 2016). In fact, there is the possibility that competition with honey bees could suppress wild bee populations (Renner et al., 2021). This presents the possibility for farmers to cut costs by reducing reliance on managed hives, and instead support preexisting wild bee communities. Reducing reliance on honey bees should also be done prior to investing in means to help wild bees such as planting wildflower strips, as their presence can offset the attempts to benefit them (Angelella et al., 2021).

Many of the bee species found in this study were also found in adjacent salt marsh and dyke habitat by Roulston (2021). When looking at the value of habitat adjacent to farmland in the Bay of Fundy dykelands, my comparison with Roulston (2021) seemed to indicate that dykes slightly edge out salt marshes as the better habitat to have near farmland for crop pollination. Further work should be done on identifying other possible habitats that may contribute to crop pollination services in this region. Past studies have indicated that close proximity of unmanaged

woodland to farms can increase visitation rates of bees to flowers on the farms (Joshi et al.,
2016). My contrasting findings with Sheffield et al. (2013) of fewer bees on the less
commercialized farms also displayed the need to understand the activities and habitats available
to bees both near the farms and directly on them.

Given both the reliance on pollination services and the numbers of wild pollinators in
crops found in this thesis, I suggest farmers invest in supporting wild pollinator populations.
Putting money into restoration of habitat like hedgerows within farmland can be beneficial both
to pollinators as well as towards other insects that may act as biological pest control, yielding a
return on investment in 5-16 years, depending on a variety of factors such as previous managed
honey bee or insecticide usage (Morandin et al., 2016). A past study on bumble bee colonies
found that little area within farmland needs to be set aside as flower-rich habitat to support these
colonies, so it seems the needs of wild pollinators can be met by farmers with some ease (Dicks
et al., 2015; Morandin et al., 2016). Relying on wild pollinators more and reducing costs
associated with honey bees could be a good way of cost saving in the wake of issues like supply
chain disruptions and costs increases the agricultural sector has faced since the onset of the
COVID-19 pandemic in early 2020 (Sridhar et al., 2023). However, it is important for farmers
who plan to rely on pollination services provided by wild pollinators to curb agricultural
intensification that may negatively impact their populations, and thus their ability to provide this
ecosystem service (Kremen et al., 2002). An ecological-based approach to pollinator
conservation should be used, focusing beyond just the economic benefits pollinators can provide
to effectively manage the trade-offs that will need to be done on a case-by-case basis between
their conservation and the valuable ecosystem service they provide (Senapathi et al., 2015).

On a broader scale, pesticide use and destruction of natural habitats should be limited, and greenhouse gas emissions need to be reduced to lessen the impacts of climate change on both human and natural systems, as these are all factors which contribute to pollinator declines (Potts et al., 2010). Agriculture makes a notable contribution to global greenhouse gas emissions, and so undertaking methods to reduce the sectors impact on Earth's climate can make significant inroads on limiting climate change (Pörtner et al., 2022). Reducing pesticide use can limit their negative impacts on pollinator populations while also increasing profit margins for farmers (Catarino et al., 2019). Limiting destruction of natural habitats, and instead encouraging their intertwining with man-made farmland in agroecosystems through habitat restoration, can be beneficial to both pollinator populations, and the crops that rely on their services (M'Gonigle et al., 2015).

b. Strategies for Successful Implementation of Pollinator Conservation Programmes

Farmers, including those within this study, have shown a strong understanding of the importance of pollinators and a willingness to adopt pollinator conservation measures (Hevia et al., 2021). Breeze et al. (2019) noted that many farmers believed they were experiencing a pollinator deficit in some of their crops, including tomatoes. However, the actual application of pollinator conservation measures is oftentimes scarce, a likely indication of barriers to their adoption in the agricultural sector, or perhaps simply the desire to satisfy researchers and conservationists (Hevia et al., 2021). Cost-share programs that bring a financial incentive to conserving pollinators are one solution, though farmers will sometimes initiate solutions that these programs would otherwise support 'off the books' due to a lack of trust in government and the bureaucracy that

can surround it (Gaines-Day and Gratton, 2017). Eliminating bureaucratic hurdles and mending

these relationships between government and farmers by ensuring they are included throughout

the decision-making process can help with the uptake of these programs, and ensure farmers are

rightly compensated for their time and efforts put towards conservation (de Snoo et al., 2012;

Gaines-Day and Gratton, 2017). A lack of technical expertise and assistance has been noted as

another barrier (Gaines-Day and Gratton, 2017; Hevia et al., 2021). Researchers should thus be

willing to go beyond the conducting and publishing of their research and assist in the adoption of

pollinator-friendly practices on farms when possible.

Beyond the agricultural sector, it is important to further the broader public's

understanding of pollinator conservation. Using a community-based approach to ensure the

broader local communities that these farmers are included within are involved in these

conservation campaigns too are important to their success (Ancrenaz et al., 2007; Horwich and

Lyon, 2007). Education campaigns are important in successful implementation of environmental

policy, including wildlife conservation (Salazar et al., 2018). This includes outreach and

marketing to raise awareness of the issue of conservation issues, like pollinator conservation

(Salazar et al., 2018). Increased reporting of pollinator declines is helpful in enacting policy

change, as though it has become reported on in mainstream media, it is often not making

headlines, so awareness of these issues is important (Althaus et al, 2020). But it is important to

ensure that the education and reporting on this issue is being directed towards the correct targets,

as it was anecdotally noted throughout this study that oftentimes when the topic of bees was

brought up with member of the public, many immediately thought of the non-native honey bee.

It seems that the honey bee, being a charismatic species, may unnecessarily end up being the

target of pollinator conservation efforts if the misconceptions surrounding the idea that they are

what needs help persist (Smith and Saunders, 2016; Colla, 2022). Finding other charismatic, but wild and native, bee species as flagship species for conservation may help to overcome this barrier to successful wild pollinator conservation.

An important aspect of effective education in pollinator conservation is keeping interest in the matter. To maintain the interest and attention on this subject, we should not just simply be throwing out numbers when dealing with the public, but perhaps try shifting to how 'cool' or interesting these bees can be, a method proven to work in conservation biology via the use of flagship species (Jarić et al., 2023). Shifting focus to aesthetics or how 'cool' an animal or group of animals are can help mitigate the apathy and lack of change that can come from repeated exposure to headlines highlighting the importance of the issue of pollinator conservation; this is a problem that has been observed in climate science (Lu, 2022). Focusing on aesthetics has been proven to work in past studies with other insect pollinators, as using striking butterfly species as pollinator 'ambassadors' increased interest amongst the general public (Barua et al., 2012). In fact, even within this study, one farmer had planted milkweed on their property to attract and help Monarchs (*Danaus plexippus*), a well-known North American example of a butterfly, and thus a pollinator, with subpopulations that have struggled in recent years (though none of these problem subpopulations occur in Nova Scotia), helping to prove the pull a charismatic flagship species can have on the public (Crone et al., 2021; Preston et al., 2021; IUCN, 2022). With close to 200 bee species native to Nova Scotia, surely some could adequately serve as flagship species for pollinator conservation in the province, to generate interest and funding for this cause (Sheffield, 2006).

Efforts to help pollinators can also improve other ecosystem services, and lessons learned in pollinator conservation can be used elsewhere (Wratten et al., 2012). Use of hedgerows and

flower strips to provide habitat for pollinating insects can also be used as habitat by insects like wasps that function as a form of biological pest control (Morandin et al., 2016). But while pursuing one ecosystem service, like crop pollination, can benefit other ecosystem services and biodiversity, targeting biodiversity conservation provides benefits to a broader range of ecosystem services, though it does not benefit the individual ecosystem services to the same degree as if they were individually being targeted (Chan et al., 2006). Thus, in conservation planning, trade-offs between ecosystem services and biodiversity should be managed accordingly to ensure that the needs for both are met (Chan et al., 2006).

c. Broader Implications and Future Research

This study is the first pollinator survey done in Nova Scotia on tomato and squash crops, and shows the important role of wild bee communities in the pollination of these crops. Future studies should be done on other agricultural crops grown in the Bay of Fundy dykelands region. A repeat of both experiments in squash should also be conducted, given the failure of the fruit exclusion experiment in the crop. If resources are limited, only the fruit exclusion can be done, but ideally the pollinator survey should be done again too as insect populations can vary greatly year-to-year (Solomon, 1957).

Future studies could include exclusion of just honey bees from flowers, to truly determine reliance of crops on wild bee pollination. This would allow for a better assessment of any similarities or differences in crop yield from pollination by both wild bees and honey bees, and to determine whether competing with honey bees for floral resources affects wild bees in Nova Scotia (Wignall et al., 2020). Surveys in other habitats found near farms in Nova Scotia should

also be conducted so they can compare to on-farm pollinator communities to determine any overlaps, with one such example of another habitat that has been found in past studies from outside the province to influence pollinator communities on farms being woodlands (Joshi et al., 2016). Finally, further analysis should be done to determine the relationship between wild pollinator community composition and the reliance of crop species on their services, ideally to determine individual pollinator species impact on crop yields.

Identification of pollinator visitors to crops can help to tailor management practices towards the species determined to be important to each crop through the surveys (Garratt et al., 2014). The economic importance of wild pollinators noted in past studies is on clear display when looking at the combined results presented here. The strongest result comes in apple, with a total economic reliance on pollinators for farming of this crop found in this study. I hope that this study highlights the importance of pollinators to the crop species looked at here and helps further support investment into pollinator conservation in agroecosystems. Given the plight pollinators have faced in recent years, they need our support, just as we rely on their support for our food and more.

d. Conclusions

To conclude, I have found that pollinators are crucial to farming of apples and tomatoes in the Bay of Fundy dykelands region of Nova Scotia. Both apple and tomato benefitted from the presence of pollinators, aligning with results from past studies on these crops (Franceschinelli et al., 2013; Samnegård et al., 2019). A diverse set of wild pollinators are responsible for much of the pollination of these crop species, many of which were slightly more abundant on dykes than

in salt marsh (Roulston, 2021). This data indicates that dykes may be the better nearby habitat for farmers exclusively looking at increasing pollination services. However, other ecosystem services should be considered prior to choosing to retain dykes or restore salt marshes. While many pollinators were also found in squash, a lack of results from the fruit-exclusion experiment prevented conclusions about this crop's reliance on pollinator services. Temporal shifts in pollinator diversity was noted, indicating that different species are responsible for crop pollination as the growing season goes on. Based on these results, I recommend a conservation-based approach to managing pollinator biodiversity within agroecosystems, incorporating farmers and their communities for best results. Successful implementation of pollinator conservation measures now will allow future generations to continue to benefit from this ecosystem service well into the future.

Chapter 5: References

Ahrenfeldt, E., Kollmann, J., Madsen, H., Skov-Petersen, H, Sigsgaard, L. (2019). Generalist ground-nesting bees dominate diversity survey in intensively managed agricultural land. *Journal of Melittology, 82*, 1-12. https://doi.org/10.17161/jom.v0i82.7057

Aizen, M., Garibaldi, L., Cunningham, S., Klein, A. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany, 103*(9), 1579-1588. doi: 10.1093/aob/mcp076

Aizen, M., Harder, L. (2009). The Global Stock of Domesticated Honey Bees is Growing Slower Than Agricultural Demand for Pollination. *Current Biology, 19*(11), 915-918. https://doi.org/10.1016/j.cub.2009.03.071

Alaux, C., Brunet, J., Dussaubat, C., Mondet, F., Tchamitchan, S., Cousin, M., Brillard, J., Baldy, A., Belzunces, L., Le Conte, Y. (2010). Interactions between *Nosema* microspores and a neonicotinoid weaken honey bees (*Apis mellifera*). *Environmental Microbiology, 12*(3), 774-782. doi: 10.1111/j.1462-2920.2009.02123.x

Albert, C., Luque, G., Courchamp, F. (2018). The twenty most charismatic species. *PLoS One, 13*(7), e0199149. https://doi.org/10.1371/journal.pone.0199149

Albrecht, M., Schmid, B., Hautier, Y., Müller, C. (2012). Diverse pollinator communities enhance plant reproductive success. *Proceedings of the Royal Society B: Biological Sciences, 279*(1748), 4845-4852. https://doi.org/10.1098/rspb.2012.1621

Armbruster, W. (2016). The specialization continuum in pollination systems: diversity of concepts and implications for ecology, evolution and conservation. *Functional Ecology, 31*(1), 88-100. https://doi.org/10.1111/1365-2435.12783

Althaus, S., Berenbaum, M., Jordan, J., Shalmon, D. (2020). No buzz for bees: Media coverage of pollinator decline. *Proceedings of the National Academy of Sciences of the United States of America, 118*(2), e2002552117. https://doi.org/10.1073/pnas.2002552117

Ancrenaz, M., Dabek, L., O'Neil, S. (2007). The Costs of Exclusion: Recognizing a Role for Local Communities in Biodiversity Conservation. *PLoS Biology 5*(11), e289. https://doi.org/10.1371/journal.pbio.0050289

Andersson, G., Birkhofer, K., Rundlöf, M., Smith, H. (2013). Landscape heterogeneity and farming practice alter the species composition and taxonomic breadth of pollinator communities. *Basic and Applied Ecology, 14*(7), 540-546. https://doi.org/10.1016/j.baae.2013.08.003

Angelella, G., McCullough, C., O'Rourke, M. (2021). Honey bee hives decrease wild bee abundance, species richness, and fruit count on farms regardless of wildflower strips. *Scientific Reports, 11*, 3202. https://doi.org/10.1038/s41598-021-81967-1

Ardoin, N., Bowers, A., Gaillard, E. (2020). Environmental education outcomes for conservation: A systematic review. *Biological Conservation, 241*. https://doi.org/10.1016/j.biocon.2019.108224

Asada, S., & Ono, M. (1996). Crop Pollination by Japanese Bumble bees, *Bombus* spp. (Hymenoptera: Apidae): Tomato Foraging Behavior and Pollination Efficiency. *Applied Entomology and Zoology, 31*(4), 581-586. https://doi.org/10.1303/aez.31.581

Ascher, J., & Pickering, J. (2022). Discover Life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila).

Ashworth, L., Quesada, M., Casas, A., Aguilar, R., Oyama, K. (2009). Pollinator-dependent food production in Mexico. *Biological Conservation, 142*, 1050-1057. doi: 10.1016/j.biocon.2009.01.016

Austin, A., Lawson-Handley, L., Gilbert, J. (2019). Plugging the hunger gap: Organic farming supports more abundant nutritional resources for bees at critical periods. *bioRxiv,* 837625. https://doi.org/10.1101/837625

Barata, R., Castro, P., Martins-Loução, M. (2017). How to promote conservation behaviours: the combined role of environmental education and commitment. *Environmental Education Research, 23*(9), 1322-1334. https://doi.org/10.1080/13504622.2016.1219317

Barbier, E., Hacker, S., Kennedy, C., Koch, E., Stier, A., Silliman, B. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs, 81*(2), 169-193.

Bartomeus, I., Ascher, J., Wagner, D., Danforth, B., Colla, S., Kornbluth, S., Winfree, R. (2011). Climate-associated phenological advances in bee pollinators and bee-pollinated plants. *Proceedings of the National Academy of Sciences, 108*(51), 20645-20649. https://doi.org/10.1073/pnas.1115559108

Barua, M., Gurdak, D., Ahmed, R., Tamuly, J. (2012). Selecting flagships for invertebrate conservation. *Biodiversity and Conservation, 21*, 1457-1476.

Beaulieu, M., MacDonald, T., Benbrook, C., Mineau, P. (2008). *Pesticide Use and Pest Management Practices of Canadian Apple Growers.* Statistics Canada Agriculture Division.

Bennett, E., Peterson, G., Gordon, L. (2009). Understanding relationships between multiple ecosystem services. *Ecology Letters, 12*, 1394-1404. doi: 10.1111/j.1461-0248.2009.01387.x

Bherwani, H., Nair, M., Kapley, A., Kumar, R. (2020). Valuation of Ecosystem Services and Environmental Damages: An Imperative Tool for Decision Making and Sustainability. *European Journal of Sustainable Development Research, 4*(4), em0133. https://doi.org/10.29333/ejosdr/8321

Biddinger, D., & Rajotte, E. (2015). Integrated pest and pollinator management - adding a new dimension to an accepted paradigm. *Current Opinion in Insect Science, 10*, 204-209. https://doi.org/10.1016/j.cois.2015.05.012

Biesmeijer, J., Roberts, S., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A., Potts, S., Kleukers, R., Thomas, C., et al. (2006). Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands. *Science, 313*(5785), 351-354. doi: 10.1126/science.1127863

Blaauw, B., & Isaacs, R. (2014). Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. *Journal of Applied Ecology, 51*(4), 890-898. https://doi.org/10.1111/1365-2664.12257

Blüthgen, N., & Klein, A. (2011). Functional complementarity and specialisation: The role of biodiversity in plant–pollinator interactions. *Basic and Applied Ecology, 12*, 282-291. doi: 10.1016/j.baae.2010.11.001

Boulanger, L., Wood, G., Osgood, E., Dirks, C. (1967). Native Bees Associated with the Low-Bush Blueberry in Maine and Eastern Canada. *Maine Agricultural Experiment Station Technical Bulletin 26.*

Bramon Mora, B., Shin, E., CaraDonna, P., Stouffer, D. (2020). Untangling the seasonal dynamics of plant-pollinator communities. *Nature Communications, 11*, 4086. https://doi.org/10.1038/s41467-020-17894-y

Breeze, T., Boreux, V., Cole, L., Dicks, L., Klein, A., Pufal, G., Balzan, M., Bevk, D., Bortolotti, L., Petanidou, T. (2019). Linking farmer and beekeeper preferences with ecological knowledge to improve crop pollination. *People and Nature, 1*(4), 562-572. https://doi.org/10.1002/pan3.10055

Breeze, T., Gallai, N., Garibaldi, L., Li, X. (2016). Economic Measures of Pollination Services: Shortcomings and Future Directions. *Trends in Ecology & Evolution, 31*(12), 927-939. https://doi.org/10.1016/j.tree.2016.09.002

Brittain, C., Vighi, M., Bommarco, R., Settele, J., Potts, S. (2010). Impacts of a Pesticide on Pollinator Species Richness at Spatial Scales. *Basic and Applied Ecology, 11*(2), 106-115. https://doi.org/10.1016/j.baae.2009.11.007

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

Bruhn, C., Vossen, P., Chapman, E., Vaupel, S. (1992). Consumer attitudes toward locally grown produce. *California Agriculture, 46*(4), 13-16.

Burkle, L., & Alarcón, R., (2011). The future of plant–pollinator diversity: Understanding interaction networks across time, space, and global change. *American Journal of Botany, 98*(3), 528-538. https://doi.org/10.3732/ajb.1000391

Calderone, N. (2012). Insect Pollinated Crops, Insect Pollinators and US Agriculture: Trend Analysis of Aggregate Data for the Period 1992–2009. *PLoS One, 7*(5), e37235. https://doi.org/10.1371/journal.pone.0037235

Cardinal, S., & Danforth, B. (2013). Bees diversified in the age of eudicots. *Proceedings of the Royal Society B: Biological Sciences, 280*(1755). doi: 10.1098/rspb.2012.2686

Cardoso, A. (2004). Depression by inbreeding after four sucessive self-pollination squash generations. *Scientia Agricola, 61*(2). https://doi.org/10.1590/S0103-90162004000200016

Carvalheiro, L., Seymour, C., Veldtman, R., Nicolson, S. (2010). Pollination services decline with distance from natural habitat even in biodiversity-rich areas. *Journal of Applied Ecology, 47*(4), 810-820. https://doi.org/10.1111/j.1365-2664.2010.01829.x

Catarino, R., Bretagnolle, V., Perrot, T., Vialloux, F., Gaba, S. (2019). Bee pollination outperforms pesticides for oilseed crop production and profitability. *Proceedings of the Royal Society B: Biological Sciences, 286*(1912). https://doi.org/10.1098/rspb.2019.1550

Chan, K., Shaw, M., Cameron, D., Underwood, E., Daily, G. (2006). Conservation Planning for Ecosystem Services. *PLoS Biology, 4*(11), e379. https://doi.org/10.1371/journal.pbio.0040379

Christmann, S. (2019). Do we realize the full impact of pollinator loss on other ecosystem services and the challenges for any restoration in terrestrial areas?. *Restoration Ecology, 27*(4), 720-725. https://doi.org/10.1111/rec.12950

Cole, L., Brocklehurst, S., Robertson, D., Harrison, W., McCracken, D. (2017). Exploring the interactions between resource availability and the utilisation of semi-natural habitats by insect pollinators in an intensive agricultural landscape. *Agriculture, Ecosystems & Environment, 246*, 157-167. https://doi.org/10.1016/j.agee.2017.05.007

Colla, S., & MacIvor, S. (2017). Questioning public perception, conservation policy, and recovery actions for honey bees in North America. *Conservation Biology, 31*(5), 1202-1204.

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

Cooley, H., & Vallejo-Marín, M. (2021). Buzz-Pollinated Crops: A Global Review and Meta-analysis of the Effects of Supplemental Bee Pollination in Tomato. *Journal of Economic Entomology, 114*(2), 505-519. https://doi.org/10.1093/jee/toab009

Cornell University. (2006). *Growing Guide: Summer Squash*. http://www.gardening.cornell.edu/homegardening/scene6420.html

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S., Kubiszewski, I., Farber, S., Turner, R. (2014). Changes in the global value of ecosystem services. *Global Environmental Change, 26*, 152-158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Courtney, S., Hill, C., Westerman, A. (1982). Pollen Carried for Long Periods by Butterflies. *Oikos, 38*(2), 260-263.

Coutinho, J., Hipólito, J., Santos, R., Moreira, E., Boscolo, D., Viana, B. (2021). Landscape Structure Is a Major Driver of Bee Functional Diversity in Crops. *Frontiers in Ecology and Evolution, 9*. https://doi.org/10.3389/fevo.2021.624835

Crespel, L., & Mouchotte, J. (2017). Methods of Cross-Breeding. *Reference Module in Life Sciences*. https://doi.org/10.1016/B978-0-12-809633-8.05005-6

Crone, E., Schultz, C. (2021). Resilience or Catastrophe? A possible state change for monarch butterflies in western North America. *Ecology Letters, 24*(8), 1533-1538. https://doi.org/10.1111/ele.13816

Cui, D., Hou, Y., Yin, P., Wang, X. (2022). A Jurassic flower bud from China. *Geological Society, London, Special Publications, 521*, 81-93. https://doi.org/10.1144/SP521-2021-122

Cunningham, S. (2000). Depressed pollination in habitat fragments causes low fruit set. *Proceedings of the Royal Society B, 267*(1448), 1149-1152. https://doi.org/10.1098/rspb.2000.1121

Daily, G., & Matson, P. (2008). Ecosystem services: From theory to implementation. *Proceedings of the National Academy of Sciences of the United States of America, 105*(28), 9455-9456. https://doi.org/10.1073/pnas.0804960105

Dainat, B., Evans, J., Chen, Y., Gauthier, L., Neumann, P. (2012a). Dead or Alive: Deformed Wing Virus and *Varroa destructor* Reduce the Life Span of Winter Honey bees. *Applied and Environmental Microbiology, 78*(4), 981-987. https://doi.org/10.1128/AEM.06537-11

Dainat, B., vanEngelsdorp, D., Neumann, P. (2012b). Colony collapse disorder in Europe. *Environmental Microbiology Reports, 4*(1), 123-125. https://doi.org/10.1111/j.1758-2229.2011.00312.x

Danforth, B., Sipes, S., Fang, J., Brady, S. (2006). The history of early bee diversification based on five genes plus morphology. *Proceeding of the National Academy of Sciences, 103*(41), 15118-15123. https://doi.org/10.1073/pnas.0604033103

De Groot, R., Wilson, M., Boumans, R. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics, 41*(3), 393-408. https://doi.org/10.1016/S0921-8009(02)00089-7

De Luca, P., & Vallejo-Marín, M. (2013). What's the 'buzz' about? The ecology and evolutionary significance of buzz-pollination. *Current Opinion in Plant Biology, 16*(4), 429-435. https://doi.org/10.1016/j.pbi.2013.05.002

de Snoo, G., Herzon, I., Staats, H., Burton, R., Schindler, S., van Dijk, J., Lokhorst, A., Bullock, J., Lobley, M., Wrbka, T. (2012). Toward effective nature conservation on farmland: making farmers matter. *Conservation Letters, 6*(1), 66-72. https://doi.org/10.1111/j.1755-263X.2012.00296.x

De Groot, R., Wilson, M., Boumans, R. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics, 41*(3), 393-408. https://doi.org/10.1016/S0921-8009(02)00089-7

De Luca, P., & Vallejo-Marín, M. (2013). What's the 'buzz' about? The ecology and evolutionary significance of buzz-pollination. *Current Opinion in Plant Biology, 16*(4), 429-435. https://doi.org/10.1016/j.pbi.2013.05.002

De Witte, K., Vercammen, J., van Daele, G., Keulemans, J. (1996). Fruit set, seed set and fruit weight in apple as influenced by emasculation, self-pollination and cross-pollination. *Acta Horticulturae, 423*, 177-184. https://doi.org/10.17660/ActaHortic.1996.423.23

Delaplane, K., & Mayer, D. (2000). *Crop Pollination by Bees*. New York, NY: CABI

Demirtas, B. (2019). Assessment of the impacts of the consumers' awareness of organic food on consumption behavior. *Food Science and Technology, 39*(4). https://doi.org/10.1590/fst.10518

Devanney, M., Reinhardt, F. (2011). An Overview of the Nova Scotia Agriculture and Agri-Food Industry, 2010. Nova Scotia Department of Agriculture. Halifax. 57 pp. (https://novascotia.ca/agri/documents/business-research/AO0102%202010%20NS%20Ag%20Overview%20w%20Appendices.pdf).

Díaz, S., Settele, J, Brondízio, E, Ngo, H., Agard, J., Arneth, A., Balvanera, P., Brauman, K., Butchart, S., Chan, K., et al. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science, 366*(6471). doi: 10.1126/science.aax3100

Dicks, L., Baude, M., Roberts, S., Phillips, J., Green, M., Carvell, C. (2015). How much flower-rich habitat is enough for wild pollinators? Answering a key policy question with incomplete knowledge. *Ecological Entomology, 40*(1), 22-35. doi: 10.1111/een.12226

Dorais, M., Papadopoulos, A., Gosselin, A. (2002). Greenhouse Tomato Fruit Quality. *Horticultural Reviews, 26*, 239-319.

Doyle, T., Hawkes, W., Massy, R., Powney, G., Menz, M., Wotton, K. (2020). Pollination by hoverflies in the Anthropocene. *Proceedings of the Royal Society B, 287*(1927). https://doi.org/10.1098/rspb.2020.0508

Droege, S. (2010). *The Very Handy Manual: How to Catch and Identify Bees and Manage a Collection.*

Drossart, M., Michez, D., Vanderplanck, M. (2017). Invasive plants as potential food resource for native pollinators: A case study with two invasive species and a generalist bumble bee. *Scientific Reports, 7*, 16242. https://doi.org/10.1038/s41598-017-16054-5

Drummond, F. (2002). *Honey Bees and Blueberry Pollination.* Fact Sheet No. 629, UMaine Extension No. 2079. Retrieved from the University of Maine website: https://extension.umaine.edu/blueberries/629-honey-bees-and-blueberry-pollination/

Ducarme, F., Luque, G., Courchamp, F. (2013). What are "charismatic species" for conservation biologists? *BioSciences Master Reviews*, *10*, 1-8.

Duffy, M. (2009). Economies of Size in Production Agriculture. *Journal of Hunger & Environmental Nutrition, 4*(3-4), 375-392. https://doi.org/10.1080/19320240903321292

Edwards, J., Griffin, A., Knoedler, M. (2019). Simultaneous Recordings of Insect Visitors to Flowers Show Spatial and Temporal Heterogeneity. *Annals of the Entomological Society of America, 112*(2), 93-98. https://doi.org/10.1093/aesa/say044

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

Eeraerts, M., Smagghe, G., Meeus, I. (2020). Bumble bee abundance and richness improves honey bee pollination behaviour in sweet cherry. *Basic and Applied Ecology, 43*, 27-33. https://doi.org/10.1016/j.baae.2019.11.004

Eickwort, G. (1977). Aspects of the Nesting Biology and Descriptions of Immature Stages of *Perdita octomaculata* and *P. halictoides* (Hymenoptera: Andrenidae). *Journal of the Kansas Entomological Society, 50*(4), 577-599.

Eilers, E., Kremen, C., Greenleaf, S., Garber, A., Klein, A. (2011). Contribution of Pollinator-Mediated Crops to Nutrients in the Human Food Supply. *PloS ONE, 6*(6), e21363. https://doi.org/10.1371/journal.pone.0021363

Elliff, C., & Kikuchi, R. (2015). The ecosystem service approach and its application as a tool for integrated coastal management. *Natureza & Conservação, 13*(2), 105-111. https://doi.org/10.1016/j.ncon.2015.10.001

Ellis, J., Evans, J., Pettis, J. (2010). Colony losses, managed colony population decline, and Colony Collapse Disorder in the United States. *Journal of Apicultural Research, 49*(1), 134-136. https://doi-org.library.smu.ca/10.3896/IBRA.1.49.1.30

Ellis, A., Myers, S., Ricketts, T. (2015). Do Pollinators Contribute to Nutritional Health? *PLoS ONE 10*(1), e114805. https://doi.org/10.1371/journal.pone.0114805

Fantinato, E., Del Vecchio, S., Giovanetti, M., Acosta, A., Buffa, G. (2017). New insights into plants co-existence in species-rich communities: The pollination interaction perspective. *Journal of Vegetation Science, 29*(6), 6-14. doi: 10.1111/jvs.12592

Foley, J., DeFries, R., Asner, G., Barford, C., Bonan, G., Carpenter, S., Chapin, F., Coe, M., Daily, G., Gibbs, H. (2005). Global Consequences of Land Use. *Science, 309*(5734), 570-574. doi: 10.1126/science.1111772

Fontaine, C., Dajoz, I., Meriguet, J., Loreau, M. (2005). Functional Diversity of Plant– Pollinator Interaction Webs Enhances the Persistence of Plant Communities. *PLoS Biology, 4*(1), e1. https://doi.org/10.1371/journal.pbio.0040001

Food and Agricultural Organization of the United Nations (FAO). (2023). FAOSTAT. https://www.fao.org/faostat/en/#data

Franceschinelli, E., Silva Neto, C., Lima, F., Gonçalves, B., Bergamini, L., Bergamini, B., Elias, M. (2013). Native bees pollinate tomato flowers and increase fruit production. *Journal of Pollination Ecology*, *11*, 41–45. https://doi.org/10.26786/1920-7603(2013)4

Friis, E., Pedersen, K., Crane, P. (2006). Cretaceous angiosperm flowers: Innovation and evolution in plant reproduction. *Palaeogeography, Palaeoclimatology, Palaeoecology, 232*(2-4), 251–293. https://doi.org/10.1016/j.palaeo.2005.07.006

Fründ, J., Linsenmair, K., Blüthgen, N. (2010). Pollinator diversity and specialization in relation to flower diversity. *Oikos, 119*, 1581-1590.

Gaines-Day, H., & Gratton, C. (2017). Understanding Barriers to Participation in Cost-Share Programs For Pollinator Conservation by Wisconsin (USA) Cranberry Growers. *Insects, 8*(3), 79. https://doi.org/10.3390/insects8030079

Gallai, N., Salles, J., Settele, J., Vaissière, B. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics, 68*(3), 810-821. https://doi.org/10.1016/j.ecolecon.2008.06.014

Ganser, D., Albrecht, M., Knop, E. (2020). Wildflower strips enhance wild bee reproductive success. *Journal of Applied Ecology, 58*(3), https://doi.org/10.1111/1365-2664.13778

Gardner, K., Ascher, J. (2006). Notes on the Native Bee Pollinators in New York Apple Orchards. *Journal of the New York Entomological Society, 114*(1-2), 86-91. https://doi.org/10.1664/0028-7199(2006)114[86:NOTNBP]2.0.CO;2

Garibaldi, L., Gomez Carella, D., Nabaes Jodar, D., Smith, M., Timberlake, T., Myers, S. (2022). Exploring connections between pollinator health and human health. *Philosophical Transactions of the Royal Society B: Biological Sciences, 377*(1853). https://doi.org/10.1098/rstb.2021.0158

Garibaldi, L., Steffan-Dewenter, I., Winfree, R., Aizen, M., Bommarco, R., Cunningham, S., Kremen, C., Carvalheiro, L., Harder, L., Afik, O., et al. (2013). Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance. *Science, 339*(6127), 1608-1611.

Garratt, M., Breeze, T., Jenner, N., Polce, C., Biesmeijer, J., Potts, S. (2014). Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. *Agriculture, Ecosystems, & Environment, 184*, 34-40. https://doi.org/10.1016/j.agee.2013.10.032

Garratt, M., Coston, D., Truslove, C., Lappage, M., Polce, C., Dean, R., Biesmeijer, J., Potts, S. (2014). The identity of crop pollinators helps target conservation for improved ecosystem services. *Biological Conservation, 169*, 128-135. https://doi.org/10.1016/j.biocon.2013.11.001

Ghaley, B., Vesterdal, L., Porter, J. (2014). Quantification and valuation of ecosystem services in diverse production systems for informed decision-making. *Environmental Science & Policy, 39*, 139-149. https://doi.org/10.1016/j.envsci.2013.08.004Get

Gibbs, J. (2011). Revision of the metallic *Lasioglossum* (Dialictus) of eastern North America (Hymenoptera: Halictidae: Halictini). *Zootaxa, 3073*(1), 1-216.

Gillespie, M., Baude, M., Biesmeijer, J., Boatman, N., Budge, G., Crowe, A., Davies, N., Evans, R., Memmott, J., Morton, R., et al. (2022). Landscape-scale drivers of pollinator communities may depend on land-use configuration. *Philisophical Transactions of the Royal Society B: Biological Sciences, 377*(1853), https://doi.org/10.1098/rstb.2021.0172

Gómez-Baggethun, E., de Groot, R., Lomas, P., Montes, C. (2010). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics, 69*(6), 1209-1218. https://doi.org/10.1016/j.ecolecon.2009.11.007

Gordon Jr., D., Cranford, P., Desplanque, C. (1985). Observations on the ecological importance of salt marshes in the Cumberland Basin, a macrotidal estuary in the Bay of Fundy. *Estuarine, Coastal and Shelf Science, 20*(2), 205-227. https://doi.org/10.1016/0272-7714(85)90038-1

Gottschalk, C., & van Nocker, S. (2013). Diversity in Seasonal Bloom Time and Floral Development among Apple Species and Hybrids. *Journal of the American Society for Horticultural Science, 138*(5), 367-374. https://doi.org/10.21273/JASHS.138.5.367

Goulsen, D. (2019, October 7). The insect apocalypse, and why it matters. *Current Biology, 29*, R967-R971.

Government of Nova Scotia. (2019). *Nova Scotia Wetland Conservation Policy*. Halifax, NS: 1-24 pp. https://novascotia.ca/nse/wetland/conservation.policy.asp

Graham, K. (2017). *Peaches in Nova Scotia – Challenges and Opportunities*. [Workshop Presentation]. ACORN Conference & Trade Show, Truro, NS. https://acornorganic.org/media/resources/Graham_PeachesInNovaScotia.pdf

Greenleaf, S., & Kremen, C. (2006). Wild bees enhance honey bees' pollination of hybrid sunflower. *Proceedings of the National Academy of Sciences, 103*(37), 13890-13895. https://doi.org/10.1073/pnas.0600929103

Greenleaf, S., Williams, N., Winfree, R., Kremen, C. (2007). Bee foraging ranges and their relationship to body size. *Oecologia, 153*(3), 589-596. doi: 10.1007/s00442-007-0752-9

Grimaldi, D. (1999). The Co-Radiations of Pollinating Insects and Angiosperms in the Cretaceous. *Annals of the Missouri Botanical Garden, 86*(2), 373–406. https://doi.org/10.2307/2666181

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

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

Hallman, C., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., et al. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS One, 12*(10), e0185809. https://doi.org/10.1371/journal.pone.0185809

Harker, F., Gunson, F., Jaeger, S. (2003). The case for fruit quality: an interpretive review of consumer attitudes, and preferences for apples. *Postharvest Biology and Technology, 28*(3), 333-347. https://doi.org/10.1016/S0925-5214(02)00215-6

Harmon-Threatt, A. (2020). Influence of Nesting Characteristics on Health of Wild Bee Communities. *Annual Review of Entomology, 65*, 39-56. https://doi.org/10.1146/annurev-ento-011019-024955

Hegland, S., Grytnes, J., Totland, Ø. (2009). The relative importance of positive and negative interactions for pollinator attraction in a plant community. *Ecological Research, 24*(4), 929–936 https://doi.org/10.1007/s11284-008-0572-3

Heithaus, E. (1974). The Role of Plant-Pollinator Interactions in Determining Community Structure. *Annals of the Missouri Botanical Garden, 61*(3), 675–691. https://doi.org/10.2307/2395023

Hevia, V., García-Llorente, M., Martínez-Sastre, R., Palomo, S., García, D., Miñarro, M., Pérez-Marcos, M., Sanchez, J., González, J. (2021). Do farmers care about pollinators? A cross-site comparison of farmers' perceptions, knowledge, and management practices for pollinator-dependent crops. *International Journal of Agricultural Sustainability, 19*(1), 1-15. https://doi.org/10.1080/14735903.2020.1807892

Hoehn, P., Tscharntke, T., Tylianakis, J., Steffan-Dewenter, I. (2008). Functional group diversity of bee pollinators increases crop yield. *Proceedings of the Royal Society B: Biological Sciences, 275*(1648), 2283-2291. https://doi.org/10.1098/rspb.2008.0405

Holzschuh, A., Dudenhöffer, J., Tscharntke, T. (2012). Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry. *Biological Conservation, 153*, 101-107. https://doi.org/10.1016/j.biocon.2012.04.032

Holzschuh, A., Steffan-Dewanter, I., Tscharntke, T. (2008). Agricultural landscapes with organic crops support higher pollinator diversity. *Oikos, 117*, 354-361. doi: 10.1111/j.2007.0030-1299.16303.x

Horwich, R., & Lyon, J. (2007). Community conservation: practitioners' answer to critics. *Oryx, 41*(3), 376-385. doi: 10.1017/S0030605307001010

Hu, S., Dilcher, D., Jarzen, D., Taylor, D. (2008). Early steps of angiosperm–pollinator coevolution. *Proceedings of the National Academy of Sciences, 105*(1), 240-245. https://doi.org/10.1073/pnas.070798910

Hung, K., Kingston, J., Albrecht, M., Holway, D., Kohn, J. (2018). The worldwide importance of honey bees as pollinators in natural habitats. *Proceedings of the Royal Society B: Biological Sciences, 285*. https://doi.org/10.1098/rspb.2017.2140

Hung, K., Kingston, J., Lee, A., Holway, D., Kohn, J. (2019). Non-native honey bees disproportionately dominate the most abundant floral resources in a biodiversity hotspot. *Proceedings of the Royal Society B: Biological Sciences, 286*(1897). https://doi.org/10.1098/rspb.2018.2901

Hünicken, P., Morales, C., Garcia, N., Garibaldi, L. (2020). Insect Pollination, More than Plant Nutrition, Determines Yield Quantity and Quality in Apple and Pear. *Neotropical Entomology, 49*, 525-532. https://doi.org/10.1007/s13744-020-00763-0

Inouye, D. (1980). The Terminology of Floral Larceny. *Ecology, 61*(5), 1251-1253. https://doi.org/10.2307/1936841

International Union for the Conservation of Nature (IUCN). (2022, July 15). *Migratory monarch butterfly now Endangered - IUCN Red List* [Press release]. https://www.iucn.org/press-release/202207/migratory-monarch-butterfly-now-endangered-iucn-red-

list#:~:text=The%20migratory%20monarch%20butterfly%20(Danaus%20plexippus%20plexipp us)%20has%20entered%20the,IUCN%20Red%20List%20as%20Endangered.

Iwasaki, J., & Hogendoorn, K. (2021). How protection of honey bees can help and hinder bee conservation. *Current Opinion in Insect Science, 46*, 112-118. https://doi.org/10.1016/j.cois.2021.05.005

Jarić, I., Normande, I., Arbieu, U., Courchamp, F., Crowley, S., Jeschke, J., Roll, U., Sherren, K., Thomas-Walters, L., Veríssimo, D., et al. (2023). Flagship individuals in biodiversity conservation. *Frontiers in Ecology and the Environment,* https://doi.org/10.1002/fee.2599

Jha, S., & Kremen, C. (2012). Resource diversity and landscape-level homogeneity drive native bee foraging. *Proceedings of the National Academy of Sciences, 110*(2), 555-558. https://doi.org/10.1073/pnas.1208682110

Johnson, M. (1981). Observations on the Biology of *Andrena (Melandrena) dunningi* Cockerell (Hymenoptera: Andrenidae). *Journal of the Kansas Entomological Society, 54*(1), 32-40.

Joshi, N., Otieno, M., Rajotte, E., Fleischer, S., Biddinger, D. (2016). Proximity to Woodland and Landscape Structure Drives Pollinator Visitation in Apple Orchard Ecosystem. *Frontiers in Ecology and Evolution, 4*, 38. https://doi.org/10.3389/fevo.2016.00038

Kendall, L., Mola, J., Portman, Z., Cariveau, D., Smith, H., Bartomeus, I. (2022). The potential and realized foraging movements of bees are differentially determined by body size and sociality. *Ecology, 103*(11), e3809. https://doi.org/10.1002/ecy.3809

Kevan, P., & Baker, H. (1983). Insects as Flower Visitors and Pollinators. *Annual Review of Entomology, 28*, 407-453.

Kevan, P., Gadawski, R., Kevan, S., Gadawski, S. (1983). Pollination of Cranberries, *Vaccinium macrocarpon*, on Cultivated Marshes in Ontario. *Proceedings of the Entomological Society of Ontario, 114*, 45-53.

Killewald, M., Costamagna, A., Gulden, L., Gibbs, G. (2023). Floral strips adjacent to Manitoba crop fields attract beneficial insects shortly after establishment regardless of management type or landscape context. *Agricultural and Forest Entomology,* 1-20. https://doi.org/10.1111/afe.12595

Kimoto, C., DeBano, S., Thorp, R., Rao, S., Stephen, W. (2012). Investigating temporal patterns of a native bee community in a remnant North American bunchgrass prairie using blue vane traps. *Journal of Insect Science, 12*(1). https://doi.org/10.1673/031.012.10801

Kimura, S., & Sinha, N. (2008). Crossing tomato plants. *CSH Protocols.* doi: 10.1101/pdb.prot5082

Klatt, B., Holzschuh, A., Westphal, C., Clough, Y, Smit, I., Pawelzik, E., Tscharntke, T. (2014). Bee pollination improves crop quality, shelf life and commercial value. *Proceedings of the Royal Society B: Biological Sciences, 281*(1775). https://doi.org/10.1098/rspb.2013.2440

Klein, A., Steffan-Dewenter, I., Tscharntke, T. (2003). Bee pollination and fruit set of Coffea arabica and C. canephora (Rubiaceae). *American Journal of Botany, 90*(1), 153-157. doi: 10.3732/ajb.90.1.153.

Klein, A., Vaissière, B., Cane, J., Steffan-Dewenter, I., Cunningham, S., Kremen, C., Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences, 274*(1068), 303-313. doi: 10.1098/rspb.2006.3721

Kordbacheh, F., Liebman, M., Harris, M. (2020). Strips of prairie vegetation placed within row crops can sustain native bee communities. *PLoS One, 15*(10), e0240354. https://doi.org/10.1371/journal.pone.0240354

Kremen, C., & Chaplin-Kramer, R. (2007). Insects as Providers of Ecosystem Services: Crop Pollination and Pest Control. In *Insect Conservation Biology* (pp. 349-382). Oxfordshire, UK: The Royal Entomological Society.

Kremen, C., Williams, N., Bugg, R., Fay, J., Thorp, R. (2004). The area requirements of an ecosystem service: crop pollination by native bee communities in California. *Ecology Letters, 7*, 1109-1119. doi: 10.1111/j.1461-0248.2004.00662.x

Kremen, C., Williams, M., Thorp, R. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences, 99*(26), 16812-16816. https://doi.org/10.1073/pnas.262413599

Kuhn-Neto, B., Contrera, F., Castro, M., Nieh, J. (2009). Long distance foraging and recruitment by a stingless bee, *Melipona mandacaia*. *Apidologie, 40*, 472-480. doi: 10.1051/apido/2009007

La Notte, A., Vallecillo, S., Marques, A., Maes, J. (2019). Beyond the economic boundaries to account for ecosystem services. *Ecosystem Services, 35*, 116-129. https://doi.org/10.1016/j.ecoser.2018.12.007

Lanterman, J., Reeher, P., Mitchell, R., Goodell, L. (2019). Habitat Preference and Phenology of Nest Seeking and Foraging Spring Bumble Bee Queens in Northeastern North America (Hymenoptera: Apidae: Bombus). *The American Midland Naturalist, 182*, 131-159.

Larsson, M. (2005). Higher pollinator effectiveness by specialist than generalist flower-visitors of unspecialized *Knautia arvensis* (Dipsacaceae). *Oeclogia, 146*, 394-403. doi: 10.1007/s00442-005-0217-y

La Trobe, H. (2001). Farmers' markets: consuming local rural produce. *International Journal of Consumer Studies, 25*(3), 181-192.

Lennartsson, T. (2002). Extinction Thresholds and Disrupted Plant-Pollinator Interactions in Fragmented Plant Populations. *Ecology, 83*(11), 3060-3072. https://doi.org/10.1890/0012-9658(2002)083[3060:ETADPP]2.0.CO;2

Lever, J., van Nes, E., Scheffer, M., Bascompte, J. (2014). The Sudden Collapse of Pollinator Communities. *Ecology Letters, 17*, 350-359. doi: 10.1111/ele.12236

Loebnitz, N., Grunert, K. (2018). The impact of abnormally shaped vegetables on consumers' risk perception. *Food Quality and Preference, 63*, 80-87. https://doi.org/10.1016/j.foodqual.2017.08.004

Loebnitz, N., Schuitema, G., Grunert, K. (2015). Who Buys Oddly Shaped Food and Why? Impacts of Food Shape Abnormality and Organic Labeling on Purchase Intentions. *Psychology & Marketing, 32*(4), 408-421. https://doi.org/10.1002/mar.20788

Lu, H. (2022). The Role of Repeated Exposure and Message Fatigue in Influencing Willingness to Help Polar Bears and Support Climate Change Mitigation. *Science Communication, 44*(4), 475-493. https://doi-org.library.smu.ca/10.1177/10755470221105068

Mace, G., Norris, K., Fitter, A. (2012). Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology & Evolution, 27*(1), 19-26. https://doi.org/10.1016/j.tree.2011.08.006

MacIvor, J., & Packer, L. (2015). 'Bee Hotels' as Tools for Native Pollinator Conservation: A Premature Verdict? *PLoS One, 10*(3), e0122126. https://doi.org/10.1371/journal.pone.0122126

MacIvor, J. (2017). Cavity-nest boxes for solitary bees: a century of design and research. *Apidologie, 48*, 311-327. https://doi.org/10.1007/s13592-016-0477-z

MacLeod, M., Reilly, J., Cariveau, D., Genung, M., Roswell, M., Gibbs, J., Winfree, R. (2020). How much do rare and crop-pollinating bees overlap in identity and flower preferences? *Journal of Applied Ecology, 57*(2), 413-423. https://doi.org/10.1111/1365-2664.13543

Main, A., Hladik, M., Webb, E., Goyne, K., Mengel, D. (2020). Beyond neonicotinoids – Wild pollinators are exposed to a range of pesticides while foraging in agroecosystems. *Science of the Total Environment, 742*, 140436. https://doi.org/10.1016/j.scitotenv.2020.140436

Mallinger, R., & Gratton, C. (2015). Species richness of wild bees, but not the use of managed honey bees, increases fruit set of a pollinator-dependent crop. Journal of Applied Ecology, 52, 323-330. doi: 10.1111/1365-2664.12377

Mashilingi, S., Zhang, H., Garibaldi, L., An, J. (2022). Honey bees are far too insufficient to supply optimum pollination services in agricultural systems worldwide. *Agriculture, Ecosystems & Environment, 335*. https://doi.org/10.1016/j.agee.2022.108003

Mathiasson, M., & Rehan, S. (2020). Wild bee declines linked to plant-pollinator network changes and plant species introductions. *Insect Conservation and Diversity, 13*(6), 595-605. https://doi.org/10.1111/icad.12429

Messiga, A., Gallant, K., Sharifi, M., Hammermeiseter, A., Fuller, K., Tango, M., Fillmore, S. (2015). Grape Yield and Quality Response to Cover Crops and Amendments in a Vineyard in Nova Scotia, Canada. *American Journal of Enology and Viticulture, 67*(1), 77-85. Doi: 10.5344/ajev.2015.15013

M'Gonigle, L., Ponisio, L., Cutler, K., Kremen, C. (2015). Habitat restoration promotes pollinator persistence and colonization in intensively managed agriculture. *Ecological Applications, 25*(6), 1557-1565. https://doi.org/10.1890/14-1863.1

Michelbacher, A., Smith, R., Hurd, P. (1964). Bees are essential: Pollination of squashes, gourds and pumpkins. *California Agriculture, 18*(5), 2-4.

Millennium Ecosystem Assessment. (2003). *Ecosystems and Human Well-Being.* Island Press, Washington, DC.

Mitchell, T.B. (1960). *Bees of the Eastern United States. I.* Technical bulletin (North Carolina Agricultural Experiment Station).

Mitchell, T.B. (1962). *Bees of the Eastern United States. II.* Technical bulletin (North Carolina Agricultural Experiment Station).

Møller, A. (2020). Quantifying rapidly declining abundance of insects in Europe using a paired experimental design. *Ecology and Evolution, 10*, 2446-2451. doi: 10.1002/ece3.6070

Montoya, D., Rogers, L., Memmott, J. (2012). Emerging perspectives in the restoration of biodiversity-based ecosystem services. *Trends in Ecology & Evolution, 27*(12), 666-672. https://doi.org/10.1016/j.tree.2012.07.004

Morales, C., Arbetman, M., Cameron, S., Aizen, M. (2013). Rapid ecological replacement of a native bumble bee by invasive species. *Frontiers in Ecology and the Environment, 11*(10), 529-534. doi: 10.1890/120321

Morandin, L., Laverty, T., Kevan, P. (2001). Bumble Bee (Hymenoptera: Apidae) Activity and Pollination Levels in Commercial Tomato Greenhouses. *Journal of Economic Entomology, 94*(2), 462-467. https://doi.org/10.1603/0022-0493-94.2.462

Morandin, L., Long, R., Kremen, C. (2016). Pest Control and Pollination Cost–Benefit Analysis of Hedgerow Restoration in a Simplified Agricultural Landscape. *Journal of Economic Entomology, 109*(3), 1020-1027. https://doi.org/10.1093/jee/tow086

Moritz, R., Härtel, S., Neumann, P. (2005). Global invasions of the western honey bee (*Apis mellifera*) and the consequences for biodiversity. *EcoScience, 12*(3), 289-301. https://doi.org/10.2980/i1195-6860-12-3-289.1

Nabors, A., Cen, H., Hung, K., Kohn, J., Holway, D. (2018). The efect of removing numerically dominant, non-native honey bees on seed set of a native plant. *Oecologia, 186*, 281-289. https://doi.org/10.1007/s00442-017-4009-y

National Research Council. (2007). *Status of Pollinators in North America*. The National Academies Press.

Nazer, I., Kasrawi, M., Al-Attal, Y. (2003). Influence of Pollination Technique on Greenhouse Tomato Production. *Journal of Agriculture and Marine Sciences, 8*(1), 21-26.

Neff, J., & Simpson, B. (1997). Nesting and Foraging Behavior of *Andrena (Callandrena) rudbeckiae* Robertson (Hymenoptera: Apoidea: Andrenidae) in Texas. *Journal of the Kansas Entomological Society, 70*(2), 100-113.

Niemelä, J., Sarrela, S., Söderman, T., Kopperoinen, L., Yli-Pelkonen, V., Väre, S., Kotze, D. (2010). Using the ecosystem services approach for better planning and conservation of urban green spaces: a Finland case study. *Biodiversity and Conservation, 19*, 3225-3243. https://doi.org/10.1007/s10531-010-9888-8

Nooten, S., Odanaka, K., Rehan, S. (2020). Characterization of wild bee communities in apple and blueberry orchards. *Agricultural and Forest Entomology, 22*(2), 157-168. https://doi.org/10.1111/afe.12370

Nooten, S., & Rehan, S. (2021). Effects of land use type and seasonal climate on ground nesting wild bees. *Agricultural and Forest Entomology, 24*(2), 229-236. https://doi.org/10.1111/afe.12486

Nowakowski, M., & Pywell, R. (2016). *Habitat Creation and Management for Pollinators.* Centre for Ecology & Hydrology, Wallingford, UK.

NSERC ResNet. (2019a). *About*. https://www.nsercresnet.ca/about.html

NSERC ResNet. (2019b). *Landscape 1: Bay of Fundy Dykeland Futures*. https://www.nsercresnet.ca/landscape-1---bay-of-fundy.html

O'Brien, C., & Arathi, H. (2021). If You Build It, They Will Come—Agroecosystem-Based Management Practices Support Pollinators, *Annals of the Entomological Society of America, 114*(3), 322–328, https://doi.org/10.1093/aesa/saaa037

Olde Furrow Farm. (n.d.). *Farm's History*. https://www.oldefurrowfarm.com/history-of-the-farm.html

Oleson, J., Bascompte, J., Elberling, H., Jordano, P. (2008). Temporal Dynamics in a Pollination Network. *Ecology, 89*(6), 1573-1582. https://doi.org/10.1890/07-0451.1

Olhnuud, A., Liu, Y., Makowski, D., Tscharntke, T., Westphal, C., Wu, P., Wang, M., van der Werf, W. (2022). Pollination deficits and contributions of pollinators in apple production: A global meta-analysis. *Journal of Applied Ecology, 59*(12), 2911-2921. https://doi.org/10.1111/1365-2664.14279

Ollerton, J., Winfree, R., Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos, 120*(3), 321-326. https://doi.org/10.1111/j.1600-0706.2010.18644.x

Packer, L., Genaro, J., Sheffield, C. (2007). The Bee Genera of Eastern Canada. *Canadian Journal of Arthropod Identification, 3*, 1-32.

Page, M., & Williams, N. (2022). Honey bee introductions displace native bees and decrease pollination of a native wildflower. *Ecology, 104*(2), e3939. https://doi-org.library.smu.ca/10.1002/ecy.3939

Paris, H. (1996). Summer Squash: History, Diversity, and Distribution. *HortTechnology, 6*(1), 6-13. https://doi.org/10.21273/HORTTECH.6.1.6

Park, M., Raguso, R., Losey, J., Danforth, B. (2016). Per-visit pollinator performance and regional importance of wild *Bombus* and *Andrena* (*Melandrena*) compared to the managed honey bee in New York apple orchards. *Apidologie, 47*, 145-160. https://doi.org/10.1007/s13592-015-0383-9

Pascual, U., Palomo, I., Adams, W., Chan, K., Daw, T., Garmendia, E., Gómez-Baggethun, E., de Groot, R., Mace, G., Martin-López, B., et al. (2017). Off-stage ecosystem service burdens: A blind spot for global sustainability. *Environmental Research Letters, 12*, 075001. https://doi.org/10.1088/1748-9326/aa7392

Pawlikowski, T., Sparks, T., Olszewski, P., Pawlikowski, K., Rutkowski, L., Jakubowski, R. (2020). Rising temperatures advance the main flight period of *Bombus* bumble bees in agricultural landscapes of the Central European Plain. *Apidologie, 51*, 652-663. https://doi.org/10.1007/s13592-020-00750-9

Penn, J., Hu, W., Penn, H. (2019). Support for Solitary Bee Conservation among the Public versus Beekeepers. *American Journal of Agricultural Economics, 101*(5), 1386-1400. https://doi.org/10.1093/ajae/aaz050

Pérez-Méndez, N., Andersson, G., Requier, F., Hipólito, J., Aizen, M., Morales, C., García, N., Gennari, G., Garibaldi, L. (2020). The economic cost of losing native pollinator species for orchard production. *Journal of Applied Ecology, 57*, 599-608. doi: 10.1111/1365-2664.13561

Poinar, G., & Danforth, B. (2006). A Fossil Bee from Early Cretaceous Burmese Amber. *Science, 314*(5799), 614–614. doi: 10.1126/science.1134103

Pörtner, H., Roberts, D., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., et al. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Porto, R., de Almeida, R., Cruz-Neto, O., Tabarelli, M., Viana, B., Peres, C., Lopes, A. (2020). Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. *Food Security, 12*(2), 1425-1442. doi: 10.1007/s12571-020-01043-w

Potts, S., Biesmeijer, J., Kremen, C., Neumann, P., Schweiger, O., Kunin, W. (2010). Global Pollinator Declines: Trends, Impacts, and Drivers. *Trends in Ecology & Evolution, 25*(6). 345-353. https://doi.org/10.1016/j.tree.2010.01.007

Potts, S., Vulliamy, B., Roberts, S., O'Toole, C., Dafni, A., Ne'eman, G., Willmer, P. (2005). Role of nesting resources in organising diverse bee communities in a Mediterranean landscape. *Ecological Entomology, 30*(1), 78-85. https://doi.org/10.1111/j.0307-6946.2005.00662.x

Poudel, S., Poudel, B., Acharya, B., Poudel, P. (2020). Pesticide Use And Its Impacts On Human Health And Environment. *Environment & Ecosystem Science, 4*(1): 47-51. doi: 10.26480/ees.01.2020.47.51

Preston, S., Liao, J., Toombs, T., Romero-Canyas, R., Speiser, J., Seifert, C. (2021). A case study of a conservation flagship species: the monarch butterfly. *Biodiversity and Conservation, 30*, 2057-2077. https://doi.org/10.1007/s10531-021-02183-x

Pritchard, D., & Vallejo-Marín, M. (2020) Quick guide: Buzz pollination. *Current Biology, 30*, R858-R860.

R Core Team. (2022). R: A language and environment for statistical computing (Version 4.2.1). R Foundation for Statistical Computing. Vienna, Austria. Retrieved from: https://www.rproject.org/

Rader, R., Bartomeus, I., Garibaldi, L., Garratt, M., Howlett, B., Winfree, R., Cunningham, S., Mayfield, M., Arthur, A., Andersson, G., et al.. (2015). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences, 113*(1), 146-151. doi: 10.1073/pnas.1517092112

Rader, R., Cunningham, S., Howlett, B., Inouye, D. (2020). Non-Bee Insects as Visitors and Pollinators of Crops: Biology, Ecology, and Management. *Annual Review of Entomology, 65*, 391-407. https://doi.org/10.1146/annurev-ento-011019-025055

Ramírez, F., & Davenport, T. (2013). Apple pollination: A review. *Scientia Horticulturae, 162*, 188-203. https://doi.org/10.1016/j.scienta.2013.08.007

Reeb, R., Acevedo, I., Heberling, J., Isaac, B., Kuebbing, S. (2020). Nonnative old-field species inhabit early season phenological niches and exhibit unique sensitivity to climate. *Ecosphere 11*(18), e03217. doi: 10.1002/ecs2.3217

Rehan, S., Leys, R., Schwarz, M. (2013). First Evidence for a Massive Extinction Event Affecting Bees Close to the K-T Boundary. *PLoS ONE, 8*(10), e76683. https://doi.org/10.1371/journal.pone.0076683

Rehan, S., & Sheffield, C. (2011). Morphological and molecular delineation of a new species in the *Ceratina dupla* species-group (Hymenoptera: Apidae: Xylocopinae) of eastern North America. *Zootaxa, 2873*(1), 35-50.

Rendón, O., Garbutt, A., Skov, M., Möller, I., Alexander, M., Ballinger, R., Wyles, K., Smith, G., McKinley, E., Griffin, J., et al. (2019). A framework linking ecosystem services and human well-being: Saltmarsh as a case study. *People and Nature, 1*(4), 486-496. https://doi.org/10.1002/pan3.10050

Renner, S., Graf, M., Hentschel, Z., Krause, H., Fleischmann, A. (2021). High honey bee abundances reduce wild bee abundances on flowers in the city of Munich. *Oecologia, 195*, 825-831. https://doi.org/10.1007/s00442-021-04862-6

Requier, F., Pérez-Méndez, N., Andersson, G., Blareau, E., Merle, I., Garibaldi, L. (2023). Bee and non-bee pollinator importance for local food security. *Trends in Ecology & Evolution, 38*(2), 196-205. https://doi.org/10.1016/j.tree.2022.10.006

Reyers, B., Polasky, S., Tallis, H., Mooney, H., Larigauderie, A. (2012) Finding Common Ground for Biodiversity and Ecosystem Services. *BioScience, 62*(5), 503-507. https://doi.org/10.1525/bio.2012.62.5.12

Richards, A. (2001). Does Low Biodiversity Resulting from Modern Agricultural Practice Affect Crop Pollination and Yield? *Annals of Botany, 88*, 165-172. doi: 10.1006/anbo.2001.1463

Rick, C. (1983). Tomato (*Lycopersicon*). *Developments in Plant Genetics and Breeding, 1*, 147-165. https://doi.org/10.1016/B978-0-444-42227-9.50011-1

Ritchie, A., Ruppel, R., Jha, S. (2016). Generalist Behavior Describes Pollen Foraging for Perceived Oligolectic and Polylectic Bees. *Environmental Entomology, 45*(4), 909-919. doi: 10.1093/ee/nvw032

Rocha, F., Peraza, D., Medina, S., Quezada-Euán, J. (2023). Pollination service provided by honey bees to buzz-pollinated crops in the Neotropics. *PLoS One 18*(1), e0280875. https://doi.org/10.1371/journal.pone.0280875

Rondeau, S., Chan, D., Pindar, A. (2022). Identifying wild bee visitors of major crops in North America with notes on potential threats from agricultural practices. *Frontiers in Sustainable Food Systems, 6*, https://doi.org/10.3389/fsufs.2022.943237

Roulston, T. (2021). *Pollinator communities in saltmarshes and dykes: comparing habitat value in agroecosystems* [Honour's thesis, Saint Mary's University]. Saint Mary's University Institutional Repository.

RStudio. (2022). RStudio: Integrated Development Environment for R (Version 2022.07.2+576). Boston, MA. Retrieved from: https://www.rstudio.com/

Salazar, G., Mills, M., Veríssimo, D. (2018). Qualitative impact evaluation of a social marketing campaign for conservation. *Conservation Biology, 33*(3), 634-644. https://doi.org/10.1111/cobi.13218

Samnegård, U., Hambäck, P., Smith, H. (2019). Pollination treatment affects fruit set and modifies marketable and storable fruit quality of commercial apples. *Royal Society Open Science, 6*(12). https://doi.org/10.1098/rsos.190326

Sardiñas, H., Ponisio, L., Kremen, C. (2016). Hedgerow presence does not enhance indicators of nest-site habitat quality or nesting rates of ground-nesting bees. *Restoration Ecology, 24*(4), 499-505. https://doi.org/10.1111/rec.12338

Sargent, R., & Ackerly, D. (2008). Plant–pollinator interactions and the assembly of plant communities. *Trends in Ecology & Evolution, 23*(3), 123-130. https://doi.org/10.1016/j.tree.2007.11.003

Saunders, M., Luck, G. (2012). Pan trap catches of pollinator insects vary with habitat. *Australian Journal of Entomology, 52*(2), 106-113. https://doi.org/10.1111/aen.12008

Schulp, C., Lautenbach, S., Verburg, P. (2014). Quantifying and mapping ecosystem services: Demand and supply of pollination in the European Union. *Ecological Indicators, 36*, 131-141. https://doi.org/10.1016/j.ecolind.2013.07.014

Schweiger, O., Biesmeijer, J., Bommarco, R., Hickler, T., Hulme, P., Klotz, S., Kühn, I., Moora, M., Nielsen, A., Ohlemüller, R., et al. (2010). Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination. *Biological Reviews, 85*, 777-795. doi: 10.1111/j.1469-185X.2010.00125.x

Senapathi, D., Biesmeijer, J., Breeze, T., Kleijn, D., Potts, S., Carvalheiro, L. (2015). Pollinator conservation — the difference between managing for pollination services and preserving pollinator diversity. *Current Opinion in Insect Science, 12*, 93-101. https://doi.org/10.1016/j.cois.2015.11.002

Settele, J., Bishop, J., Potts, S. (2016). Climate change impacts on pollination. *Nature Plants, 2*, 1-3. https://doi.org/10.1038/nplants.2016.92

Sheffield, C. (2006). *Diversity and management of bees for the pollination of apple in the Annapolis Valley of Nova Scotia* [Doctoral dissertation, University of Guelph]. Library and Archives Canada.

Sheffield, C. (2014). Pollination, seed set and fruit quality in apple: studies with Osmia lignaria (Hymenoptera: Megachilidae) in the Annapolis Valley, Nova Scotia, Canada. *Journal of Pollination Ecology*, *12*, 120–128. https://doi.org/10.26786/1920-7603(2014)11

Sheffield, C., Kevan, P., Pindar, A., Packer, L. (2013). Bee (Hymenoptera: Apoidea) diversity within apple orchards and old fields in the Annapolis Valley, Nova Scotia, Canada. *The Canadian Entomologist, 145*(1), 94-114. doi: 10.4039/tce.2012.89

Sheffield, C., Kevan, P., Smith, R., Rigby, S., Rogers, R. (2003). Bee Species of Nova Scotia, Canada, with New Records and Notes on Bionomics and Floral Relations (Hymenoptera: Apoidea). *Journal of the Kansas Entomological Society, 76*(2), 357-384.

Sheffield, C., Kevan, P., Westby, S., Smith, R. (2008). Diversity of cavity-nesting bees (Hymnoptera: Apoidea) within apple orchards and wild habitats in the Annapolis Valley, Nova Scotia, Canada. *The Canadian Entomologist, 140* (2), 235-249. https://doi.org/10.4039/n07-058

Sheffield, C., Ratti, C., Packer, L., Griswold, T. (2011). Leafcutter and Mason Bees of the Genus Megachile Latreille (Hymenoptera: Megachilidae) in Canada and Alaska. *Canadian Journal of Arthropod Identification, 18*. doi: 10.3752/cjai.2011.18

Sheffield, C., Westby, S., Kevan, P., Smith, R. (2008). Winter Management Options for the Orchard Pollinator *Osmia lignaria* Say (Hymenoptera: Megachilidae) in Nova Scotia. *Journal of the Entomological Society of Ontario, 139*, 3-18.

Sherren, K., Ellis, K., Guimond, J., Kurylyk, B., LeRoux, N., Lundholm, J., Mallory, M., van Proosdij, D., Walker, A., Bowron, T., et al. (2021). Understanding multifunctional Bay of Fundy dykelands and tidal wetlands using ecosystem services—a baseline. *Facets, 6*, 1446-1473. https://doi.org/10.1139/facets-2020-0073

Sherren, K., Loik, L., Debner, J. (2016). Climate adaptation in 'new world' cultural landscapes: The case of Bay of Fundy agricultural dykelands (Nova Scotia, Canada). *Land Use Policy, 51*, 267-280. http://dx.doi.org/10.1016/j.landusepol.2015.11.018

Simanonok, M., & Burkle, L. (2019). Nesting success of wood-cavity-nesting bees declines with increasing time since wildfire. *Ecology and Evolution, 9*(22), 12436-12445. https://doi.org/10.1002/ece3.5657

Singh, K., Walters, B., Ollerhead, J. (2007). Climate Change, Sea-Level Rise and the Case for Salt Marsh Restoration in the Bay of Fundy, Canada. *Environments, 35*(2), 71-84.

Small, N., Munday, M., Durance, I. (2017). The challenge of valuing ecosystem services that have no material benefits. *Global Environmental Change, 44*, 57-67. https://doi.org/10.1016/j.gloenvcha.2017.03.005

Smith, K., Loh, E., Rostal, M., Zambrana-Torrelio, C., Mendiola, L., Daszak, P. (2013). Pathogens, Pests, and Economics: Drivers of Honey Bee Colony Declines and Losses. *EcoHealth, 10*, 434-445.

Smith, M., Mueller, N., Springmann, M., Sulser, T., Garibaldi, L., Gerber, J., Wiebe, K., Myers, S. (2022). Pollinator Deficits, Food Consumption, and Consequences for Human Health: A Modeling Study. *Environmental Health Perspectives, 130*(12). https://doi.org/10.1289/EHP10947

Smith, T., & Saunders, M. (2016). Honey bees: the queens of mass media, despite minority rule among insect pollinators. *Insect Conservation and Diversity, 9*, 384-390. doi: 10.1111/icad.12178

Solís-Montero, L., Vergara, C., Vallejo-Marín, M. (2015). High incidence of pollen theft in natural populations of a buzz-pollinated plant. *Arthropod-Plant Interactions, 9*(6), 599–611. doi: 10.1007/s11829-015-9397-5

Solomon, M. (1957). Dynamics of Insect Populations. *Annual Review of Entomology, 2*, 121-142. https://doi.org/10.1146/annurev.en.02.010157.001005

Soltis, D., Bell, C., Kim, S., Soltis, P. (2008). Origin and Early Evolution of Angiosperms. *Annals of the New York Academy of Sciences, 1133*(1), 3-25. https://doi.org/10.1196/annals.1438.005

Sridhar, A., Balakrishnan, A., Jacob, M, Sillanpää, M., Dayanandan, N. (2023). Global impact of COVID-19 on agriculture: role of sustainable agriculture and digital farming. *Environmental Science and Pollution Research, 30*, 42509-42525. https://doi.org/10.1007/s11356-022-19358-w

Stanley, D., Garrat, M., Wickens, J., Wickens, V., Potts, S., Raine, N. (2015). Neonicotinoid pesticide exposure impairs crop pollination services provided by bumble bees. *Nature, 528*(7583), 548-550. doi: 10.1038/nature16167

Statistics Canada. (2022). *Production and value of honey, 2022*. Retrieved from Statistics Canada website: https://www150.statcan.gc.ca/n1/daily-quotidien/221214/dq221214f-eng.htm

Stephen, W. (1966). *Andrena (Cryptandrena) viburnella*. I. Bionomics. *Journal of the Kansas Entomological Society, 39*(1), 42-51.

Stoner, K. (2020). Pollination Is Sufficient, Even with Low Bee Diversity, in Pumpkin and Winter Squash Fields. *Agronomy, 10*(8), 1141. https://doi.org/10.3390/agronomy10081141

Striebig, B., Smitts, E., Morton, S. (2019). Impact of Transportation on Carbon Dioxide Emissions from Locally vs. Non-locally Sourced Food. *Emerging Science Journal, 3*(4), 222-234. http://dx.doi.org/10.28991/esj-2019-01184

TapRoot Farms. (2019). *TapRoot Farms – Organic Farming in Nova Scotia*. https://taprootfarms.ca/

Tesic, D., Keller, D., Hutton, R. (2007). Influence of vineyards floor management practices on grapevine vegetative growth, yield, and fruit composition. *American Journal of Enology and Viticulture, 58*(1), 1-11.

Thomson, D. (2004). Competitive Interactions Between the Invasive European Honey Bee and Native Bumble Bees. *Ecology, 85*(2), 458-470. https://doi.org/10.1890/02-0626

Thralls, E., & Treadwell, D. (2017). *Home Vegetable Garden Techniques: Hand Pollination of Squash and Corn in Small Gardens*. Institute of Food and Agriculture Sciences, University of Florida. https://edis.ifas.ufl.edu/publication/HS398

Timberlake, T., Vaughan, I., Memmott, J. (2019). Phenology of farmland floral resources reveals seasonal gaps in nectar availability for bumble bees. *Journal of Applied Ecology, 56*(7), 1585-1596. https://doi.org/10.1111/1365-2664.13403

Torné-Noguera, A., Rodrigo, A., Arnan, X., Osorio, S., Barril-Graells, H., da Rocha-Filho, L., Bosch, J. (2014). Determinants of Spatial Distribution in a Bee Community: Nesting Resources, Flower Resources, and Body Size. *PLoS One, 9*(5), e97255. https://doi.org/10.1371/journal.pone.0097255

Ullmann, K., Meisner, M., Williams, N. (2016). Impact of tillage on the crop pollinating, ground-nesting bee, *Peponapis pruinosa* in California. *Agriculture, Ecosystems & Environment, 232*, 240-246. https://doi.org/10.1016/j.agee.2016.08.002

United States Forest Service. (n.d.). *What is Pollination?* U.S. Department of Agriculture. https://www.fs.usda.gov/managing-land/wildflowers/pollinators/what-is-pollination

Valido, A., Rodríguez-Rodríguez, M., Jordano, P. (2019). Honey bees disrupt the structure and functionality of plant-pollinator networks. *Scientific Reports, 9*. https://doi.org/10.1038/s41598-019-41271-5

Vallejo-Marín, M. (2018). Buzz pollination: studying bee vibrations on flowers. *New Phytologist, 224*(3), 1068-1074. https://doi.org/10.1111/nph.15666

Vanbergen, A. (2013). Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and Environment, 11*(5), 251-259. https://doi.org/10.1890/120126

van der Sluijs, J. (2020). Insect decline, an emerging global environmental risk. *Current Opinion in Environmental Sustainability, 46*, 39-42. https://doi.org/10.1016/j.cosust.2020.08.012

van der Sluijs, J., Simon-Delso, N., Goulson, D., Maxim, L, Bonmatin, J., Belzunces, L. (2013). Neonicotinoids, bee disorders and the sustainability of pollinator services. *Current Opinion in Environmental Sustainability, 5*(3-4), 293-305. https://doi.org/10.1016/j.cosust.2013.05.007

van der Sluijs, J., & Vaage, N. (2016). Pollinators and Global Food Security: the Need for Holistic Global Stewardship. *Food Ethics, 1*, 75-91. https://doi.org/10.1007/s41055-016-0003-z

Vázquez, D., Lomáscolo, S., Maldonado, M., Chacoff, N., Dorado, J., Stevani, E., Vitale, N. (2012). The strength of plant–pollinator interactions. *Ecology, 93*, 719-725. https://doi.org/10.1890/11-1356.1

Vilcinskas, A. (2019). Pathogens associated with invasive or introduced insects threaten the health and diversity of native species. *Current Opinion in Insect Science, 33*, 43-48. https://doi.org/10.1016/j.cois.2019.03.004

Wagner, D. (2020). Insect Declines in the Anthropocene. *Annual Review of Entomology, 65*, 457-480. https://doi.org/10.1146/annurev-ento-011019-025151

Walker, E., Pindar, A., Lundholm, J. (2021). Diverse heathland bee communities provide limited pollination services for lowbush blueberry species. *Journal of the Acadian Entomological Society, 17*, 1-15.

Wallace, K. (2007). Classification of Ecosystem Services: Problems and Solutions. *Biological Conservation, 139*, 235-246. https://doi.org/10.1016/j.biocon.2007.07.015

Westman, W. (1977). How Much are Nature's Services Worth? *Science, 197*(4307), 960-964.

Weston, P. (2023, June 7). Insect decline a threat to fruit crops and food security, scientists warn MPs. *The Guardian*. https://www.theguardian.com/environment/2023/jun/07/insect-decline-a-threat-to-fruit-crops-and-food-security-scientists-warn-mps-aoe

Wietzke, A., Westphal, C., Gras, P., Kraft, M., Pfohl, K., Karlovsky, P., Pawelzik, E., Tscharntke, T., Smit, I. (2018). Insect pollination as a key factor for strawberry physiology and marketable fruit quality. *Agriculture, Ecosystems & Environment, 258*, 197-204. https://doi.org/10.1016/j.agee.2018.01.036

Wignall, V., Brolly, M., Uthoff, C., Norton, K., Chipperfield, H., Balfour, N., Ratnieks, F. (2020). Exploitative competition and displacement mediated by eusocial bees: experimental evidence in a wild pollinator community. *Behavioral Ecology and Sociobiology, 74*(152). https://doi.org/10.1007/s00265-020-02924-y

Wilson, J., Griswold, T., Messinger, O. (2008). Sampling Bee Communities (Hymenoptera: Apiformes) in a Desert Landscape: Are Pan Traps Sufficient? *Journal of the Kansas Entomological Society, 81*(3), 288-300.

Wilson, H., Wong, J., Thorp, R., Miles, A., Daane, K., Altieri, M. (2018). Summer Flowering Cover Crops Support Wild Bees in Vineyards. *Environmental Entomology, 47*(1), 63-69. https://doi.org/10.1093/ee/nvx197

Wine Growers of Nova Scotia. (2022, November 16). *We're growing Nova Scotia, one vine at a time.* https://winesofnovascotia.ca/were-growing-nova-scotia/

Winfree, R., Gross, B., Kremen, C. (2011). Valuing pollination services to agriculture. *Ecological Economics, 71*, 80-88. doi: 10.1016/j.ecolecon.2011.08.001

Winfree, R., Williams, N., Dushoff, J., Kremen, C. (2007). Native bees provide insurance against ongoing honey bee losses. *Ecology Letters, 10*, 1105-1113. doi: 10.1111/j.1461-0248.2007.01110.x

Wratten, S., Gillespie, M., Decourtye, A., Mader, E., Desneux, N. (2012). Pollinator habitat enhancement: Benefits to other ecosystem services. *Agriculture, Ecosystems & Environment, 159*, 112-122. https://doi.org/10.1016/j.agee.2012.06.020

Wynn, G. (1979). Late Eighteenth-Century Agriculture on the Bay of Fundy Marshlands. *Acadiensis, 8*(2), 80-89.

Chapter 6: Appendices

6.1. APPENDIX A
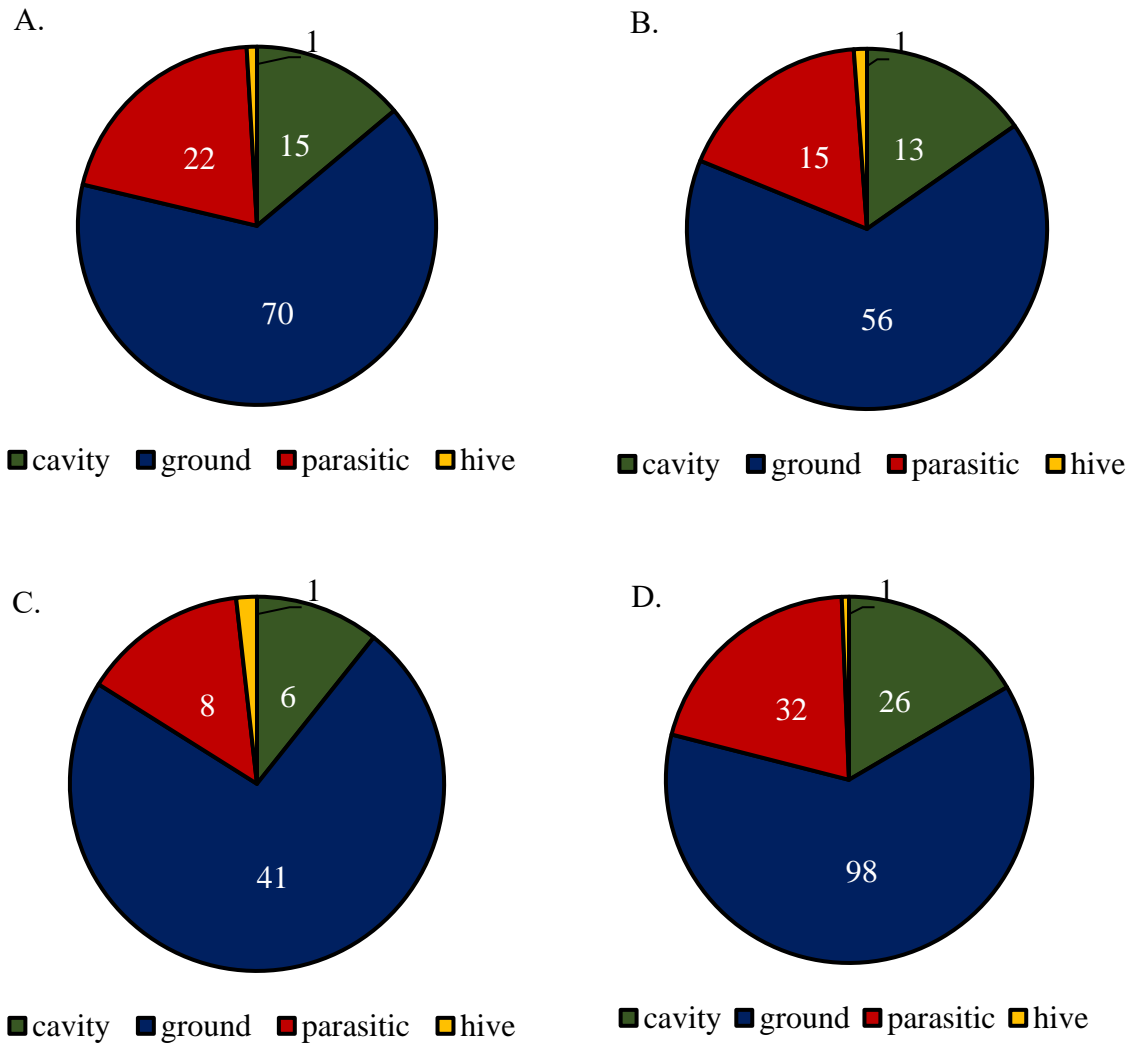
Figure 6.1. Proportions of different nesting biologies amongst bee taxa in different crops, for purposes of comparison with Roulston (2021). From the top, left to right: A. Apple, B. tomato, C. squash, and D. all crops studied combined.

6.2. APPENDIX B

Table 6.1. List of bee genera and species caught and identified over the course of this study. Nesting biology information has been described by Packer et al., 2007[1]; Colla et al., 2011[2]; Sheffield et al., 2003[3]; and Sheffield et al., 2011[4].

Family	Genus	Species	Nesting Biology	Apple Abundance	Tomato Abundance	Squash Abundance	Total Abundance
Andrenidae	*Andrena*	*algida*	Ground[1]	6	1		7
		alleghaniensis	Ground[1]	10	1		11
		asteris	Ground[1]	1			1
		barbilabris	Ground[1]	1			1
		bisalicis	Ground[1]	6			6
		bradleyi	Ground[1]	34	1		35
		brevipalpis	Ground[1]	16			16
		carlini	Ground[1]	10			10
		carolina	Ground[1]	1			1
		ceanothi	Ground[1]	1			1
		clarkella	Ground[1]	3			3
		commoda	Ground[1]	19	1		20
		crataegi	Ground[1]	6			6
		cressonii	Ground[1]	62	11		73
		dunningi	Ground[1]	32			32
		erythrogaster	Ground[1]	1			1
		forbesii	Ground[1]	2			2

Family	Genus	species					
		geranii	Ground[1]	5			5
		imitatrix	Ground[1]	1	1		2
		kalmiae	Ground[1]	1			1
		mandibularis	Ground[1]	5			5
		mariae	Ground[1]	9	2		11
		milwaukeensis	Ground[1]	4			4
		miranda	Ground[1]	1			1
		miserabilis	Ground[1]	7			7
		nasonii	Ground[1]	6			6
		nigrihirta	Ground[1]	5			5
		nivalis	Ground[1]	25	2		27
		persimulata	Ground[1]	1			1
		regularis	Ground[1]	3			3
		sigmundi	Ground[1]	2			2
		spiraeana	Ground[1]	4			4
		vicina	Ground[1]	16			16
		virginiana	Ground[1]	4	1		5
		wheeleri	Ground[1]	6	1		7
		wilkella	Ground[1]	6	2		8
		w-scripta	Ground[1]	4			4
	Calliopsis	*andreniformis*	Ground[1]		14	2	16
	Perdita	*octomaculata*	Ground[1]		18		18
Apidae	*Apis*	*mellifera*	Hive[1]	213	48	194	455
	Bombus	*ashtoni*	Parasitic[2]			1	1

Genus	Species	Nesting				Total
	borealis	Ground[1,2]			2	2
	citrinus	Parasitic[2]		1		1
	fervidus	Ground[1,2]			2	2
	impatiens	Ground[1,2]	16	2	89	107
	perplexus	Ground/Trees & Logs[2]			1	1
	sandersoni	Ground[1]		2		2
	ternarius	Ground[1,2]		3		3
	vagans	Ground[1,2]		2	2	4
Ceratina	*calcarata*	Stem Cavities[1]	81	4		85
	dupla	Stem Cavities[1]	21			21
	mikmaqi	Stem Cavities[1]	112	4		116
Melissodes	*druriellis*	Ground[3]			7	7
	subillatus	Ground[3]			1	1
Nomada	*articulata*	Parasitic[1]	4	3		7
	australis	Parasitic[1]	1			1
	composita	Parasitic[1]		1		1
	cressonii	Parasitic[1]	8	4		12
	depressa	Parasitic[1]	15	1		16
	florilega	Parasitic[1]	4			4
	gracilis	Parasitic[1]	4			4
	imbricata	Parasitic[1]	2			2
	integerrima	Parasitic[1]	7			7
	lehighensis	Parasitic[1]	6	3		9
	luteoloides	Parasitic[1]	2			2

Family	Genus	species	Nesting				Total
		obliterata	Parasitic[1]	5			5
		pygmaea	Parasitic[1]	3			3
		sayi	Parasitic[1]	1			1
		valida	Parasitic[1]	1			1
Colletidae	*Colletes*	*validus*	Ground[3]	1			1
	Hylaeus	*affinis*	Stem Cavities[1, 3]			1	1
		annulatus	Stem Cavities[1, 3]		6	4	10
		mesillae	Stem Cavities[1, 3]		4	4	8
		modestus	Stem Cavities[1, 3]		2		2
		verticalis	Stem Cavities[1, 3]		2		2
Halictidae	*Agapostemon*	*virescens*	Ground[1]	10	249	13	272
	Augochlora	*pura*	Wood Cavities[1]	1			1
	Augochlorella	*aurata*	Ground[1]	3	14	2	19
	Halictus	*confusus*	Ground[1]	21	6	15	42
		ligatus	Ground[1]	71	20	14	105
		rubicundus	Ground[1]	7	22	3	32
	Lasioglossum	*albipenne*	Ground[1]	11	14		25
		athabascense	Ground[1]	4	2	2	8
		atwoodi	Ground[1]	12			12
		birkmanni	Ground[1]			1	1
		boreale	Ground[1]		1		1
		cinctipes	Ground[1]		3		3
		coriaceum	Ground[1]	9	9	1	19
		cressonii	Ground[1]	33	172	1	206

ephialtum	Ground[1]	5	2	1	8
foxii	Ground[1]	1	2	3	6
fuscipenne	Ground[1]		1		1
georgeickworti	Ground[1]	1			1
heterognathum	Ground[1]		2	1	3
illinoense	Ground[1]	7			7
imitatum	Ground[1]	9	3	7	19
inconditum	Ground[1]			1	1
katherineae	Ground[1]	2	3	3	8
laevissimum	Ground[1]	26	7		33
leucocomum	Ground[1]	25	14	3	42
leucozonium	Ground[1]	7	166	84	257
lineatulum	Ground[1]	2			2
macoupinense	Ground[1]		2	4	6
nelumbonis	Ground[1]	1		1	2
nigroviride	Ground[1]	3	2		5
novascotiae	Ground[1]	3	2		5
obscurum	Ground[1]		1	1	2
paradmirandum	Ground[1]		1	1	2
paraforbesii	Ground[1]		1		1
pectorale	Ground[1]			1	1
perpunctatum	Ground[1]	26	6	8	40
pilosum	Ground[1]	64	24	22	110
planatum	Ground[1]	4		2	6

	quebecense	Ground[1]		3		3
	rufilpes	Ground[1]			1	1
	sagax	Ground[1]	53	6	4	63
	subversans	Ground[1]		1	1	2
	subviridatum	Ground[1]	10	1	3	14
	timothyi	Ground[1]		4	3	7
	truncatum	Ground[1]		1		1
	versans	Ground[1]	140	29	7	176
	viridatum	Ground[1]		2	2	4
	zephyrum	Ground[1]	23	9		32
	zonulum	Ground[1]	16	36	51	103
Sphecodes	*aroniae*	Parasitic[1]			1	1
	banksii	Parasitic[1]			1	1
	clematidis	Parasitic[1]			1	1
	confertus	Parasitic[1]	1	1		2
	davisii	Parasitic[1]			1	1
	dichrous	Parasitic[1]	1	3		4
	galerus	Parasitic[1]	4			4
	johnsonii	Parasitic[1]	1	1		2
	levis	Parasitic[1]	3			3
	persimilis	Parasitic[1]	2	4	1	7
	pimpinellae	Parasitic[1]		1		1
	ranunculi	Parasitic[1]	2	1		3
	solonis	Parasitic[1]		1	2	3

		stygius	Parasitic[1]	1	4	6	11
Megachilidae	*Coelioxys*	*rufitarsus*	Parasitic[1]		1		1
	Hoplitis	*producta*	Cavity[3]		2		2
		spoliata	Cavity[3]	4	1		5
	Megachile	*gemula*	Cavity[3, 4]			1	1
		melanophaea	Ground[3, 4]		2		2
		montivaga	Cavity/Ground[3, 4]		1		1
	Osmia	*albiventris*	Cavity[1]	4			4
		atriventris	Cavity[1]		1		1
		bucephala	Cavity[1]		1	2	3
		caerulescens	Cavity[1]	2			2
		cornifrons	Cavity[1]	4			4
		inermis	Cavity[1]	1			1
		inspergens	Cavity[1]		1		1
		laticeps	Cavity[1]	1			1
		lignaria	Cavity[1]	3		1	4
		near trevoris	Cavity[1]	5			5
		simillima	Cavity[1]	1	1		2
		taurus	Cavity[1]	3			3
		virga	Cavity[1]	1			1
TOTAL				1487	1018	594	3099

a. References used for Appendix B

Colla, S., Richardson, L., Williams, P. (2011). Bumblebees of the Eastern United States. United States Forest Service and Pollinator Partnership. 104 pp. (https://www.researchgate.net/publication/259460463_Bumblebees_of_the_eastern_United_States).

Packer, L., Genaro, J., Sheffield, C. (2007). The Bee Genera of Eastern Canada. Canadian Journal of Arthropod Identification, 3, 1-32.

Sheffield, C., Ratti, C., Packer, L., Griswold, T. (2011). Leafcutter and Mason Bees of the Genus Megachile Latreille (Hymenoptera: Megachilidae) in Canada and Alaska. Canadian Journal of Arthropod Identification, 18. doi: 10.3752/cjai.2011.18

Sheffield, C., Kevan, P., Smith, R., Rigby, S., Rogers, R. (2003). Bee Species of Nova Scotia, Canada, with New Records and Notes on Bionomics and Floral Relations (Hymenoptera: Apoidea). Journal of the Kansas Entomological Society, 76(2), 357-384.