The quality of citizen scientists' bee observations: An evaluation of PollinatorWatch at Royal Botanical Gardens and the ***rare*** Charitable Research Reserve

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.
I understand that my thesis may be made electronically available to the public.

Abstract

Citizen science engages members of the nonscientific community in academic research, contributing to our collective knowledge of the natural environment through biological monitoring and environmental observations. Observation plots are often used to assess pollinator diversity and abundance in citizen science monitoring programs. To ensure that data collected are reliable, citizen observations should be evaluated against controlled scientific studies. I designed this project to assess the accuracy of citizen observations of bees in order to enhance the efficacy of PollinatorWatch, a Canadian pollinator monitoring program. PollinatorWatch engages volunteers in collecting observational data on bees visiting flowers but the program's effectiveness at reporting on bee faunal information has not been evaluated. Specifically, I was interested in determining how PollinatorWatch could be standardized to validate the efforts of participants. Research took place in mixed meadow habitats at two urban conservation areas, the Royal Botanical Gardens in Burlington, ON and the ***rare*** Charitable Research Reserve in Cambridge, ON. I trained 19 citizen scientists to observe and record bees visiting flowers using broad species-groups based on recognizable features (e.g. Green bee) or familiar bees (e.g. Bumble bee). Over the course of one summer, I conducted a survey of bees using pan-trapping and sweep netting at eleven sites. I collected 1864 bees of 74 species, verified by experts. Additionally, volunteers made observations at six of the eleven sites. To evaluate the reliability of citizen science data, I compared observations (observation data set, 590 bees) to specimens (specimen data set, 1041 bees) collected from the same sites. I found positive correlations in bee abundance among the two data sets (Spearman's ρ ranged from 0.8 to 1, *p*-values 0.017 to 0.333), though information collected by volunteers was more robust over the long-term (season-wide observations) than the short-term (single observations). Observations more closely matched netted + pan-trapped bees than netted bees alone but observers recorded approximately half as many bees as were collected. Discrepancies between observational and specimen-based data were greatest for species-groups that lumped a large variety of bees (e.g. Small bee), so I propose changes to the PollinatorWatch protocol to reduce identification errors. Although the scope of this project was limited by the number of participants and the habitats surveyed, I suggest that PollinatorWatch can be improved by further studies that examine a revised, standardized observation protocol that would serve to improve data quality. In this way, citizen science contributions may more reliably complement more localized, hypothesis-driven bee research while also enhancing participants' own understanding of environmental monitoring.

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Foreword

From a young age I was engaged with the natural world. I have always felt most at home and at ease in the out-of-doors and have been an ardent advocate for environmental conservation for as long as I can recall. Pursuing an undergraduate degree in Biology and Environmental Studies provided me with an academic grounding to understand the world around me in an ecological sense, but also fostered in me a way to look critically at our social impacts on the environment.

Following my BSc degree, I was fortunate to work at Environment Canada's Ecological Monitoring and Assessment Network Coordinating Office where I learned the ins and outs of community-based monitoring and citizen science. There, I had occasion to meet many passionate, caring people who really do love what they do and have a vested interest in the environment. Through their work I was inspired to pursue this thesis project.

Beginning with my undergraduate thesis and continuing through my work at both Environment Canada and during this masters thesis project, I have learned that community-based ecological monitoring is an important way to encourage people to take an interest in the natural environment; it brings together all stakeholders and makes learning about and monitoring the local environment relevant to people's own needs and values. In fact, I think that knowing what inhabits our backyards, neighbourhood green spaces, protected areas, and other public spaces might be the best way for people to get involved and take positive action for conserving the environment. And the most ideal way to do that is to get outside and learn together.

I now have a teaching degree specializing in Outdoor and Experiential Education and aim to educate young children about the wonders of the natural world by playing in it. Today's lesson: combine my lifelong inclinations toward natural history and understanding local diversity – biologically, socially, culturally, and otherwise – with excellent citizen science programs and projects to foster healthy ecosystems and people through education and stewardship.

Chapter 1
Introduction

Conservation efforts by field ecologists, entomologists, and other science experts can help to protect wild bees, and they should be made in concert with public education and citizen engagement. “Science generates information that can be effectively used to educate the public, who may in turn practice stewardship that enhances our conservation efforts” (Caverhill, 2006, xvi). Effective citizen science programs allow for the public to complement efforts of scientists while also increasing public knowledge of problems being addressed by the conservation community, thereby enhancing public input into policy. Through popular media attention surrounding honey bees—with localized overwintering losses and fewer beekeepers—plus the effects of pesticides on bumble bees and other pollinators, and the subsequent impact on pollination, there is now general concern over bee declines (e.g. Bergland, 2007; Munro, 2012; Kelly, 2013). People want to get involved and help to make a difference. Gardeners, naturalists, land owners, land managers, and policy makers can all play a role in the conservation and monitoring of bees.

1.1 Pollinators and Pollination Ecology

Three quarters of flowering plant taxa depend on animal pollinators for their reproduction (National Research Council, 2007; Ollerton *et al*., 2011). Pollination occurs when pollen is moved from the anther to the stigma of a flower or carried from one flower to another. Certain groups of insects, birds, small mammals, and even lizards, as well as wind and water can move pollen, facilitating successful fertilization of flowering plants which ultimately allows flowers to develop seeds and reproduce (Proctor *et al*., 1996; Willmer, 2011).

In addition to assisting in the propagation and diversification of plants, animal pollinators provide ecosystem services by contributing to the production of fruit, nuts, berries, and seeds that are food for wildlife and human beings, who depend on the work of pollinators for as much as one-third of our diet (Klein *et al*., 2007).

Although many species of flies, butterflies, moths, beetles and birds can act as pollinators world-wide, bees are the major group of pollinators in ecosystems that contain flowering plants in the northern hemisphere (Kevan and Baker, 1983). Bees have a strong and often necessary facultative cooperation with pollinating flowers because they are completely dependent on pollen and nectar for every stage of their development, requiring these floral resources as food for themselves and their offspring (Michener, 2007).

Wild bees are crucial for the pollination of most non-crop flowering plants, so play an essential role in most terrestrial ecosystems (Kevan, 2001). Although people rely heavily on a single introduced species, the honey bee (*Apis mellifera*), for much of our crop pollination, there are at least 800 species of wild, native bees in Canada that contribute to pollination and other ecosystem services (Packer *et al*., 2007; Sheffield *et al.*, 2011).

Evidence is mounting that insect pollinators of crops and wild plants are threatened by habitat destruction, pesticide use, invasive species, and the spread of parasites and diseases (e.g. Biesmeijer *et al*., 2006; Potts *et al*., 2010). For example, almond acreage in California increased dramatically over 26 years (149,000 ha in 1980 to 560,000 ha in 2006), resulting in a heavy reliance on managed honey bees and a decreased capacity of native bee pollination (Ghazoul, 2007). Intensification of agriculture in Canada's mixedwood plains resulted in cropland increases from 61 to 70% of the agricultural landscape between 1986 and 2006. Yet during this same period, the average wildlife habitat capacity on agricultural land declined greatly (Javorek and Grant, 2011). Landscape-scale changes and other pressures on insect pollination may reduce suitable habitat needed to sustain bee populations and have serious implications for food security and ecosystem functioning (Vanbergen *et al*., 2013). Pollinator declines can result in a loss of pollination services which could lead to decreased plant variety and availability (Taki *et al*., 2007; Kaiser-Bunbury *et al*., 2010). Because plants form the base of most terrestrial food webs, a loss of plant diversity can lead to spatial and temporal gaps in the availability of floral resources for pollinators and significantly affect wider ecosystem stability (Matheson, 1994; Banaszak, 1996; Potts *et al*., 2010).

1.2 Addressing Pollinator Declines

Over a decade and a half ago, experts called for policies to address pollinator decline in light of potentially major long-term ecological implications (Allen-Wardell *et al*., 1998). More recently, reports of bee declines in North America have highlighted the need for greater understanding of bee ecology and habitat conservation (e.g. Colla and Packer, 2008). Despite the importance of bees to our everyday lives, little is known about most species to allow for an evaluation of population changes (National Research Council, 2007). In order to systematically address this knowledge gap, a group of over twenty field scientists across North America called for a long-term monitoring protocol to collect baseline data to assess changes in the diversity and abundance of pollinators (Allen-Wardell *et al*., 1998). Additionally, the Committee on the Status of Pollinators in North America (CSPNA) has recommended a long-term and large-scale ecological monitoring program to quantify the diversity and abundance of bees (National Research Council, 2007). While many specimen-based survey protocols exist, experts stress that such monitoring schemes should be carried out using standardized methods (Dias *et al*., 1999; Williams *et al*., 2001). Specimen-based surveys require the technical expertise of taxonomists to identify bees but there is a shortage of trained taxonomists in North America (referred to as the taxonomic impediment). So the challenge is to establish standardized protocols that provide useable data yet don't rely heavily on the few experts to verify all of the information.

As part of a long-term monitoring program, the CSPNA recommends "monitoring that integrates the work of professional scientists and citizen-scientists in tracking pollinator status…to maximize the depth and breadth of effort" (National Research Council, 2007, p. 204). Citizen science programs engage a widespread network of volunteers in collecting data using prescribed protocols that have been developed by or in consultation with professional scientists as a way to address questions raised by researchers. The main advantage of citizen science is that research can be conducted at broad scales without necessarily requiring experts to be at each study site (Cooper *et al*., 2007). Previous studies have shown that data collected through citizen science programs can enrich our understanding of population trends in wildlife (e.g. Prysby and Oberhauser, 2004; Cannon *et al*., 2005; Bonter and Harvey, 2008), though it tends to be most valuable when examining broad scales of information. With citizen science programs, participants submit their data to a central location where it can be accessed by other participants and analyzed and published by researchers (Bhattacharjee, 2005).

Citizen science efforts can produce large, longitudinal data sets but their potential for error and bias is not well understood. Sampling bias is an issue, specifically variation in sampling effort (e.g. Niemuth *et al*., 2007; McGowan and Zuckerberg, 2008). Citizen scientists vary in age, training, education, collection skills, and length of participation in a program. So observer quality—the variation in observers' ability to collect data—is an ongoing concern regarding citizen science, especially as it compares to professional science quality. As such, there is a recognized need for wider data quality assessment in citizen science programs (Dickinson *et al*., 2010). With strong programs, scientists can have a certain degree of confidence that information gathered by volunteers is reliable, relevant, and useable.

1.3 Research Objectives and Design

Mayer *et al*. (2011) posed several prominent questions facing pollination ecologists, citizen science, and the monitoring of bees, including: (1) How can we successfully raise awareness among the general public about plants, pollinators, and pollination services? and (2) How can we better make use of plants and their pollinators as educational tools for increasing public awareness? My thesis project helps illuminate at least an aspect of the answers to these questions, contributing to PollinatorWatch (www.pollinationcanada.ca), a citizen science pollinator monitoring program in Canada.

PollinatorWatch has not yet been evaluated for its effectiveness at capturing bee fauna information in a meaningful way, specifically whether or not observations provide a useful approximation of bee diversity. Thus, I sought to address the following research question: *How can PollinatorWatch be standardized and tailored so that volunteers provide valuable, reliable bee observations to ecologists?* The first objective of my study was to assess the performance of volunteers in observing bees using a modified PollinatorWatch protocol. To carry out this assessment, I compared citizen science observations to specimen-based collections in two ways: (i) season-wide and (ii) visit-by-visit. My second objective was to evaluate options for reporting observations in PollinatorWatch based on field data and volunteer experiences. This was done by drawing on three schemes for participants to record observations, each based on easily recognized morphological features or familiar taxa.

Citizen science protocols are most effective when designed in ways that account for relatively untrained volunteers to collect data while still allowing researchers to use the data as appropriate (e.g. assessing broad trends, making generalizations about population status). The outcome of my research will help improve PollinatorWatch by strengthening the protocol and will assist in developing a useful data collection method for long-term bee monitoring using observations.

Chapter 2
Literature Review

This literature review aimed to address the following framework questions: (1) What design features are characteristic of successful citizen science programs? and (2) How is the value of citizen science data addressed in the literature? The major themes I reviewed in the literature were how citizen science contributes to long-term ecological monitoring, quality control of volunteer-based data, standardizing citizen science protocols, and evaluating data collected by citizen scientists. The aim of the following literature review was to identify general perspectives and approaches used in citizen science programs in pursuit of delivering valuable results to the scientific community.

2.1 Long-term Ecological Monitoring

Biodiversity monitoring involves three activities: (1) repeatedly measuring a specified set of variables in a target area over an extended period of time; (2) analyzing temporal and spatial patterns; and (3) interpreting results to distribute to intended users (Schmeller *et al*., 2008). Standardized protocols are used in monitoring programs so that research can be repeated in successive seasons or years, and data can be collected in the same way at geographically dispersed sites. By following the same procedure each time, valuable records of status and trends are established.

Land managers, planners, and engineers often require monitoring data to make informed decisions. Through long-term monitoring of status and trends, pollination biologists can share scientific knowledge on pollinators with decision-makers to encourage its incorporation into land management plans where appropriate (Frankie *et al*., 2002). For instance, population changes of the Rusty-patched Bumble bee (*Bombus affinis*) over 35 years led to its inclusion on Canada’s Species at Risk Act in 2010, which provides habitat protection that benefits many pollinators. Monitoring information is most effectively conveyed in a form that is accessible and credible to decision-makers, so in the interest of pollinator conservation, pollination biologists are challenged with carrying their findings beyond traditional scientific meetings and journal publications (Danielsen *et al*., 2005). Canada's own Canadian Pollinator Initiative (CANPOLIN) is leading the field in gathering and analyzing information on pollinator issues across the country—including honey bee health, the economics of beekeeping, and climate change modeling—and is also sharing information with government, industry, and environmental non-government organizations to inform policy and regulatory processes (Kevan *et al*., 2010; NSERC-CANPOLIN, 2013).

Although there is no large-scale monitoring program in Canada for bees yet, CANPOLIN has implemented widespread diversity surveys using a standardized method in order to gather baseline data for long-term bee monitoring. The protocol recommends using passive sampling through Malaise traps, trap nests, and/or pan-traps. Pan-trapping has its limitations (see McLeod, 2013), but it is a commonly used technique (Kearns and Inouye, 1993; Dafni *et al*., 2005), a particularly efficient, cost-effective way to detect species richness, and can be augmented by sweep netting specimens from flowers which provide an indication of plant-pollinator associations (Frankie *et al*., 2002; Westphal *et al*., 2008). Using these standard methods, CANPOLIN researchers across the country have been able to inventory and map most of Canada's bee fauna over the span of about five years.

In monitoring systems, two general types of objectives are used: assessment of state and detection of change (Vos *et al*., 2000). Now that we have a baseline measure of Canada's bees (see for e.g. Sheffield *et al*., 2011), pollination researchers can begin recording changes in bee populations over time across wide biogeographic areas.

In addition to the typical sampling carried out by researchers, citizen scientists can play a complementary role in monitoring bees by collecting observational data on local diversity and abundance. Data gathered by citizen scientists forms the basis of many extensive monitoring programs and contributes valuable long-term records to environmental knowledge.

2.2 Strengths of Citizen Science

In citizen science, volunteers are involved in science as researchers through data collection (Trumbull *et al*., 2000). Volunteers play a role in gathering biodiversity and environmental information across an assortment of habitats and locations over long periods of time. Citizen science programs represent a partnership between volunteers and professional scientists and are designed to answer research questions (Cooper *et al*., 2007). Through integrating public outreach with scientific data collection protocols, citizen science has become an established approach to advancing scientific knowledge of population trends in wildlife (Prysby and Oberhauser, 2004; Cannon *et al*., 2005).

In order to have effective citizen science, though, it is imperative to have good research science and professional studies. In complementing the work of scientists, participating citizens can improve the relevance of ecological indicators and scenarios, help identify key issues and areas of concern for biodiversity, and facilitate action on public policy for managing ecosystems (Couvet *et al*., 2008).

When designing citizen science projects, developers tend to choose research questions that rely on basic skills for data collection—for example determining the number of frogs calling in a pond or the first day a plant blooms—because most participants are amateur observers. Projects also tend to be kept simple to attract a large number of participants. Questions that require higher levels of skill or knowledge—such as determining the change in abundance of tree-dwelling lichens—can be successfully developed however, but they require significant inputs to participant training and support materials. Simple projects can address complex questions by recruiting a subset of participants to complete more complex tasks (Bonney *et al*., 2009).

Most citizen science programs use a model of surveillance monitoring, which is carried out without specific hypotheses in mind. Such programs involve monitoring numerous species over broad geographic regions and anticipate that the data will be useful to answer a variety of ecological questions. This approach to monitoring allows researchers to address any unanticipated threats to biodiversity that may arise out of the patterns and trends in long-term data sets (Dickinson *et al*., 2010).

Citizen science programs are often designed to provide a meaningful and relatively inexpensive method to track changes in the distribution and abundance of a target group of wildlife and to be applicable at a variety of scales (Genet and Sargent, 2003). Examples include large-scale amphibian, bird, and butterfly monitoring programs such as the North American Amphibian Monitoring Program, the Breeding Bird Survey, and Monarch Watch as well as the localized Great Lakes Worm Watch.

Engaging a broad network of volunteers inevitably draws participants from a variety of interest groups. Citizen groups that may participate in observing and recording information include cottage associations, anglers and hunters, amateur naturalists, and ornithologists (Stokes *et al.*, 1990). In this way, citizen science can include community-based monitoring, "a process where concerned citizens, government agencies, industry, academia, community groups, and local institutions collaborate to monitor, track and respond to issues of common community concern" (Whitelaw *et al*., 2003, p. 410).

In volunteer-based monitoring programs, people may be most motivated and engaged if they are involved with the entire process, and when they have the opportunity to share and exchange knowledge (Bell *et al.*, 2008; Lawrence, 2009). In traditional science outreach, citizens act solely as the recipients of information; in contrast, in citizen science programs volunteers and scientists truly interact. This is a key component of successful citizen science regimes (Cooper *et al*., 2007; Braschler, 2009). Volunteers are eager to understand that their individual efforts have been recognized and that they have contributed to the whole (Mackechnie *et al*., 2011).

Most citizen scientists work with professional scientists on projects that have been designed specifically to give amateurs a role, and though citizen scientists often do not analyze the data or write technical papers, they are essential to gathering the information on which studies are developed (Cohn, 2008; Silvertown, 2009). The value of data collected by volunteers to research agendas is particularly apparent when efforts of citizen scientists appear in peer-reviewed publications (e.g. Bonter and Harvey, 2008; Chung *et al*., 2011).

Despite the number of publications and programs that involve citizen science, the use of volunteers in scientific research projects is often criticized on the basis that information collected is unreliable (Darwall and Dulvy, 1996). Although best practices are needed at every step in the citizen science program model, high quality data is critical to program success (Bonney *et al*., 2009). Volunteer data should be validated to make comparisons across habitats, sites, or years. Quality control measures must be in place, and where feasible, professional biologists should screen data collected by volunteers so that it is useful to scientists and policy makers (Fore *et al*., 2001; Dickinson et al. 2010).

To be most valuable, programs that involve volunteers should be closely guided by experienced researchers. Program participants can produce high quality results when the program is well structured and well supported, with training, appropriate techniques, and the overall experience of volunteers taken into consideration (Lovell *et al*., 2009). Once proper, standardized protocols are established, data quality can be maintained through regular monitoring of volunteer performance to ensure that sampling design and training remain satisfactory (Danielsen *et al*., 2005).

Collecting good quality field data is not difficult but it's also not intuitive. So if citizen science programs are to generate quality numbers, those who design programs must clearly train volunteers and articulate the 'how's' and 'why's' of the methodology. Guidelines need to be precise and adequate training provided on all aspects of data collection in order to produce consistent and reliable data from volunteers (Foster-Smith and Evans, 2003).

Training may include in-person workshops, instructional information on protocols, and in-field practice. Field training during the data collection season has been shown to benefit novice observers (McLaren and Cadman, 1999). Useful supporting materials can also bolster participants' confidence and a program's data quality (Lovell *et al*., 2009). Materials may include identification guides, manuals, videos, posters, and podcasts that address the challenges in recording observations (Bonney *et al*., 2009).

Appropriate training can also reduce bias and error. Program managers should assess whether personalized, in-person training is needed or whether observers can simply train themselves over the internet or by other means as is commonly done in large citizen science programs (Dickinson *et al*., 2010).

Issues of statistical bias, error, and effort are important to consider in the design of citizen science projects. In general, large sample sizes—in the form of data gathered by many participants—can compensate for individual biases to some degree (Stokes *et al.*, 1990). In an effort to minimize detection error and observer error though, researchers can use methods that limit subjectivity and standardize observer effort (Cooper *et al*., 2007; Lovell *et al*., 2009).

One important way to reduce error is by having volunteers collect data using explicit protocols. As one of the primary goals of monitoring is to gather comparative data over time and space, consistency in technique is crucial. This can be accomplished with clearly stated, standardized procedures and repeated visits to sampling site(s) which are representative of the broader landscape (Dickinson *et al*., 2010; Ottinger, 2010). When programs are developed based on scientific excellence and rigorous protocols, adequate statistical tools can be developed to assess data quality and analyze the data (Newman *et al*., 2003; Couvet *et al*., 2008).

Additionally, studies must be designed with observer motivations and abilities in mind. Protocols should limit what participants are asked to do. For example, they can be expected to identify 5 or 10 indicator species rather than the entire flora and fauna in an area. But the information should not be so vague that it becomes difficult to detect changes or support conclusions. So specific protocols should be used and the results measured for reliability. Both bird and amphibian surveys tend to have well-established protocols for volunteer observers. They are popular and successful because birds, frogs, and toads are relatively easy to learn and recognize by both sight and sound. The programs frequently have particular dates or times of the year within which to record observations as well as discrete lengths of time to spend observing (e.g. Genet and Sargent, 2003). Additionally, programs often—though not always—limit data to a particular subset of species, such as songbirds visiting bird feeders as in Project FeederWatch.

It is also important to use standardized protocols when engaging an audience that is spatially dispersed, ranges in age, and/or brings a variety of experiences to a volunteer-based program. Citizen scientists provide many eyes and ears on-the-ground, recording information simultaneously that would otherwise not be logistically feasible to pursue, and adhering to protocols ensures consistency in the data (Bhattacharjee, 2005).

By designing research projects that engage a network of volunteers to collect large volumes of information across a dispersed landscape and over a longer time period than would be possible with a traditional science research approach, researchers are more able to observe anomalies in the data, distinguish trends, compare the results from one time with another, and understand differences among subpopulations or geographic areas (Cohn, 2008).

Collecting scientific data is not the only reason to engage the public in research. Allowing and encouraging participants to study project information is a key educational aspect of citizen science, so all of the data collected in a program is made available for analysis by both research scientists and the public (Bonney *et al*., 2009).

Not only do participants personally gain additional knowledge and understanding of the environmental issues at-hand, but their feelings of responsibility towards the environment may be enhanced (Darwall and Dulvy, 1996; Evans and Birchenough, 2001). Many volunteers take pride in helping to advance scientific knowledge and protect the wild species and spaces near their homes (Bell *et al*., 2008; Cohn, 2008). The opportunity to undertake fieldwork can open the eyes of citizen scientists to the diversity of life and broaden participant’s perspectives (Foster-Smith and Evans, 2003).

Engaging the public also has merit in raising awareness to governments and other decision makers on important conservation issues. In fact, the public response to pollinator declines has convinced governments to fund research (e.g. CANPOLIN is funded by the Natural Sciences and Engineering Research Council of Canada), protect species and habitats (e.g. listing the Rusty-patched Bumble bee as endangered), and ensure long-term health of ecosystems (e.g. Health Canada is making strides to protect bees from exposure to neonicotinoid pesticides).

2.3 Evaluating Citizen Science Data

Researchers continually emphasize that successful citizen science programs must be properly developed if they are to produce valuable data that can be integrated with professional science data. A key component of well-developed programs involves evaluating their efficacy against controlled scientific studies.

Much of the literature that compares the quality of citizen science data to that of professional research science efforts focuses on water quality monitoring (physical and chemical testing, collecting and identifying macroinvertebrates, e.g. Fore *et al*., 2001) and bird observations (including breeding bird surveys and feeder counts, e.g. Ryder *et al*., 2010), and to a lesser extent amphibian calling surveys (e.g. Genet and Sargent, 2003). In general, results of these studies show that volunteers can be trained to collect samples that are similar in richness and composition to those collected by professionals and to classify collected specimens with relatively high accuracy. For example, Darwall and Dulvy (1996) compared volunteer and expert identification and size estimates of reef fish and found that with practice, volunteers reached a mean level of precision equivalent to that attained by a professional researcher. Similarly, Fore *et al*. (2001) found that although volunteers could not identify freshwater macroinvertebrates reliably to species level, they could produce results on par with professional taxonomists when specimens were identified to family level. In another study, Lovell *et al*. (2009) found that volunteers were able to sample an equivalent diversity of target invertebrate taxa as experts; there was little qualitative difference in sampling assemblages.

Because monitoring protocols for invertebrates typically involve specimen sampling, most studies comparing volunteer and professional data include specimen collections. Kremen *et al*. (2011), however, developed an observation-based pollinator monitoring protocol and assessed how well volunteer observers performed in comparison to professionally sampled bees. Their study revealed similar trends in bee abundance, richness, and community composition between amateurs and experts, though many fewer observations were made than specimens collected. Kremen *et al*. (2011) is the only published study I have encountered that evaluates the quality of bee observations made by volunteers.

2.4 Bee Monitoring in Citizen Science

Observation plots are often used to assess pollinator diversity and abundance, especially in citizen science monitoring programs (Westphal *et al*., 2008). The standard monitoring techniques used by the research community—setting pan-traps and sweep netting at flowers—usually involves pinning each specimen so that a taxonomist can identify it to species level. These collection techniques provide refined data and information, but they can be labour intensive and costly (Marshall *et al*., 1994; Danks, 1996). Collecting observational data about floral visitors is an effective and economical alternative to monitor bee populations (Ullmann *et al*., 2010).

Pollination Canada, an organization dedicated to protecting Canada's pollinators, recruits volunteers to collect observation data through PollinatorWatch. Pollination Canada was developed jointly by Environment Canada's Ecological Monitoring and Assessment Network Coordinating Office (EMAN) and Seeds of Diversity Canada, a non-government organization. EMAN has developed and coordinated several observation-based citizen science programs for Canadians, including PlantWatch and FrogWatch. Seeds of Diversity, as a national organization invested in conserving food crops and garden plants, was a natural partner to deliver PollinatorWatch. The PollinatorWatch program was designed to monitor pollinator populations in Canada and to address the need for educational campaigns that encourage greater awareness of which flower visitors serve as pollinators for both wild and cultivated plants. Participants have the flexibility to select which plants they monitor, and in the process learn about plant-pollinator interactions. Through PollinatorWatch, gardeners, farmers, conservation biologists, and municipal governments are engaged in the close observation of insect pollinators.

In PollinatorWatch, citizen scientists select a patch of flowers in their backyards, parks, and other green spaces and record the number of pollinating insects visiting the flowers. Volunteers can observe as often as they wish throughout the spring, summer, and autumn.

Other observation-based citizen science bee monitoring programs work on the same principles as PollinatorWatch, but are designed slightly differently: some are only interested in visitors to particular flowers while others are focused on particular types of bees; some protocols delineate a space to examine and others seek casual photographs of bees; some programs designate monitoring times while others encourage opportunistic observations (Table 1).

Table 1. Observation-based citizen science bee monitoring programs, a description of methods, and where the programs are conducted.

Program Name	Description	Location	Website

BeeSpotter	• Photos are submitted, then bees are identified and verified by program experts
	• Options for participating:
	  • Regular—casual, opportunistic photos from any place, any time
	  • Standardized—photographs of the same site, same plants in same flowering stage for same length of time in successive years
		Illinois	beespotter.mste.illinois.edu

Bee Watchers	• Observe bees visiting selected flowering plant species • Gather data at assigned times in summer and autumn	New York City	www.greatpollinatorproject.org
Great Sunflower Project	• Record length of time for 5 bees to visit a sunflower for max. 30 minutes • Seeds of a single species and cultivar of sunflower are sent to participants at various times of the year	Every US state and Canadian province	www.greatsunflower.org
Urban Bee Garden Monitoring	• Monitor all flowers in 1.5m x 1.5m patch • Record number of bees visiting reproductive parts of flowers	San Francisco Bay region of California	www.helpabee.org

Though observational approaches to bee monitoring are designed for participants who are not experts in insect identification, accurate monitoring can be accomplished by identifying groups of bees within broad categories. Using an approach known as parataxonomy, amateurs can support the work of taxonomists (Janzen *et al.*, 1993). When selected carefully, broad categories can reflect the ecological diversity of a bee community, and from a citizen science perspective, ecological characteristics are more important than taxonomic resolution. Though it is not necessarily feasible to survey an entire bee fauna with citizen science, reliable information on population and community changes may be gathered from comparing the dynamics and diversity of functional groups of bees (Williams *et al*., 2001). That is, it is possible to group and compare those species that differ biologically in variables such as degree of floral specialization or nesting habit and still infer meaningful ecological information (Sheffield *et al*., 2013). Functional diversity may be a non-taxonomic way to see trends that are not based on species-level taxonomy. It is also possible to group together those species that have a similar appearance based on categories called morphotypes (Abadie *et al*., 2008). This is good news for studies that engage citizen scientists to report on bees visiting flowers because it is easy for them to group bees into functional groups or morphotypes.

In fact, all of the citizen science bee monitoring programs that I am aware of—except those restricted to honey bees and bumble bees—make use of morphological characteristics of bees. For the most part, observers note the size and colour of bees visiting flowers. In a similar fashion, Fore *et al*. (2001) report on a study where volunteers used morphological features rather than dichotomous keys to identify benthic macroinvertebrates. This meant that they did not have to learn precise taxonomic features or jargon, which may have prevented their participation (Oliver and Beattie, 1997). This was precisely the approach taken in the design of the PollinatorWatch program. In fact, Fore *et al*. (2001) suggest that a field guide that focuses on overall body shape—similar to a bird field guide—would be more helpful than a dichotomous key emphasizing specific features.

There are relatively few species of vertebrates commonly used in citizen science schemes–such as birds and amphibians—as compared to invertebrates. With insects, even pollinating insects, the unit of monitoring has to be non-taxonomic for the most part because there are so many species, most of which require taxonomic expertise for correct identification. Citizen science programs that monitor bees have been designed to make bee observation monitoring accessible to an extensive audience much like bird and amphibian monitoring programs by utilizing a small set of categories in which observations are recorded.

For the most part, citizen science-based bee monitoring programs have been designed with unique systems for grouping bee observations, depending of course on the goals of the program (Table 2). Most programs use morphotypes to approximate ecological diversity, but PollinatorWatch asks observers to distinguish between each type of bee seen and give them descriptive names, whether they are the recognized common names or something made up by the observer. The PollinatorWatch system has been criticized by both participants and scientific researchers for its subjectivity and for the difficulties it poses to individual observers who have to recall what name they give to each bee throughout the season. This is problematic particularly because PollinatorWatch has not yet been evaluated for its effectiveness at capturing the bee fauna in a meaningful way.

Table 2. Morphological descriptions used by observers in citizen science bee monitoring programs.

Program	Honey bee	Bumble bee	Carpenter bee	Green bee	Other bee	Large bee	Small bee	Any bee
BeeSpotter	x	x						
Great Sunflower Project	x	x	x	x	x			
Urban Bee Garden Monitoring	x	x				x	x	
PollinatorWatch								x

Bee observation programs have merit without taxonomic clarity. Broad categories are informative when they reflect ecological diversity in the bee community. Bees require food and nesting habitat, so examining life-histories and the specific resource needs for functional groups of bees reveals important information about their ecology (Fontaine *et al*., 2006). For instance, bees are central place foragers so once a bee establishes a nest, it seeks food resources within a limited area. Several studies have compared body size to flight range and found that the smaller a bee, the narrower its options for foraging (e.g. Gathmann and Tscharntke, 2002; Greenleaf *et al*., 2007). Small bees forage within about 200-300m of their nest while medium- to large-sized bees have foraging ranges between 500m and 1km.

Many small bees that emerge in the spring nest in the ground, some medium-sized bees are cavity nesters, and large carpenter bees require wood to nest in. Where these types of bees are observed indicates that the habitat resources are meeting their needs.

Breaking down the coarse ‘small bee’ category into small- and medium-sized bees reveals distinctions between functional groups and easily recognized morphotypes. Small black and brown coloured bees cover broad life-histories as well as taxonomic and ecological diversity, but most bees included in it nest in the ground; while the exceptions are not ground nesters (e.g. *Heriades, Hoplitis,* and *Hylaeus*), they represent only a small proportion of the bees in this category and aren’t observed very frequently. Green bees include a limited number of taxa (e.g. *Agapostemon, Augochlora, Augochlorella,* and *Augochloropsis*), their colouration is particularly distinctive, and most importantly, their body sizes reveal foraging distance.

Other small- and medium-sized bees include cleptoparasites, most of which have recognizable red or orange markings on their bodies and legs. Also known as cuckoo bees, cleptoparasites lay their eggs in the nests of other bees and rely on food gathered by their hosts to feed their young (Rozen, 2001). Cuckoo bees depend on a healthy and abundant host population, so their presence indicates a certain level of stability in the community. Without a sufficiently large host population, their own numbers would be depleted. In this way, the presence and abundance of cleptoparasitic bees is reflected in changes to the resources available to their hosts. Cleptoparasites respond in ways that are reflective of the entire bee community, providing early warning of habitat disturbances, and as such may be considered as sensitive indicator species (Sheffield *et al*., 2013). Because cleptoparasites don’t provide for their young, they don’t visit flowers as frequently as other bees but with red and orange colouration they are easily recognized (Michener, 2007). The most common and abundant bees included in this category (about 80-90%) are small (*Nomada, Sphecodes*) and the remainder are medium-sized (e.g. *Epeolus* and *Triepeolus*). They may not be important pollinators—indeed, they make short visits to plants for energy from nectar rather than pollen—but observations of cuckoo bees can reveal much about the community and habitat supporting them.

Large bees include bumble bees (*Bombus*) and large carpenter bees (*Xylocopa*). Although they have discrete nesting habits and the taxonomic characters of these two types of bees are different, carpenter bees may be difficult to distinguish from female bumble bees except from a close vantage point. They are both large bees and fly great distances from their nests, and these types of bees play equivalent functional roles in their community.

There is redundancy in habitats and the functioning of a community as a whole is more relevant than individual members of the team (i.e., it doesn't matter which species of bumble bees are present, but rather that there are bumble bees in the community) (Tilman *et al*., 1997). Functional bee groups, then, are important in citizen science as they can be used as a proxy for diversity. With many citizen scientists making observations of functional groups of bees, over time a profile of conditions needed to support bees can be built. Then when population changes occur—say, all of the cleptoparasites are lost—clues emerge to use in assessing what else is happening in the habitat.

By using an approach to citizen science that takes advantage of specially selected, easily recognized types of bees, pollinator monitoring can be carried out without taxonomic expertise. Functional diversity measures that reflect the bee community may be the only way to avoid the taxonomic impediment.

While using functional groups is a practical approach for conducting observational bee surveys, building a local reference (synoptic) collection of bee species can be a useful tool for assessing the efficacy of those observations (Abadie *et al*., 2008; Ullmann *et al*., 2010). Drawing on the Canadian taxonomic expertise, synoptic collections of various areas can be created or existing collections utilized as a benchmark for the species that occur there. With background knowledge about the types of bees in an area, the information citizen scientists collect can be understood.

If pollination researchers are to follow up on recommendations for strategic, long-term monitoring of bee populations, it is important to ensure that an effective, meaningful citizen science program for widespread application in Canada has been developed. With this in mind, I designed my thesis to evaluate and tailor the PollinatorWatch program.

Chapter 3

Methods

3.1 Study Region and Site Selection

Conservation areas are ideal for implementing research and monitoring projects such as mine because they provide plenty of suitable bee habitat and have staff and visitors who are keen to be involved. Two urban conservation areas were selected for my study, both of which expressed an interest in gaining a better understanding of their pollinator communities. They were also selected because their employees and members were willing to take part in the study and were located in close proximity to the University of Waterloo. Royal Botanical Gardens (RBG), in Burlington, ON (43° 17' 24" N, 79° 52' 34" W; Figure 1), seeks to be a living museum to develop and promote public understanding of our relationship with plants and the rest of nature. RBG's 1100-hectare property comprises a rich diversity of natural habitats in four nature sanctuaries. The ***rare*** Charitable Research Reserve (***rare***), Canada's largest privately owned urban green space, is located in Cambridge, ON (43° 23' 1" N, 80° 23' 6" W; Figure 1). Its 370-hectare property of natural and agricultural habitats is a dedicated research and monitoring facility.

Figure 1. Map of southwestern Ontario indicating the location of the ***rare*** Charitable Research Reserve in Cambridge (left marker) and Royal Botanical Gardens in Burlington (right marker) (map data CC-BY-SA by openstreetmap.org and is available under the Open Database License).

3.1.1 Habitats

The main habitat for my study was mixed meadow having a variety of floral resources available throughout the season. The meadows ranged from fallow corn and soybean fields and post-burn prairie restoration to variably aged open fields and parkland. I chose the particular research sites based on their dominant floral resources and assessed each site's suitability using information available through each organization, including aerial photos, checklists of flora, and site visits. They were also selected to reflect the habitats that a typical observer would likely use as part of PollinatorWatch.

Where possible, I selected sites to provide a range of plant assemblages, from relatively simple (only a few species in bloom at a time) to complex (many species blooming simultaneously). I expected that examining an assortment of high (complex species groupings) and low (simple species groupings) quality sites would help to reveal the best habitats for participant observers in PollinatorWatch to select, and whether site quality makes a difference in the assemblage and richness of bees reported.

3.1.2 Sites

I established six sites at ***rare*** (Figure 2) and five sites at RBG (Figure 3), for a total of eleven sites in the study areas. Three sites on each property were selected for the citizen science portion of the study, based on their distinctiveness from other sites—in geographical distance and floral composition—and their accessibility to volunteers. The sample size was chosen based on the availability of suitable habitat and volunteer effort required. A stratified random sampling design was used to select the location of each site within an area of relatively homogeneous habitat that was at least 50m long and 10m wide. All specimen sampling and observations were made in these sites.

© OpenStreetMap contributors

Figure 2. Location of each site at the ***rare*** Charitable Research Reserve. All sites were visited to collect data for the specimen data set, but only those sites indicated by a dot (•) were visited by citizen scientists to collect data for the observation data set. From left to right, sites are named Preston Flats, Blair Flats, Indian Woods, Springbank Farm, Hogsback Old Field, and Grand Trunk Trail.

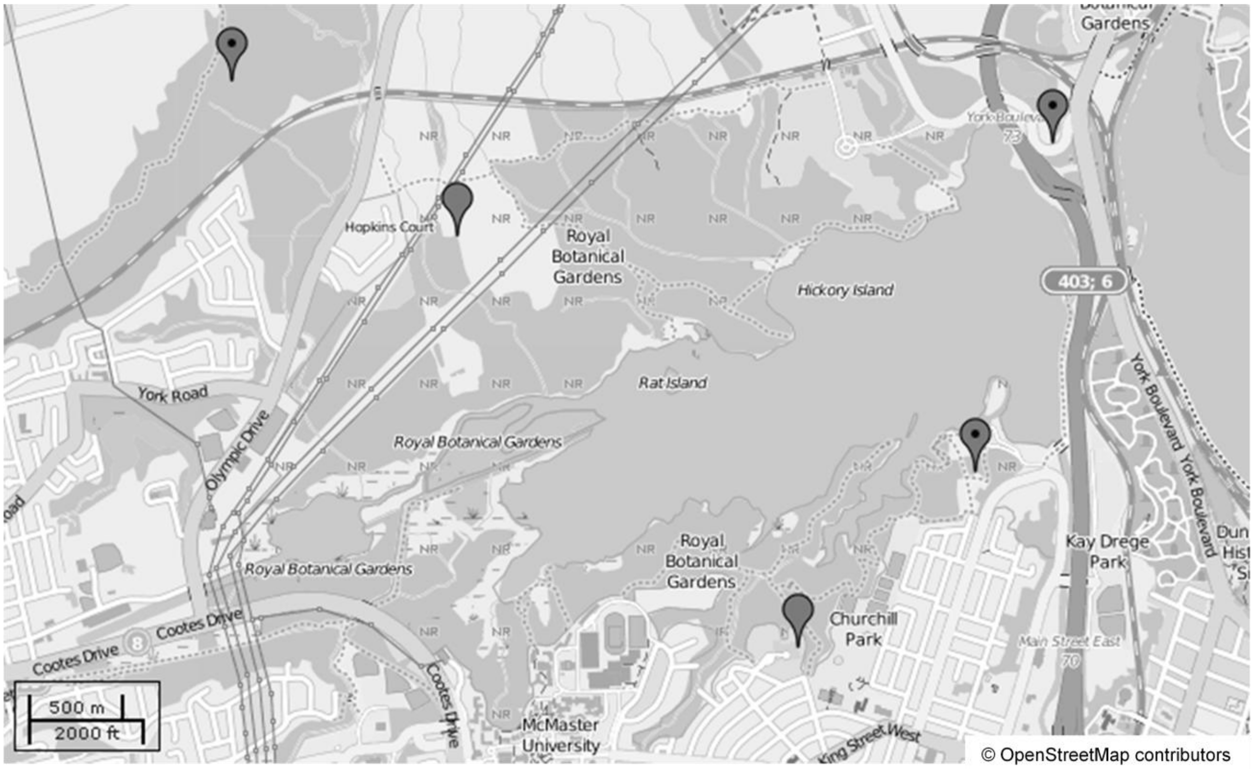

Figure 3. Location of each site at Royal Botanical Gardens. All sites were visited to collect data for the specimen data set, but only those sites indicated by a dot (•) were visited by citizen scientists to collect data for the observation data set. From left to right, sites are named Rock Chapel, Pinetum Trail, Aviary, Princess Point, and Butterfly Walk.

3.2 Collection of Bee, Plant, and Weather Data

To collect data on the bees present at each location, I used a modified version of the CANPOLIN 2009 Survey of Pollinator Diversity in Canada sampling protocol (available at www.uoguelph.ca/canpolin/Sampling/protocols.html). This involved setting out pan-traps and sweep netting to capture bees. Complementing pan-trapping with netting at flowers is an accurate way to characterize the local bee fauna while also allowing for comparison to bees observed by citizen scientists (Roulston *et al*., 2007).

3.2.1 Bee Sampling Procedure

I sampled bees at every site during a 2-3 week period and then resampled each site about every 2-4 weeks. This schedule allowed me to capture flower phenology and bee diversity while accounting for seasonal variability. Sampling took place only during suitable weather conditions for pollinators—minimum of 15˚C, low wind, no rain, and dry vegetation—from early July through mid-September 2009. This resulted in three samples for each site.

To sample bees with pan-traps I established one 42m long linear transect, in the centre of each site. The transect was oriented along an east-west axis with a south facing aspect where possible, and marked on both ends with a flag. Fifteen pan-traps were set out 3m apart along the transect line, placed on level, bare ground or matted vegetation following CANPOLIN protocols.

The pan-traps consisted of Solo brand 3.25 oz. white polystyrene soufflé cups. One-third of the pans were left white, one-third were spray-painted fluorescent yellow, and the remaining one-third were spray-painted fluorescent blue. The coloured cups serve as a proxy for flowers, and are thus attractive to flying insects which visit flowers (Marshall *et al*. 1994). Along the transect, the pans alternated blue, yellow, and white (see Figure 4) to account for different colour preferences by bee species (Leong and Thorp, 1999). Each pan was filled ½ to ¾ full with soapy water prepared with 5 drops of dish detergent per litre of water (as per The Handy Bee Manual, 2009). The detergent was added to break the surface tension of the water so small insects would sink. Pan-traps were placed at each site by 9:00am on sampling days and retrieved by 6:00pm.

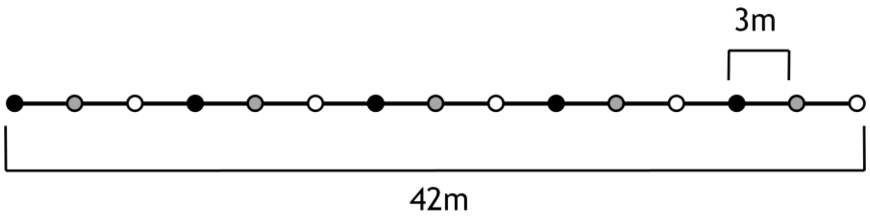

Figure 4. Diagram of site layout. A 42m long transect was established with 15 pan-traps spaced every 3m.

To sample bees using sweep netting, I used a 15”-diameter white aerial net. I netted bees throughout each site for thirty minutes during their active foraging hours, between 10:00am and 3:00pm, on the same day the pan-traps were set out. The timing of the netting corresponded with the observation times that were to be used by volunteer observers. Netting was made on the most abundant and conspicuous plants at each site as well as near bare ground. I recorded the plant species from which bees were collected.

There were three site-dates when netting was difficult due to strong winds; few to no bees were able to be captured. One site where this occurred was adjacent to the Grand River (Blair Flats, on August 1st) and the other was an old corn field (Grand Trunk Trail, on August 21st) on ***rare*** property. The third site was on RBG property in a large open meadow (Rock Chapel, on August 17th).

Following CANPOLIN’s protocols for preparing bee specimens for identification, I euthanized netted specimens in kill jars using ethyl acetate. They were then stored in vials or Whirl-Paks filled with 95% ethanol and kept in a freezer until they could be pinned.

3.2.2 Vegetation Surveys

I normally surveyed flowering herbaceous plants—using a quadrat-based method—on the same day bees were sampled. However, when poor weather conditions prevented bee sampling (e.g. overcast sky, rain, or wind), plants were recorded anyway and bees sampled on the next appropriate day. Thus, the flora was recorded at least within the same sampling period as the bees.

To estimate the floral resources available to bees, I sampled plants using fifteen 1m x 1m quadrats placed on either side of the pan-trap line transect using a partial randomized design (see Figure 5) biased towards areas with flowering plants. This bias allowed for a comparison with the volunteer observation sites (see 3.3.3 Recording Bee Observations below). To determine the placement of each quadrat, I selected a patch of flowers and tossed a tennis ball into it, then placed the quadrat over the patch (with the ball located in the centre of the quadrat).

Only those plants in flower on the visit date were reported. I measured the density of each species in terms of (i) the number of stems in the quadrat, and (ii) its percent cover in one of six cover classes (<1%, 1-5%, 6-25%, 26-50%, 51-75%, >75%). Additionally, any species in bloom that were not captured in the fifteen quadrats were reported on a presence/absence basis.

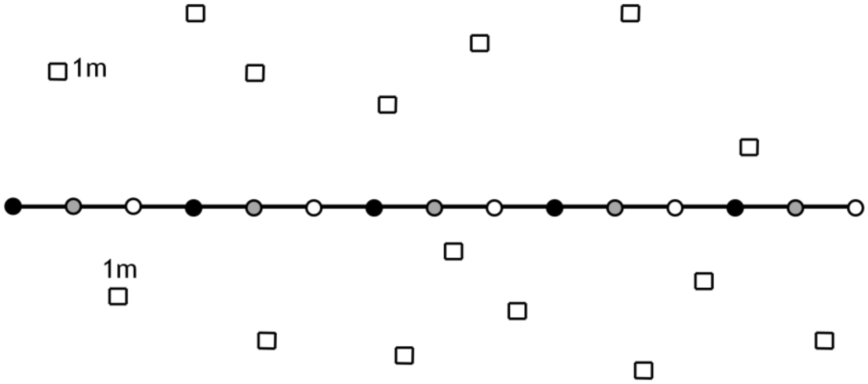

Figure 5. Sample orientation of vegetation survey quadrats at each site.

3.2.3 Environmental Variables

Following the PollinatorWatch protocol, I recorded weather details on each sampling day, using discrete, ‘common sense’ categories to describe the weather (Foster-Smith and Evans, 2003). They were also the same categories used by citizen scientists. ‘Cloud cover’ recorded whether the sky was sunny, cloudy, or overcast. A cloudy sky meant that the sun was out but the sky was not clear. In contrast, an overcast sky meant that cloud cover was 100% with no sun peeking through. Bee activity could be affected if the sun was hidden behind clouds. ‘Wind’ was described using five categories (windy, steady; windy, gusts; light breeze, steady; light breeze, gusts; calm). ‘Temperature’ categories included cold, cool, seasonal, warm, and hot. Seasonal meant that the temperature was about as expected for that time of year.

3.2.4 Bee and Plant Species Identification

All bees collected were identified to species using keys, including Packer *et al*. (2007), Michener *et al*. (1994), and Mitchell (1960 and 1962). Bumblebees were identified using Laverty and Harder (1988). To distinguish between *Ceratina dupla* and *C. calcarata*, Rehan and Richards (2008) was consulted. Additionally, Dr. Jason Gibbs identified *Lasioglossum* subgenus *Dialictus* and Dr. Cory Sheffield identified and/or verified specimens throughout the collection.

All plants in bloom were identified to species using guides such as Newcomb (1977) and Peterson and McKenny (1996). Voss (1985) was consulted, as were Smith (2003) and the ***rare*** plant list created in March 2004 by the ***rare*** Environmental Advisory Committee. Goldenrods were identified using Semple *et al.* (1999) and asters were identified using Semple *et al*. (2002). Allison Scovil and Natalie Iwanycki at RBG provided consultation and plant identification as well.

3.3 Collection of Citizen Science Data

3.3.1 Participating Citizen Scientists

Participants in this study included any interested volunteers, visitors, or staff at the research locations who could commit to observing on a regular basis throughout the field season. They were recruited from current staff and volunteers as well as the local naturalist clubs and master gardeners. Though citizen science programs are designed to be accessed by many audiences, a target audience such as the one utilized here can be particularly effective by helping to intensify participation (Cooper *et al*., 2007).

Participants for citizen science projects can be recruited from existing groups or partner organizations (Cooper *et al*., 2007). The RBG and ***rare*** fit this requirement, because I had previous working relationships with staff at both organizations, and there were willing participants from programs already running at each location. Prior to recruiting volunteers, my study was reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo.

I used e-mail as the main form of contact to enlist volunteers. I contacted people in the following positions who forwarded information about this study on my behalf: the staff Land Steward at ***rare*** sent details to the Volunteer Land Stewards and other staff; the President of the Kitchener Master Gardeners and the Cambridge Master Gardeners sent out information to the membership of both clubs; the Auxiliary President at Royal Botanical Gardens, the Membership Director and the Volunteer Director of the Hamilton Naturalists' Club, and the Coordinator of the Halton Master Gardeners each sent out details to their respective memberships; and the Lead Garden Interpreter and the Herbarium Curator at RBG passed along information to other RBG staff. In total, about 1000 people were invited to participate. Interested volunteers contacted me to find out about participating.

At ***rare***, Volunteer Land Stewards formed the main participant base. In addition to this study, they took part in plant, bird, and other monitoring activities on the property. Other participants included staff members who were responsible for the conservation and restoration of a healthy ecosystem at ***rare***.

At RBG, volunteers included Auxiliary members and staff. The Auxiliary members were volunteers involved in gardening, trail monitoring, and various community events at RBG. Staff monitored ecosystem health and delivered education programs.

Additionally, members of the Hamilton Naturalists' Club and the Halton Region Master Gardeners participated in the research at RBG. Their keen observation skills and interest in plants, their pollinators, and the natural world in general made them ideal participants for such a study.

In total, nineteen citizen scientists took part in the research. At ***rare***, fifteen volunteers made observations throughout the season; two were staff members involved in ecological program management and the remainder were Volunteer Land Stewards. At RBG, four volunteers were able to contribute data; one was a staff member in land conservation and stewardship, one was an Auxiliary member, one a Master Gardener, and one a member of the local naturalist's club.

3.3.2 Training

Training for volunteers is an important component of any successful citizen science program. Training may include in-person workshops, instructional information on protocols, as well as species- or taxa-specific descriptions including photographs and other examples of what observers may see in the field (see for e.g. Genet and Sargent, 2003). As well, Lovell *et al*. (2009) emphasize that project coordinators should provide guidance and contextualize volunteer activities as much as possible. Based on these recommendations, I developed and conducted an in-class and field training workshop for the volunteer observers at each research location before data collection began.

The workshop included a presentation to provide volunteers with background information on PollinatorWatch; the aims and objectives of the research project and its relevance to ecology, monitoring, and conservation; how to identify and observe bees, including how to distinguish between bees, flies, wasps, and other similar flower visitors; and how to record observations. I conducted a group ‘quiz’ of different flower visitors using photos, and displayed pinned specimens (borrowed from Dr. Cory Sheffield then at York University) for the volunteers to examine. In the field, plant identification was reviewed, practice observations were made, and relevant field perimeters were delineated. As successful citizen science projects have discovered, participant tasks must be adequately supported by various information resources such as identification cards, so volunteers were given appropriate reference materials to keep with them, including a laminated field ‘guide’ that provided photos and descriptions of samples of bees they could see visiting flowers (Lovell *et al*., 2009). They also received all of the relevant field sheets and a map of the observation sites. Additionally, each volunteer was given a DVD that included a photo album of bees in the area, more field sheets to print, and the training presentation. During the training, volunteers were invited to ask questions and seek clarification to ensure each of them was comfortable with the observation and recording procedure before commencing data collection.

3.3.3 Recording Bee Observations

Each participant selected a 1m x 1m patch of flowers in full bloom—delineated with a portable, collapsible wood frame—each time they visited a site. This bias toward flowering patches was used to ensure that the volunteers participating would have the opportunity to observe bees actually visiting flowers throughout the season and is consistent with other, established citizen science pollinator monitoring protocols. Participants observed this patch for 10 minutes and recorded the number of bees and the flowers they visited (Appendix D).

Volunteers reported either common or scientific names of flowers. When available, a list of the flowers in bloom at each site was provided to the volunteer observers to assist them. To standardize all of the plant data following the field season, any plants that were listed by observers using common names were translated to their scientific binomial names, using the sources listed earlier. These sources allowed me to compare plants known to exist in the areas as well as triangulate species to ensure the common names used coincided with the known species at the sites.

Because bees are attracted to areas with both high quality and quantity of flowers, participants also counted the number of floral units (e.g. a single daisy head or a goldenrod raceme constituted one floral unit, much like ‘anthia’ described by Faegri and van der Pijl, 1978) present in their own 1m x 1m quadrat on each observation date. This method made the plant recording procedure simple and expedient.

Each citizen scientist was provided with a clear ruler to help determine the size of bees and flowers they encountered, and a magnifying glass to use for close-up observations if necessary.

Observations were to be made approximately every 10-14 days at each site to coincide with the pan-trapping and netting surveys. However, the observers were volunteering their own time and weather was sometimes unsuitable, so this schedule was not always feasible. Ultimately, observations were made as often as possible, though only some observers were able to visit on the designated schedule.

Research projects similar in nature to this one have specified collecting and observing days where professionals and citizen scientists visit the field sites together (e.g. Foster-Smith and

Evans, 2003; Kremen *et al*., 2011), but I designed this project to allow for flexibility in the volunteers' own schedules, so that they could make observations whenever it was appropriate. My design decision was made primarily for three reasons: (1) it appeared prohibitive to organize all of the volunteers to visit the field sites on the same dates with me through the season; (2) the PollinatorWatch protocol asks volunteers to visit their field sites without a researcher present, so my design provided a truer reflection of the volunteer experience with the program; and (3) I didn't want to confound my sampling with volunteers' observations.

As with my sampling, the volunteers made observations when weather conditions were suitable for pollinators (minimum of 15˚C, low wind, no rain, and dry vegetation), from early July through late September. Observations were to be made during the active foraging hours for bees, between 10:00am and 3:00pm, though nearly one-quarter of observations were made outside of this window, as early as 9:30am and as late as 6:30pm.

I used a modification of the PollinatorWatch recording procedure, in part to compare observations to specimens, but also to examine the most effective grouping of bees (i.e., functional groups and morphotypes) through field-based observations. By drawing names from a hat, participants were randomly split into three groups to determine the best categories for recording observations (Table 3). Each citizen scientist used one of the three schemes to organize their bee observations, all of which were based on functional groups, morphological characteristics, or recognizable bees, here referred to as species-groups. The species-groups for scheme A were selected based on consultation with Dr. Cory Sheffield and designed to investigate a new system for bee monitoring (Table 4). The categories account for a broad spectrum of functional diversity, and the design intention was that habitat quality should be reflected in the bees represented by each species-group. The species-groups for schemes B and C were selected based on existing, successful citizen science bee monitoring programs, so it was sensible to examine how well those groupings would work in the context of the PollinatorWatch protocol. The bee species-groups used in scheme B were based on the Great Sunflower Project (Table 5) and those in scheme C followed the categories for Urban Bee Gardens (Table 6).

Table 3. Three categorical schemes used by citizen scientists to record observations.

Scheme A		Scheme B	Scheme C
Small bee (<10mm)	Black/Brown	Honey bee	Honey bee
	Green/Blue	Bumble bee	Bumble bee
	Red/Orange	Large Carpenter bee	Small bee (<20mm)
		Green bee	Large bee (>20mm)
Medium sized bee (10-20mm)	Black/Brown	Other bee	
	Green/Blue		
	Red/Orange		
	Honey bee		
Large bee (>20mm)	Bumble bee or Bumble bee-like		

Table 4. Bee taxa possibly included in each species-group for scheme A.

Small bee (<10mm)			Medium sized bee (10-20mm)				Large bee (>20mm)
Black/Brown	Green/Blue	Red/Orange	Black/Brown	Green/Blue	Red/Orange	Honey bee	Bumble bee or Bumble bee-like
Andrena	*Agapostemon*	*Nomada*	*Andrena*	*Agapostemon*	*Nomada*	*Apis mellifera*	*Bombus*
Calliopsis	*Augochlora*	*Sphecodes*	*Anthidium*	*Osmia*			*Xylocopa*
Ceratina	*Augochlorella*		*Colletes*				
Chelostoma	*Augochloropsis*		*Coelioxys*				
Dialictus	*Osmia*		*Halictus*				
Halictus confusus			*Hoplitis*				
Heriades			*Megachile*				
Hoplitis			*Melissodes*				
Hylaeus			*Peponapis*				
Lasioglossum			*Triepeolus*				
Perdita							
Pseudopanurgus							

Table 5. Bee taxa possibly included in each species-group for scheme B.

Honey bee	Bumble bee	Large Carpenter bee	Green bee	Other bee	
Apis mellifera	*Bombus*	*Xylocopa*	*Agapostemon*	*Andrena*	*Hylaeus*
			Augochlora	*Anthidium*	*Lasioglossum*
			Augochlorella	*Calliopsis*	*Megachile*
			Augochloropsis	*Ceratina*	*Melissodes*
			Osmia	*Chelostoma*	*Nomada*
				Colletes	*Peponapis*
				Coelioxys	*Perdita*
				Dialictus	*Pseudopanurgus*
				Halictus	*Sphecodes*
				Heriades	*Triepeolus*
				Hoplitis	

Table 6. Bee taxa possibly included in each species-group for scheme C.

Honey bee	Bumble bee	Large bee (>20mm)	Small bee (<20mm)	
Apis mellifera	*Bombus*	*Xylocopa*	*Andrena*	*Heriades*
			Anthidium	*Hoplitis*
			Agapostemon	*Hylaeus*
			Augochlora	*Lasioglossum*
			Augochlorella	*Megachile*
			Augochloropsis	*Melissodes*
			Calliopsis	*Nomada*
			Ceratina	*Osmia*
			Chelostoma	*Peponapis*
			Colletes	*Perdita*
			Coelioxys	*Pseudopanurgus*
			Dialictus	*Sphecodes*
			Halictus	*Triepeolus*

3.4 Data Analysis

3.4.1 Pan-Trapping and Netting

I computed a species accumulation curve over the season for the bees sampled using both pan-trapping and netting. This was done to determine if these surveys captured the total diversity of bee species at the sites (Tuell *et al*., 2009). Site visits were added in random order to find the mean species accumulation curve and its standard deviation based on 100 random permutations of the data. The bootstrap estimate is useful for estimating the number of species in a community and as such was used to estimate total species richness for all sites taken together. All statistical analyses were computed with R 2.15.0 (R Development Core Team, 2012), using the vegan package (Oksanen *et al*., 2012). The species accumulation curve was run using the 'specaccum' function.

Bee species richness, evenness, and diversity were calculated for each site over the entire season. Analysis of species diversity was calculated using the Shannon-Wiener Index ($H' = -\Sigma\, p\mathrm{i} \log p\mathrm{i}$) and Pielou's Evenness Index ($J' = H'/H'_{\mathrm{max}}$). Values calculated from Shannon's Diversity Index typically range from 1.5 to 3.5, with higher values indicating a greater richness and evenness of the community. Pielou's Evenness Index is constrained between 0 and 1, where a community with little variation (i.e., high evenness) has a value close to 1.

Bray-Curtis dissimilarity matrices and Mantel tests were used to compare bee species composition from pan-traps and netting. To carry out the Mantel test, I first created Bray-Curtis dissimilarity matrices based on bee species abundance for each site visit, one for pan-trapped bees and one for netted bees (completed using the 'vegdist' function in R). Then I conducted a Mantel test to compare the two distance matrices and obtain correlation values. Following Kremen *et al*. (2011), the Mantel test determines if the netting and pan-trapping data sets are significantly correlated, which helps in later exploring if observational data shows the same trends as the more complete and typical sampling procedures of netting + pan-trapping, or like Westphal *et al*. (2008) suggest, that netting is the best analogue to bee observations. Here, the Mantel test was used to determine if patterns of community dissimilarity between site-dates were correlated for the netting versus the pan-trapping data sets. Because the elements of a distance matrix are not independent, the Mantel test uses randomization to correlate the two matrices being compared by subjecting the rows and columns of one matrix to random rearrangements and recalculating the correlation with the original matrix after each iteration. The distribution of values for the Mantel statistic is generated from many permutations of this procedure. I used the standardized Mantel statistic *r* and assessed its statistical significance with 999 trials (using the ‘mantel’ function in R). *r* falls in the range of -1 to +1, where -1 indicates a strong negative correlation, 0 indicates no correlation, and +1 indicates a strong positive correlation.

3.4.2 Volunteer Observations

Data from citizen scientist observations were tabulated by scheme (A, B, C) and within each species-group (Green bee, Large Carpenter bee, Honey bee, etc.). Results are presented using the mean number of bees observed per visit.

3.4.3 Comparing Observational and Specimen-based Data

Only data from the six sites visited by citizen scientists were used to compare their observations with the netting and pan-trapping surveys.

The pan-trapping and netting data were grouped into coarser categories so that they could be compared to each of the citizen science recording methods (i.e., into Honey bees, Large bees, Green bees, etc., as appropriate for schemes A, B, and C). In this way, the post-hoc categorization of specimen data matched the species-groups that observers used in the field.

However, because the pan-trapped and netted bees were placed into a broader species-group category post-hoc, some of them would be duplicated for scheme A (e.g. all *Andrena* would be placed in both Small and Medium Black/Brown bees). So I ran the comparison between scheme A observations, pan-traps, and netting in two ways:

1) With all bees that would be duplicated included in the pan-trap and netting data (e.g. all *Andrena* included in both Small and Medium Black/Brown bees); and

2) With all bees that would be duplicated excluded from the pan-trap and netting data.

The first approach made for a bias towards more bees from pans and netting, whereas the second approach did not allow for a comparison of the complete fauna. Neither approach is ideal, so instead I weighted those genera that would be duplicated to 0.5 so that each specimen would only be considered once.

The Shapiro-Wilk test was used to determine if bee abundance data followed a normal distribution. I examined the counts per visit of bees caught in pan-traps, by netting, and in pan-traps + netting taken together, as well as observations made by citizen scientists. The Shapiro-Wilk Test is appropriate for small sample sizes (< 50 samples), but can also handle sample sizes as large as 2000. For this test, the null hypothesis is that the data are normally distributed. With a chosen α level of 0.05, if the *p*-value is less than 0.05, the null hypothesis is rejected; if the *p*-value is greater than 0.05, the null hypothesis is not rejected.

The observation counts did not respond to common transformations (such as square root, log, and inverse normal) so I used the non-parametric Spearman's Rank-Order test for correlations between observation and specimen-based data (using the 'cor.test' function in R). For all species-groups, I examined correlations between bee abundance in observation versus netting or netting + pan-trapping data. Spearman's correlation coefficient, ρ, can take values between +1 and -1. The test measures the association between each variable; a value of +1 indicates a perfect positive association and a value of -1 indicates a perfect negative association, while the closer ρ is to 0, the weaker the association. Due to the nature of data collection intensity, there are differences in magnitude between the abundance of bees in the observational data set and the specimen data set. To account for this and to provide a clearer picture of trends, results are presented as proportions rather than absolute abundance values.

Correlations were made across the entire season at all sites from all observers and researchers because (i) the sites were selected to be homogeneous, so it should not matter where the data was collected, and (ii) the data collector should not play a role in differences in bee abundance. A significant positive correlation between the two data sets indicates that volunteers can generate high quality bee observation records.

To assess whether patterns of community composition were correlated between the specimen versus the observation data sets, Bray-Curtis dissimilarity was calculated. I compared observations to netting and observations to netting + pan-trapping. A distance matrix based on proportions of bee abundance was calculated for each data set to obtain distances between all pairs of site-dates and then correlated using a Mantel test. Following Lovell *et al*. (2009) and Kremen *et al*. (2011), I used site-date as the unit of replication.

As in Kremen *et al*. (2011), where there were fewer than 70 total records in a group, I combined groups of bees before computing community dissimilarity. For example, Small Green/Blue bee had a count of 12 and Medium Green/Blue bee had a count of 2, so they were pooled as Green/Blue bee with a total abundance of 14 to use in analysis for scheme A. In fact, in each of the Small and Medium size bee categories there were too few observations in scheme A, so data were lumped with that of the same colour group (e.g. Small and Medium Black/Brown bees were taken together as Black/Brown bees).

My primary goal here was to detect differences in bee community attributes and if these differences could be detected equally well by assessing either observational or specimen data sets. These analyses used a subset of site-dates that included all collections and all volunteer observations made in a 7-day window around a collection. For example, if I made Visit 1 to Indian Woods on July 10th, then it was compared to all volunteer visits made at that site from July 7th through July 13th. This subset allowed for the most direct comparison of the bee fauna, because the study was not designed for volunteers and researchers to visit sites on the same dates. If the community compositions emerging from both data sets are similar, we have a further indication of the quality of volunteer bee observations.

The final comparative analysis provided an indication of the most reliable bee species-groups to use in PollinatorWatch. To determine whether there were significant differences between the specimen and observation data for each bee species-group, I ran a Mann-Whitney *U* test (using the ‘wilcox.test’ function in R). This is a paired-difference test used to assess whether the population mean ranks differ between two matched samples. Here, proportion of bee abundance was used for each species-group within the subset of site-dates. The resulting differences in proportion provide an assessment of which species-groups were the most closely matched between the two data sets. The non-parametric Mann-Whitney *U* test requires that data from each population is an independent random sample, and both distributions have the same shape. The Mann-Whitney *U* test is also used for small sample sizes. In using the subset of site-dates where volunteer visits matched researcher visits within a 7-day window, the observation and specimen data sets met the assumptions for this test.

To display results of this test graphically, I used the paired visits and found the mean proportion of each bee species-group from the observation and specimen data sets. I then subtracted the observation mean from the specimen mean. Where numbers fall in the positive scale, observers reported proportionally fewer bees than were actually present. Likewise, where numbers are in the negative scale, observers accounted for too many bees in that category. The bee species-groups with the smallest differences between the two data sets are the most reliable groups for volunteer observers to use.

3.4.4 Flowering Plants

Flowering plant diversity was calculated using the Shannon-Wiener Index and species evenness using Peilou's Evenness Index. To indicate the availability of floral resources for visiting bees, the mean density of stems for flowering plants was calculated for each species reported in fifteen 1m x 1m quadrats. All calculations were performed on the pooled number of flowering stems at each site across the season.

As part of the second objective in this study, I sought to examine if site selection—based on the plants present—plays a part in citizen science bee observation reports (i.e., would more bees be observed by selecting a site with high plant diversity?). To do this, I used a superficial comparison to imitate the experience of volunteers in PollinatorWatch. For the most part, these citizen scientists will select their observation site(s) based on what flowers they see at a given time of year. To assess the impact of site selection, I pooled plant diversity, density, and richness, as well as bee richness and abundance, over all visits at each site, to complete a post-hoc site ranking following Fore *et al*. (2001). I compared the mean bee abundance for specimens and observations, overall bee and plant species richness, the mean number of plant stems per m^2, and the effective number of plant species.

To determine the effective number of plant species, I transformed the Shannon-Weiner Index. As a measure of diversity, the Index incorporates both the richness and evenness of a community in its calculation. However, the calculation is made on a nonlinear scale, so it is difficult to interpret and assess differences in diversity between sites (Magurran, 1988). For example, a diversity index of 1 in community A is not necessarily twice as high as a diversity index of 2 in community B. However, by transforming the value using the exponential function ($e^{H'}$), all species become equally common (Whittaker, 1972). This process converts Shannon's Diversity Index to the effective number of species, which we can use as a more accurate representation of diversity to compare communities (Jost, 2006).

Chapter 4

Results

4.1 Pan-Trapping and Netting

This survey used a combination of pan-trapping and sweep netting to sample bees. Using both methods, I collected a total of 1864 individuals from five families, Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae (Appendix A). 1107 of the bees were caught in nets (59% of sample) and 757 in pan-traps (41% of sample) (Table 7). These bees belong to 27 genera, 22 of which were from nets and 21 from pan-traps (Table 7). They represent 74 species, 36 (49%) of which were detected by both methods. Sixty species (81%) were collected by netting and fifty (68%) were captured in pan-traps. Some species were collected by only one of the methods: pan-trapping caught 14 unique bee species while netting collected 24 (Appendix A).

Bees were sampled over 33 site-dates; the species accumulation curve created using pan-trapping and netting data approached an asymptote (Figure 6). Bootstrapping estimated the entire species pool at 82.3 ± 3.2 species, suggesting that ~90% of the species were accounted for in the samples. This indicates that sampling effort was sufficient to represent most of the community of bees likely to be captured by these sampling methods in these meadow habitats.

There was no significant correlation between the pan-trapping and netting data sets by site-date for bee abundance (Mantel $r = 0.0258$, $p >> 0.05$; $n = 33$ site-dates). Because the two data sets differed in species composition, they were considered separately for the comparisons with citizen observations.

4.1.1 Bee Community Structure

Based on the numbers of sampled individuals, Apidae was the most abundant bee family (54% of the total collection) (Table 7), and primarily collected through netting. The second most prevalent family was Halictidae, with 36% of the total catch, and primarily from pan-traps. Colletidae, Megachilidae, and Andrenidae were captured with less frequency, at 7%, 2%, and 1% of individuals, respectively.

The three most abundant bee species were members of Apidae: *Bombus impatiens*, with 19% of the catch, followed by *Apis mellifera* at 17%, and *Ceratina calcarata* at 7% (Appendix A). Three species from Halictidae made up the next most numerous samples: *Halictus confusus* and *Lasioglossum anomalum*, each with 6% of the catch, and *Augochlorella aurata* at 5%. Seven species comprised between 2 and 4% of captured bees. The remaining 61 species comprised less than 1% of the catch.

The most species-rich genera were *Bombus* (9 species), *Sphecodes* (8), *Lasioglossum* and *Megachile* (7 each), and *Hylaeus* (6), though there were few individuals of many of these species.

Table 7. Summary of the number of individuals, genera, and species of bees collected using pan-trapping and netting at Royal Botanical Gardens and the ***rare*** Charitable Research Reserve.

Family	Pan-trapping			Netting			Total		
	no. of individuals	no. of genera	no. of species	no. of individuals	no. of genera	no. of species	no. of individuals	no. of genera	no. of species
Andrenidae	2	2	2	16	3	6	18	4	7
Apidae	200	7	14	805	7	17	1005	9	21
Colletidae	53	1	4	77	2	9	130	2	9
Halictidae	479	5	20	186	6	19	665	6	23
Megachilidae	23	6	10	23	4	9	46	6	14
Total	757	21	50	1107	22	60	1864	27	74

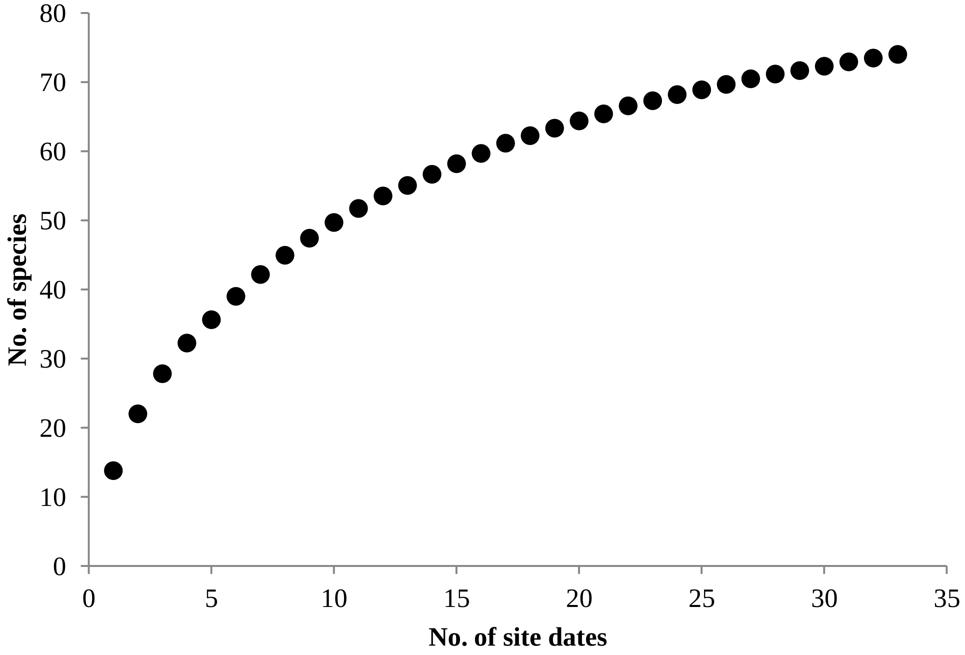

Figure 6. Species accumulation curve generated from combined pan-trap and netted sampling data.

Bee diversity was qualitatively higher at ***rare*** sites (average *H′* = 2.53) than at Royal Botanical Gardens sites (average *H′* = 2.16) (Table 8). Among the sites, Indian Woods and Grand Trunk Trail at ***rare*** hosted the most diverse assemblages of bees (*H′*), as indicated by the high species richness and evenness values (the latter indicating that numbers of species were more equal there). Species richness at Butterfly Walk and Princess Point at RBG, and Hogsback Old Field and Springbank Farm at ***rare***, were qualitatively similar, although species abundances were distributed less evenly.

Table 8. Bee species richness, Shannon Diversity Index, and Pielou Evenness Index of bee specimens collected using pan-trapping and netting within each site at Royal Botanical Gardens and the ***rare*** Charitable Research Reserve.

Site	Species richness	Shannon diversity (*H*′)	Pielou evenness (*J*′)
Royal Botanical Gardens			
Butterfly Walk	29	2.44	0.72
Princess Point	28	2.13	0.64
Aviary	23	2.44	0.78
Pinetum Trail	17	1.98	0.7
Rock Chapel	16	1.79	0.65
rare			
Indian Woods	28	2.71	0.81
Grand Trunk Trail	29	2.75	0.82
Hogsback Old Field	29	2.58	0.76
Springbank Farm	26	2.59	0.79
Blair Flats	24	2.55	0.8
Preston Flats	23	2.02	0.65

4.2 Volunteer Observations

The nineteen participating citizen scientists observed a total of 590 bees through the season. Volunteers using scheme A reported 156 bees (Table 9), while those using scheme B found 330 bees (Table 10), and those using scheme C recorded 104 bees (Table 11) visiting flowers.

Each volunteer visited the observation sites a different number of times depending on their availability when the weather conditions were suitable for recording data. Compared to normal, July and August 2009 were wet, July was quite cool, and September was warm and dry (Environment Canada, 2009a, 2009b, 2009c). This meant that observing conditions were often sub-optimal, especially for the first month or so of the season. Some citizen scientists were able to record observations only once while others made observations up to 12 times. Over the season, there were 58 site visits from volunteers using the scheme A categories, 98 site visits from scheme B observers, and 34 site visits from scheme C volunteers.

Table 9. Abundance of observed bees from volunteers using scheme A species-groups.

Species-group		No. bees
Small bee (<10mm)	Black/Brown	63
	Green/Blue	12
	Red/Orange	2
Medium sized bee (10-20mm)	Black/Brown	5
	Green/Blue	2
	Red/Orange	0
	Honey bee	35
Large bee (>20mm)	Bumble bee or Bumble bee-like	37
		156

Table 10. Abundance of observed bees from volunteers using scheme B species-groups.

Species-group	No. bees
Honey bee	56
Bumble bee	98
Large Carpenter bee	23
Green bee	9
Other bee	144
	330

Table 11. Abundance of observed bees from volunteers using scheme C species-groups.

Species-group	No. bees
Honey bee	23
Bumble bee	36
Small bee (<20mm)	43
Large bee (>20mm)	2
	104

4.3 Comparing Observational and Specimen-based Data

For the analyses comparing observations to netting and pan-trapping surveys, I used only those bees caught at the six sites visited by citizen scientists. This data subset included 18 site-dates in which I netted 619 bees, with a total of 1041 specimens captured by netting +

pan-trapping together. In comparison, observers recorded 590 bees, which is proportionally ~57% the size of the pan-trapping + netting data set or ~95% of the netting data set.

Citizen scientists observed 3.09 (± 0.3) bees on average during each visit, while 34.39 (± 7) bees were captured by netting, and 57.83 (± 7.7) were collected by pan-traps + netting together. From both the observational and sampling data sets, Bumble bees, Honey bees, Black/Brown, Small, and Other bees were the most common species-groups reported (Table 12). Similar trends emerged between the observational and netted + pan-trapped data sets for the mean number of bees per visit and the proportion of total bees.

Table 12. Mean number (± SE) of bees observed or collected on each site visit and proportion of bees observed or collected over the season, by species-group.

Species-group	Mean no. bees per visit			Proportion of total bees		
	Observed	Netted	Netted + pan-trapped	Observed	Netted	Netted + pan-trapped
Scheme A						
Black/Brown bee	1.14 ± 0.3	11.41 ± 2.3	29.72 ± 5.8	0.43	0.31	0.51
Green/Blue bee	0.24 ± 0.1	1.80 ± 0.5	4.00 ± 0.8	0.09	0.01	0.06
Red/Orange bee	0.03 ± 0	1.80 ± 0.6	3.29 ± 0.9	0.01	0.01	0.02
Honey bee	0.60 ± 0.2	17.20 ± 5.6	15.82 ± 5.2	0.23	0.28	0.17
Bumble bee/Bumble bee-like	0.64 ± 0.1	15.67 ± 5.8	16.33 ± 5.8	0.24	0.38	0.24
Scheme B						
Honey bee	0.57 ± 0.1	17.20 ± 5.6	15.82 ± 5.2	0.17	0.28	0.17
Bumble bee	1.00 ± 0.2	16.43 ± 5.9	17.14 ± 5.9	0.30	0.37	0.23
Large Carpenter bee	0.23 ± 0.1	1.67 ± 0.7	1.67 ± 0.7	0.07	0.01	0.00
Green bee	0.09 ± 0	1.80 ± 0.5	4.00 ± 0.8	0.03	0.01	0.06
Other bee	1.47 ± 0.3	11.94 ± 2.3	31.00 ± 6.1	0.44	0.33	0.54
Scheme C						
Honey bee	0.68 ± 0.4	17.20 ± 5.6	15.82 ± 5.2	0.22	0.28	0.17
Bumble bee	1.06 ± 0.3	16.43 ± 5.9	17.14 ± 5.9	0.35	0.37	0.23
Small bee (<20mm)	1.26 ± 0.3	12.47 ± 2.4	34.56 ± 6.6	0.41	0.34	0.60
Large bee (>20mm)	0.06 ± 0	1.67 ± 0.7	1.67 ± 0.7	0.02	0.01	0.00

4.3.1 Correlations of Observations and Specimens

Results from Spearman's Rank-Order tests suggest that all of the associations were strongly positively correlated (Table 13). However, the correlation was significant only for the case of observations compared with netting + pan-trapping data for bee abundance using scheme A species-groups ($\rho(3) = 1$, $p = 0.017$). The comparison included proportionally more Black/Brown, Green/Blue, and Red/Orange bees and fewer Bumble bee/Bumble bee-like and Honey bees than observations versus netted bees alone (Figure 7). Observations using scheme A were not significantly correlated with netting data for bee species-group abundance ($\rho(3) = 0.87$, $p = 0.054$).

When species-groups were categorized using schemes B and C, there was no significant correlation between observations and netting ($\rho(3) = 0.8$ ($p = 0.133$), scheme B; $\rho(2) = 0.8$ ($p = 0.333$), C) or between observations and netting + pan-trapping for bee abundance ($\rho(3) = 0.9$ ($p = 0.083$), scheme B; $\rho(2) = 1$ ($p = 0.083$), C). For scheme B, including pan-traps in the correlation provided proportionally more of every species-group except Large Carpenter bees (Figure 8). In scheme C, the netting + pan-trapping data set included proportionally more Small bees and fewer of every other species-group than the netting data set alone (Figure 9).

Table 13. Season-wide correlations between each categorical scheme of reporting bee observations (left column) and specimen-based data (middle and right columns). Significant p-values are in bold.

Bee group comparison	Netting data (Spearman's ρ, *p*)	Netting + pan-trapping data (Spearman's ρ, *p*)
Scheme A	0.87, > 0.05	1, < **0.05**
Scheme B	0.8, > 0.1	0.9, > 0.05
Scheme C	0.8, > 0.1	1, > 0.05

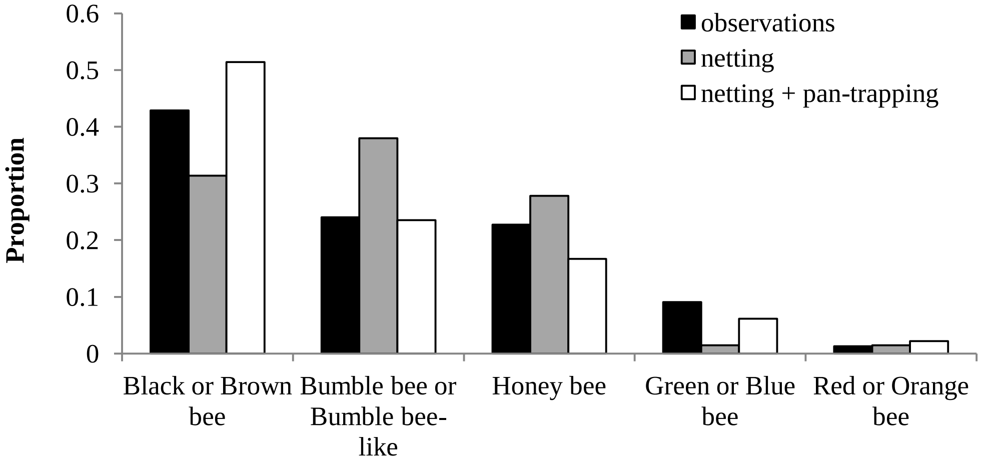

Figure 7. For scheme A, proportion of observations, netted, and netted + pan-trapped bee specimens by species-group. For each collection method, the sum of proportions across all species-groups is equal to 1.

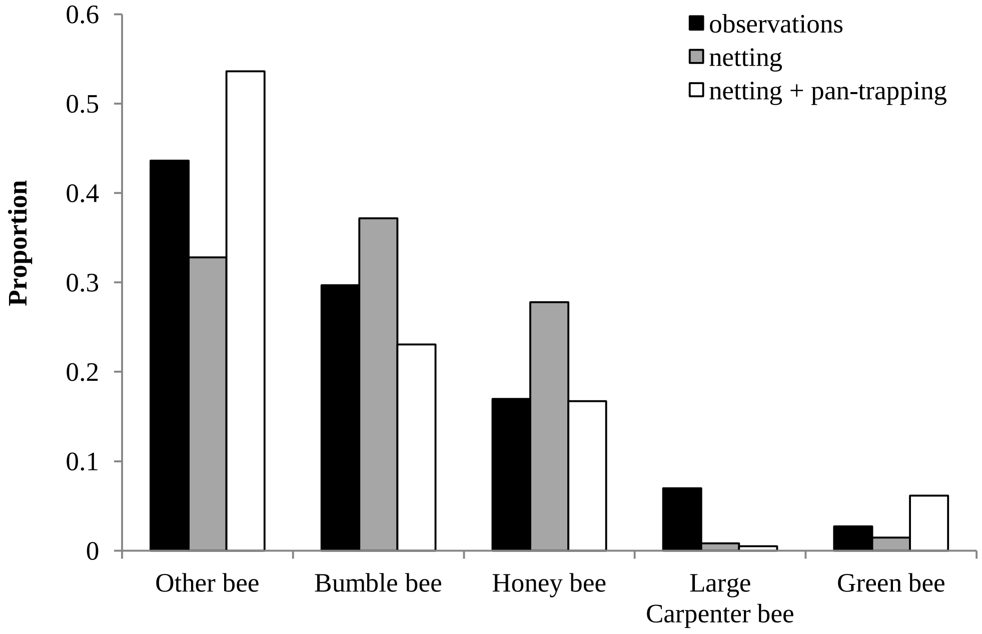

Figure 8. For scheme B, proportion of observations, netted, and netted + pan-trapped bee specimens by species-group. For each collection method, the sum of proportions across all species-groups is equal to 1.

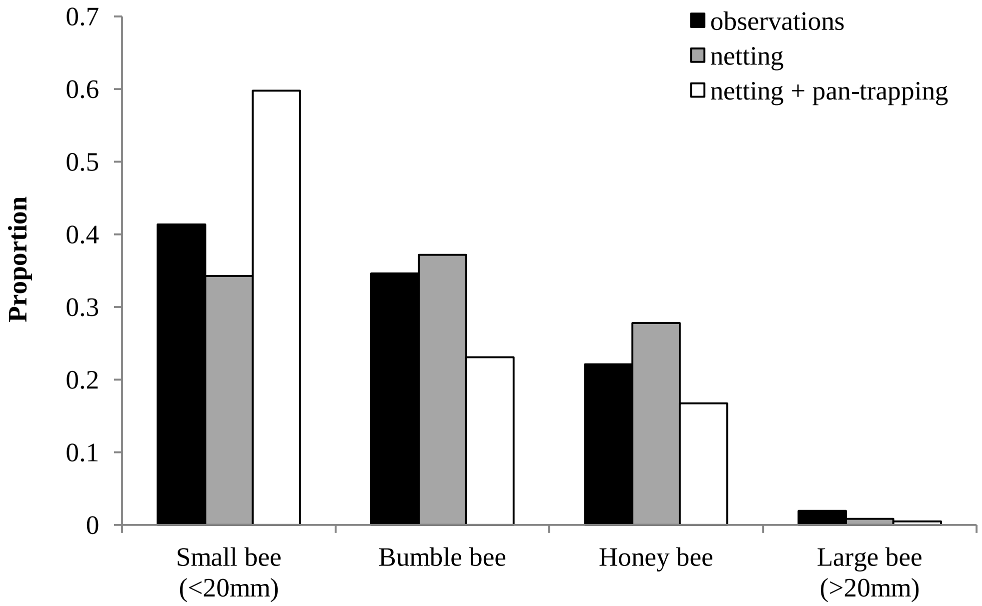

Figure 9. For scheme C, proportion of observations, netted, and netted + pan-trapped bee specimens by species-group. For each collection method, the sum of proportions across all species-groups is equal to 1.

4.3.2 Patterns of Community Composition

Though strong relationships between observational and specimen-based data sets were found over the whole season, the same was not true upon examining the data on a visit-by-visit basis. The Mantel tests revealed that patterns of bee community assemblages were not significantly correlated between specimens and observations ($p > 0.1$ for schemes A, B, and C). The data sets were compared by site-date, with bee abundances represented as proportions. Scheme B showed the strongest relationship between observations and netted specimens ($r = 0.271$, $n = 10$ matched site-dates) while scheme A had the closest link between observations and netting + pan-trapping ($r = -0.202$, $n = 9$), followed by scheme B ($r = 0.134$, $n = 10$). The remainder of the comparisons showed no correlation at all (scheme A: $r = -0.043$, $n = 9$ for netting; scheme C: $r = -0.043$, $n = 5$ for netting, $r = 0.081$, $n = 5$ for netting + pan-trapping).

4.3.3 Assessing Bee Species-Groups

The Mann-Whitney *U* test revealed a significant difference in the proportions of Black/Brown, Green, and Small bees ($p < 0.05$) between observational and netting + pan-trapping data (Table 14). There were no statistically significant differences between the proportions of bees in the observational and netting data alone. The most closely matched species-groups between the observational and specimen-based data sets were Bumble bees, Honey bees, Green/Blue, and Red/Orange bees (Figures 10-12). In the matched-visit data subset I did not catch any bees that could be placed in the Large bee category for scheme C, so no comparisons could be made against the observations (Figure 12).

Table 14. Results of Mann-Whitney U test comparing observation data to netted and to netted + pan-trapped bee data. Bold values show a statistically significant difference between observational and specimen-based data ($p < 0.05$).

Species-group	Netted bees	Netted + pan-trapped bees
	Mann-Whitney *U*(df)	Mann-Whitney *U*(df)
Scheme A		
Black/Brown bee	41(9)	**51(9)**
Green/Blue bee	1(9)	22(9)
Red/Orange bee	6(9)	10(9)
Honey bee	18.5(9)	18(9)
Bumble bee/Bumble bee-like	19(9)	11(9)
Scheme B		
Honey bee	27.5(10)	24(10)
Bumble bee	51(10)	32(10)
Large Carpenter bee	1(10)	1(10)
Green bee	6(10)	**55(10)**
Other bee	26(10)	46(10)
Scheme C		
Honey bee	7(5)	7(5)
Bumble bee	2(5)	1(5)
Small bee (<20mm)	**15(5)**	**15(5)**
Large bee (>20mm)	--	--

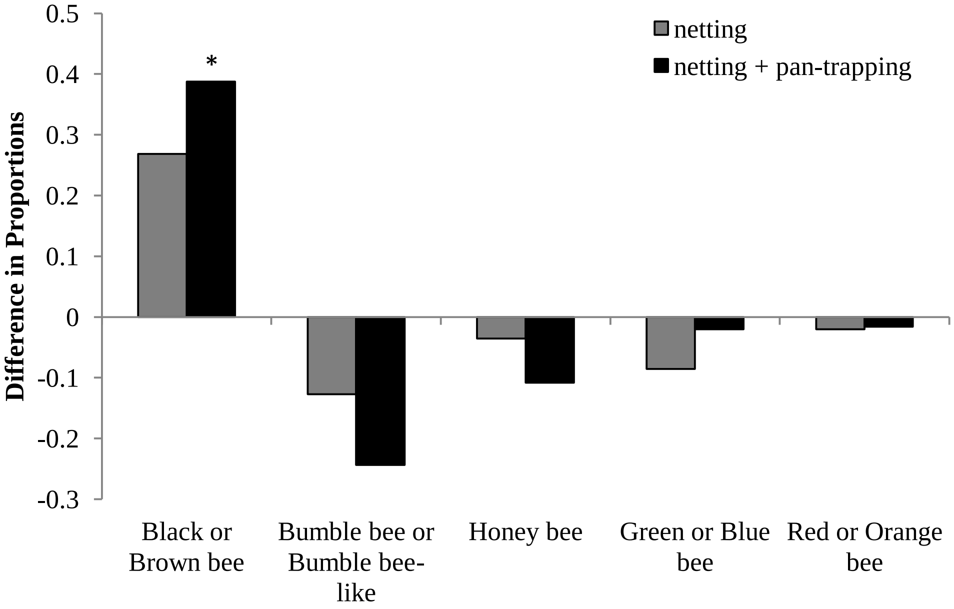

Figure 10. For scheme A, difference in proportions between observational and netted or netted + pan-trapped bee specimens (specimens - observations) by species-group. Matched pairs of specimens and observations marked with * are significantly different from one another ($p < 0.05$).

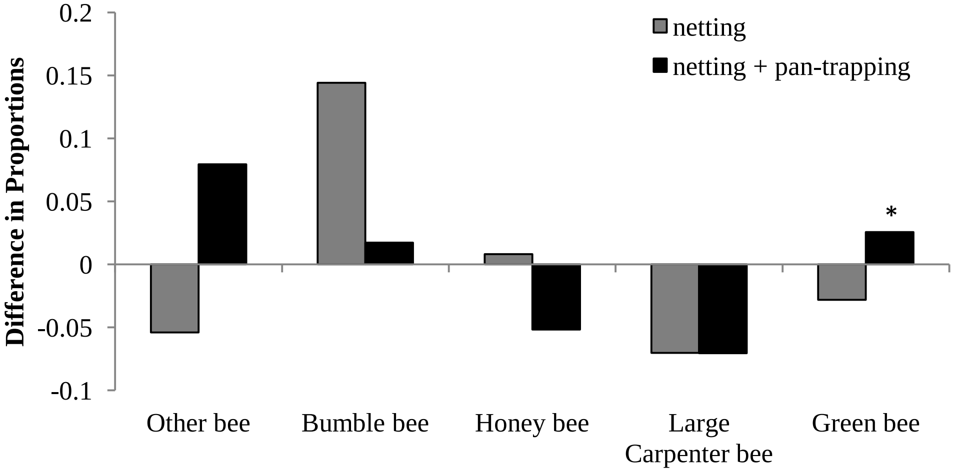

Figure 11. For scheme B, difference in proportions between observational and netted or netted + pan-trapped bee specimens (specimens - observations) by species-group. Matched pairs of specimens and observations marked with * are significantly different from one another ($p < 0.05$).

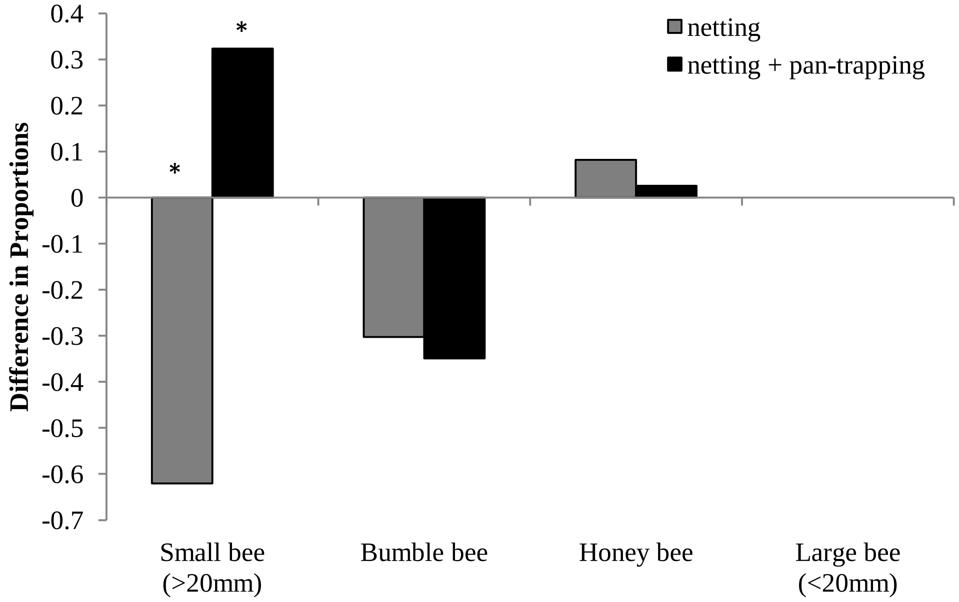

Figure 12. For scheme C, difference in proportions between observational and netted or netted + pan-trapped bee specimens (specimens - observations) by species-group. Matched pairs of specimens and observations marked with * are significantly different from one another ($p < 0.05$).

4.4 Flowering Plants

4.4.1 Species Diversity and Stem Density

Over the course of this study, the plant survey detected 103 species of flowering plants representing 24 families (Appendix B). Most of the recorded flowering plant taxa were members of Asteraceae (41 species) and Fabaceae (10 species), making up 39.8% and 9.7% of the total taxa, respectively. Lamiaceae was represented by eight species, making up 7.8% of the total taxa. Eleven families were represented by only one species each (<1% of the total taxa).

Overall, ***rare*** sites had a higher species richness than those at RBG (Table 15). In fact, species richness was higher at each ***rare*** site than at any RBG site. Stem density was slightly higher across all ***rare*** sites than RBG sites as well. All but two sites—Aviary at RBG and Blair Flats at ***rare***—had a Pielou evenness index between 0.61 and 0.79. Springbank Farm showed the most even spread of species but the lowest stem density at ***rare***, and Pinetum Trail and Rock Chapel followed the same trend at RBG.

Table 15. Species richness, Shannon Diversity Index, Pielou Evenness Index, and mean density (stems/m^2 ± SE) of flowering plant stems counted within fifteen 1m x 1m quadrats at Royal Botanical Gardens and the ***rare*** Charitable Research Reserve, by site.

Site	Species richness	Shannon diversity (*H*′)	Pielou evenness (*J*′)	Density (stems/m^2)
Royal Botanical Gardens				
Princess Point	30	2.34	0.69	11.3 ±2.6
Rock Chapel	27	2.61	0.79	5.3 ±0.7
Pinetum Trail	26	2.59	0.79	4.1 ±0.4
Aviary	22	1.47	0.48	14.5 ±3.8
Butterfly Walk	21	2.42	0.8	6.7 ±1
rare				
Preston Flats	40	2.67	0.72	9.8 ±1.4
Grand Trunk Trail	39	2.65	0.72	11.3 ±1.7
Indian Woods	39	2.28	0.62	17.2 ±4.2
Springbank Farm	37	2.69	0.74	7.5 ±1.4
Blair Flats	36	1.36	0.38	15.3 ±3.2
Hogsback Old Field	35	2.18	0.61	9.5 ±1.2

4.4.2 Selecting an Observation Site

The post-hoc site ranking illuminated some parameters relevant to choosing a bee observation site. A high species richness and mid- to high density of plants appears to be related to high bee numbers and diversity, as seen at Indian Woods, Grand Trunk Trail, and Preston Flats (Table 16). But a diverse plant assemblage was not always associated with the bee abundance or diversity at a site: Indian Woods and Princess Point had low plant diversity, for example, but high bee diversity (though few bees were observed at Princess Point and many were collected). As another example, high plant diversity at Grand Trunk Trail, Preston Flats, and Rock Chapel did not result in equivalently high bee abundance or diversity. Rock Chapel had low bee counts and diversity as opposed to high numbers at the other two sites.

Low plant density may not be associated with bee diversity but it may affect observation results. For instance, Rock Chapel and Butterfly Walk had low observation numbers while Butterfly Walk also had low netting abundance but high pan-trap counts and a richness of bee species.

Table 16. Effective number of plant species (transformed Shannon Diversity Index, $e^{H'}$), plant species richness, mean plant density (stems/m^2), bee species richness, and mean abundance from citizen science bee observations, netting, and netting + pan-trapping bees at Royal Botanical Gardens and the ***rare*** Charitable Research Reserve, by site.

Site	Plant diversity ($e^{H'}$)	Plant richness	Plant density (stems/m^2)	Bee richness	No. observed bees	No. netted bees	No. netted + pan-trapped bees
Preston Flats	14.38	39	9.78	23	126	102	130
Grand Trunk Trail	14.17	39	11.26	29	137	79	167
Rock Chapel	13.59	27	5.34	16	73	96	113
Butterfly Walk	11.29	21	6.71	29	50	67	219
Princess Point	10.36	32	11.29	28	62	160	193
Indian Woods	9.77	38	17.15	28	142	115	219
Totals					590	619	1041

Chapter 5

Discussion, Conclusions, and Recommendations

The results of my research project indicate that PollinatorWatch, a citizen science program designed to monitor pollinating bees, can be successful at producing high quality data through volunteer observations, especially over the long-term. However, the scope of my project was limited and PollinatorWatch requires refinements before results can be useful to researchers. Primarily, adjustments should be made to the manner in which bee data are gathered in PollinatorWatch, but the program will also benefit from changes to its overall protocol. The following discussion focuses on lessons learned through my research project and how those lessons can be translated to improve a citizen science bee monitoring program for Canada.

5.1 Assessing the Efficacy of Citizen Data

Defining the statistical precision of observation protocols is an important component of ecological monitoring schemes. Studies have shown that amateur observers can produce reliable records on the presence of species, but may not provide precise accounts of abundance (e.g. Shirose *et al*., 1997; Genet and Sargent, 2003; Crall *et al*., 2011). Citizen scientists are not responsible for data precision, however; even professionals detect lower species richness and abundance when they make bee observations than when they use specimen-based data gathering techniques (Westphal *et al*., 2008). The precision of results depends on the method used to collect information.

Not surprisingly, my study found that though citizen scientists can readily identify bee species-groups, their observations provide a measure of relative bee abundance rather than a true representation of abundance on a per-visit basis. While a single instance of a volunteer observing bees for 10 minutes afforded only a small amount of gathered data, when all observations from all observers were pooled, trends emerged. Those trends tended to follow patterns of bee abundance collected by netting + pan-trapping, an important point because the netting + pan-trapping represented the entire community of bees, so in following the same patterns, observations may be representative of the functional diversity of the community and the quality of habitat.

Although there were large differences in the mean number of bees collected versus bees observed on each visit, the relative proportions of each species-group were roughly equivalent between the two collection methods, with observations more closely following the trends of bees caught in nets + pan-traps than of bees caught only by netting.

5.1.1 Comparing Observations to Specimens

For all of the species-groupings I assessed, observational data were positively correlated with specimen data over the season. Spearman’s correlations for bee abundance were strongest between observations and netting + pan-trapping for each recording scheme. These results suggest that, in contrast to Kremen *et al*. (2011), the observational data showed more similarities to the more thorough sampling design of netting + pan-trapping than to netting alone.

My findings suggest that information collected by volunteers is more robust over the long-term than the short-term, indicating there is a need for more long-term studies, perhaps with modified protocols. Season-wide correlations were much stronger than matched-visit correlations for observations versus specimens. The lack of correlations between specimens and observations on a per-visit basis may be a result of changing weather conditions because my samples weren’t necessarily taken on the same day or at the same time as volunteer observations were made. Bee foraging activity could have easily changed if cloud cover, wind, or temperature differed between our data collection events. Alternatively, the bees observed may have been in a different part of a plot than where they were sampled. Study sites were large enough that volunteers may have selected a $1m^2$ patch of flowers that wasn’t included in the netting and pan-trap sampling. In hindsight, this was a design flaw and perhaps I should have restricted participants to particular areas of each site. Instead, future studies should consider the approach by Kremen *et al*. (2011) who used a transect: a volunteer made observations by slowly walking the length of the transect while a researcher simultaneously netted bees starting at the other end of the same transect.

5.1.2 Using Bee Species-Groups

Results from my research study suggest that citizen scientists with moderate training can collect useful observational data for detecting bees, but at a coarse level of identification. In a citizen science study on freshwater invertebrates, Fore *et al*. (2001) found that although professional and volunteer metrics for taxon richness were highly correlated, they were not equal. This is because the range of possible values of richness was smaller for volunteers because they identified many fewer taxa. The same holds true for my study, especially when surveying differences between the numbers of bee species sampled and the crude species-group categories used by citizen scientists. These coarse groupings have, however, been effectively used as a way to involve volunteers in sorting bees into easily recognizable taxonomic units (Abadie *et al*., 2008).

Foster-Smith and Evans (2003) found that for shoreline organisms, volunteers were able to learn to recognize a range of target species, in a short period of time, and to provide reliable information on their presence/absence. Yet to reduce error in the general sense, program managers should determine whether certain attributes or species are particularly difficult to distinguish (Dickinson *et al*., 2010). Especially when developing categories for scheme A, I attempted to use easily recognizable species-groups, such as Bumble bees and Honey bees, or distinguishing features, like green or black bodies.

Most bees were reported from the following groups: Bumble bees, Honey bees, Black/Brown, Small, and Other bee species-groups. However, discrepancies between observational and specimen-based data were greatest for species-groups that lumped a large variety of bees such as Small or Black/Brown bee. While such categories make reporting simple and may solicit a lot of data, information that can be drawn from them is limited. However, as species-groups may be used as a proxy for the ecological diversity of the bee community, conclusions can still be drawn from broad categories. For instance, small bees have a small flight range from their nests, indicating that their needs are being met in the vicinity of where they are observed. Coarse categories used for bee observations also allow species that may be confused with one another to be lumped together in one group to limit misclassification.

Additionally, Crall *et al*. (2011) found that identification errors could be reduced by including only those species in the protocol for which correct identification rates were high. Based on the results from the Mann-Whitney *U* test, the best species-groups to use, then, would include Bumble bees, Honey bees, and Red/Orange bees. McLaren and Cadman (1999) suggest that novices can provide reliable data for a carefully selected subset of species, so I am inclined to also include readily distinguishable bees in the list, including Large Carpenter bees and Green or Green/Blue bees. Although there was a statistically significant difference between observed and netted + pan-trapped Green bees in scheme B, it seems counterintuitive to exclude such recognizable bees from a citizen science program, especially based on recommendations from other studies (e.g. Dickinson *et al*., 2010).

My original design for the species-groups in scheme A was too refined for observations made in this study, so data for each type of Small and Medium sized bees had to be pooled for analysis. This changed the number of species-groups from eight to five, which if incorporated, would ultimately make the PollinatorWatch recording format simpler for volunteers to utilize but reduce the ecological relevance of information gathered. With these changes, the species-groups in scheme A became similar to those of scheme B, as used in The Great Sunflower Project: Bumble bee, Honey bee, and Green bee were included. But scheme B separated Bumble bee from Large Carpenter bee while scheme A lumped them together in a Large bee category called Bumble bee and Bumble bee-like. Scheme A's Black/Brown bee captured much of what's in Scheme B's Other bee category (see Tables 6 and 7), though not everything; the unique species-group I included in Scheme A was Red/Orange bee.

Even though it doesn't appear to be a category that observers will encounter frequently—and in fact these bees were present in small numbers in the sampling data set as well—the Red/Orange bee group contains primarily cleptoparasitic bees which may be useful as indicators of community health (Sheffield *et al*., 2013). The small number of genera included in the Red/Orange bee species-group (mainly *Nomada* and *Sphecodes* and the much less frequently observed *Epeolus* and *Triepeolus*) is represented in many Canadian locales (Packer *et al*., 2007), and they are easily recognized for their distinctive colouration (Michener, 2007). The Red/Orange bee species-group may not provide an abundance of data points in a citizen science program, but I suggest that it can be a useful category to provide important information on ecosystem health to PollinatorWatch coordinators and scientists.

5.2 Creating an Effective Citizen Science Program Using Bee Observations

Mayer *et al*. (2011) asked how we can effectively raise awareness about plants, pollinators, and pollination services while also using plants and their pollinators as educational tools. Through this research project and my discussions with citizen scientists, I firmly believe that programs like PollinatorWatch can answer the call. Those citizen science programs that are the most successful at raising our collective understanding of pollination services have been carefully designed and thoroughly field-tested. While PollinatorWatch is well on its way to joining the ranks of successful programs, my research findings illuminate some areas in need of improvement.

5.2.1 Standardize Protocols

Research on citizen science consistently emphasizes the need for well-designed, standardized protocols to ensure the most effective use of volunteer collected data. When citizen science programs use standardized protocols that include repeated visits to the same field site(s), researchers can then use rigorous methods of data analysis to deepen their understanding of sources of variation inherent in the data. Likewise, when field sites are representative of the broader landscape in which they are located, researchers are able to discern biological patterns and trends. With this in mind, I designed the standardized PollinatorWatch protocol for this thesis project to eliminate variation in observer sampling effort using the following measures: (i) selecting only mixed meadow habitats, (ii) requiring observers to repeat sampling at the same sites through the season, (iii) setting a 10-minute window for collecting bee data, (iv) using a 1m x 1m sampling frame, and (v) counting floral units. Prior to the current project, none of these measures were in place as part of the PollinatorWatch protocol. Rather, participants could select any size of a patch of flowers at any site and observe for as long as they wished. The training, guidelines, supplementary materials, and personal support I provided to volunteers was incentive for them to adhere to the protocol.

I didn't use the quantitative plant data collected by citizen scientists for analyses, but I did find it valuable to have participants record plant information on their site visits. In discussions with observers following the field season, I discovered that they appreciated using the 1m x 1m quadrats for delineating where to look for bees (see Appendix C). I also learned that some participants would have preferred to count the number of stems for flowering plants rather than floral units. Counting the number of stems would standardize this measure for PollinatorWatch across all plant species and in all habitats.

Another important feature to standardize is plant names listed by volunteers. I did not anticipate the difficulties I encountered in deciphering plant species names. Volunteers in my study used common names but were not asked to specify which source or field guide they used for plant identifications. So after the field season, I assessed where participants accessed their information and converted data entries to scientific binomial names. Dealing with this was not a major setback for my project, but I think PollinatorWatch program administrators will save time and effort by enforcing a standard nomenclature, either by asking participants to submit scientific names (which are backed by international codes for botanical nomenclature that can be used by volunteers), indicating their source for common names, or by providing them with a reference guide.

5.2.2 Select Ideal Sites and Establish a Baseline

A diverse assemblage of plants may not consistently provide resources for an abundance or richness of bees. Results show that sites with low plant diversity can support a variety of bees while sites with high plant diversity provide for both high and low bee numbers and variety. But high plant species richness coupled with mid- to high plant density appears to provide for a rich diversity of bees. This means that citizen scientists may benefit from seeking out sites with a variety of flowers in bloom, though the species do not necessarily have to be equally abundant.

It appears that observers could have more success when selecting sites with a collection of flowers that are large or easily seen than those with inconspicuous or otherwise hidden flowers. Contrasting Princess Point and Indian Woods provides an example: while few bees were observed at Princess Point, many were collected. The meadow was dense with vegetation, though much of it was waist-high. Many of the flowers were rather small or difficult to find among the tall greenery so observers may have missed opportunities to record bees at them. Indian Woods, on the other hand, was an open meadow with fairly low-growing plants that made the entire site easy to examine and access. Each plant in flower was readily seen, so it was easier for citizen scientists to observe bees. While sites like Princess Point and Indian Woods, with high plant density but low diversity, do not result in uniform counts of bees from observers, netting and pan-trapping reveal that they have a consistently high abundance and richness of bees. At these sites, it could be that the floral resources provide good food for bees but those plants are not necessarily conducive to watching bees forage.

Meadows with low flowering plant density frequently result in low observation counts likely because of the lack of flowers on which to observe bees foraging. At Rock Chapel, the ground was densely covered with plants but many of them were not in bloom throughout the season. Perhaps there were insufficient food and nesting resources to support many bees. ButterflyWalk, another site with low plant density, had extensive areas of bare ground in which bees could nest. At that site, many bees were caught in pan-traps but few were observed or netted from flowers. Many of the bees at the site were small or cleptoparasitic, so it is possible that they escaped observation or simply did not visit the flowers frequently. Citizen scientists, then, may benefit from choosing sites with a high density of flowering plants.

My study comprised a one-season snapshot, so it may not have reflected a representative sample of the bee population. Rather, I suggest my study provides the beginning of baseline measures that represent life-histories of pollinators in natural habitats at RBG and ***rare***.

Through long-term studies these organizations can build a profile of ideal conditions that support healthy bee communities and be alert to changes that affect populations.

In a similar way, PollinatorWatch should put efforts into engaging the scientific community to establish a baseline at reference sites across Canada; the recent work of CANPOLIN will certainly be valuable in this endeavour. An initial 3-5 year sampling is ideal, especially if it includes drastically different seasonal conditions (e.g. a spring with flooding that could kill a number of ground nesting bees vs. a dry spring). Reference sites also need to be representative of geographic and temporal variability (i.e., prairie conditions are different than mixedwood plains; early spring has a different phenology than late summer) and monitored frequently. With regional baselines captured in synoptic collections, PollinatorWatch program administrators can have an account of what to expect in ideal areas. Reference sites can be used in comparisons to individual observers' sites, much like the community-based Ontario Benthos Biomonitoring Network which uses what's called the reference condition approach. Organizations and individuals interested in gardening for bees or restoring bee habitat can use the reference condition as an ideal to strive for. They can ask: Is one of the functional groups missing because those bees are not actually present in the area, or are there habitat requirements missing? If the latter, approaches such as clearing patches of earth for ground nesters or leaving rock piles from rodent dens in which bumble bees can nest may be beneficial.

5.2.3 Connect With Participants

It is important to design volunteer-based programs in such a way that the tasks are realistic and achievable and the methods are easily understood (Foster-Smith and Evans, 2003). To ensure the ongoing collection of high quality data, volunteers should be closely managed in the field and project coordinators should provide guidance whenever possible (Lovell *et al.*, 2009). Keeping this in mind, I was constantly in contact with volunteers throughout the season, answering questions and concerns and providing additional information when necessary.

I frequently received inquiries and comments about recognizing plants. Participants accurately identified plants in bloom though some citizen scientists were comfortable with plant identification while others were rather unfamiliar with the task. The latter were likely successful due to the resources that they had available at each site, including lists of plants in bloom throughout the season as well as good field guides.

A full-time program administrator is required for the successful operation of a citizen science program. While participating citizen scientists may be drawn to programs because they care for the natural world, they need guidelines, support, and feedback for their efforts.

5.2.4 Increase Sampling Effort

Though the observational and specimen-based bee data showed similar trends, they were quantitatively greatly different. The effort involved in each sampling scheme was not equivalent, with many citizen scientists collecting observational data and one researcher collecting specimens. Sampling specimens included active netting across a plot for thirty minutes as well as passively capturing bees in fifteen pans for several hours. In contrast, observations lasted for ten minutes in a $1m^2$ quadrat. On a per-visit basis, the specimen collection yielded higher results, yet the many citizen scientists collecting observational data could gather vast amounts of information. In this way, the PollinatorWatch program data may be made more robust by increasing the number of sites and observations each year.

Schmeller *et al*. (2008) found that in general, the number of volunteers involved in a monitoring program directly affects the sampling effort of that scheme. Their study showed a strong positive relationship between the number of observers and the number of sites monitored, the number of visits to a site, and the number of species monitored. Given the importance of pollination to provide ecosystem services, PollinatorWatch has direct relevance to gardeners, food producers, conservation land managers, and ecologists, so participation among these groups should be amplified. Providing that the volunteer training is sufficient, the program may benefit from a more concerted effort to engage more citizens, because increasing the number of observations can reduce variability in the data (Kline, 1998; Dickinson *et al*., 2010). In fact, Schmeller *et al*. (2008) suggest that a higher sampling effort could result in a more precise estimate of a taxonomic group's status and improve the chances of detecting any statistical changes to status and trends.

5.2.5 Engage and Retain Volunteers

The summer of 2009 was characterized by periods of wet, cool, and cloudy weather, none of which are particularly favourable for foraging bees. Under those conditions, pan-trapping may have been especially useful as it allowed catch to occur during brief windows of sun on days when net-collecting or observations would have been unrewarding. In fact, there were always catches from pan-traps but several volunteer visits resulted in few or no bees. Though null results are scientifically valuable, this can be discouraging for citizen scientists, especially when they spend a considerable amount of time travelling to sites before making observations. Weather conditions strongly affect bee foraging behaviour, and therefore bee diversity and abundance, so to optimize bee sightings, observations should really only be made during favourable weather conditions. Despite weather variability however, baseline measures from reference sites could be valuable for examining results from volunteers in PollinatorWatch, especially to determine whether observations are indicative of the life-history traits of pollinators or if there is something else happening at the observation site.

When a pool of volunteers is involved in data gathering, it is difficult to coordinate site visits and invariably monitoring takes place under differing weather conditions. Fortunately for bee monitoring, there are only a few weather guidelines to follow. As with other citizen science protocols, PollinatorWatch participants should be aware of weather conditions before trying to make observations, ensuring that the temperature is at least 15˚C, there is low wind, no rain, and skies are not overcast. In a study on volunteer-based amphibian monitoring, Milne *et al*. (2013) suggest that when weather is not suitable, protocols should adapt to include additional site visits. If necessary, for example, PollinatorWatch observers could gather plant details one day and revisit sites within a day or two so that they can make use of their efforts under suitable conditions.

Providing more flexibility for visiting sites may increase volunteer success and result in more engaged participants. In addition to providing clear weather guidelines, PollinatorWatch may improve participation rates if fewer site visits are required through the season. My project asked volunteers to visit field sites every 10-14 days, but this was clearly not achievable by most participants. Instead, a minimum of three visits could be made: late spring/early summer, mid-summer, and late summer. Extra visits could be added, either monthly or more frequently, if a participant has time available to do so. This approach would provide participants with a clear window of time and expectations for gathering data. Seasonal timeframes for observing are reasonable because bee communities vary significantly over time. Understanding the life-histories of bees is useful in this endeavour. Some bee groups appear consistently from spring through autumn, but other groups are abundant only at certain times of the year. Because of this, it will be important for PollinatorWatch observers to monitor study sites at least three times throughout the foraging season.

5.3 Influence of Volunteer Experiences on Data Collection and Analyses

Although the results of my study help in responding to the research question, there remain a number of issues that need clarification. The small number of participating citizen scientists restricted the sample size of observational data. Thus, the limited observational data points may have prevented statistically significant results in comparative analyses between observations and specimens.

Additionally, the volunteers in this study were all first-time bee observers. After a season of practice in the field, it is possible that their efforts the next year could yield more records, as many of them noted that their visual recognition, comfort levels, and identification skills improved over the season (see Appendix C). Kendall *et al.* (1996) found that removing participants' first year records in the North American Breeding Bird Survey had an impact on results in some cases as they became more adept at counting birds. Likewise, Darwall and Dulvy (1996) found that participants were more consistent in reporting on fish size estimates and census data after they had more experience with diving at a research location. In the case of bee monitoring programs, many participants may be attuned to noting components of natural history, but they may not be well practiced at visually observing and noting the details of tiny flying insects visiting individual flowers. As Sauer *et al*. (1994) and McLaren and Cadman (1999) found then, observation quality could increase after the first year of participating in PollinatorWatch.

The training I developed lasted for only one day (approximately 5-6 hours). In contrast, Kremen *et al*. (2011) conducted a two-day training for volunteers. Though much of the training between that study and mine was similar, on day two of the training by Kremen *et al*. (2011), experts spent time in the field with each observer, providing continuous feedback on the accuracy of each observation and ensuring that volunteers were using the monitoring methods consistently. In hindsight, this would have been a beneficial component to the training I provided to the volunteers. Taking this approach, however, would not have provided an accurate reflection of the experience of citizen scientists in PollinatorWatch, who currently receive no personalized training at any point during their participation.

Additionally, I could have collected observational data as the volunteers did, but I decided against this approach on the basis that I felt my familiarity with observing bees was distinctly different from that of the participants, and as such the results wouldn't provide a comparable assessment of observations. Foster-Smith and Evans (2003) had experts and volunteers collect shoreline data in the same way at the same time and discussed problems with their approach: results from experts differed from those of amateurs because of differences in familiarity with the study organisms and their habitat preferences. On the other hand, Fore *et al*. (2001) had volunteers and professionals use identical field techniques for macroinvertebrate collections to assess water quality, though each group collected their samples about one month apart. They found that field samples from volunteers and professionals differed very little.

Had I been present to collect data in the field with the observers, I may have gained further insights, not to mention that I would have been able to provide clarification and to address unexpected circumstances more readily. One clear downfall of not collecting data alongside volunteers came when comparing specimens and observations over the season. To rectify this design consideration, I attempted to compare both data sets using a subset of the sampling days, examining volunteer visits within three days of each visit I made. The resulting Mantel test unfortunately yielded few significant results; a more intentionally blocked design may have improved the correlation.

I could have also designed this project such that volunteers only collected data at multiple sites at one research locale, either RBG or ***rare***. Although this approach may have made data comparisons more straightforward, it might have limited volunteers' involvement because they chose to observe at the research location that was most convenient for them to visit.

5.4 Recommended Revisions for PollinatorWatch

The PollinatorWatch program ought to undergo an iterative process of updates and modifications over time (Bonney *et al.*, 2009; Dickinson *et al.*, 2012). My project tested new ways to construct a bee observation program but PollinatorWatch is as yet imperfect. It is likely that the refined materials I created need to be re-tested and PollinatorWatch subsequently adapted. Enacting simple refinements to the program will no doubt enhance results.

To ensure participants can collect and submit accurate data, three components must be in place: clear data collection protocols, simple and logical data forms, and support for volunteers in following the protocols and submitting their information (Bonney *et al*., 2009). I used the PollinatorWatch protocol for this study, but I revised and simplified it slightly to use a particular time-frame (10 minutes) and to delineate the observation frame (1m x 1m) rather than leaving both undefined. I also refined the simple data forms for volunteers to use and provided constant support and open communication throughout the season. I suggest that the PollinatorWatch program should use the modified protocol and field sheets that I employed and that program coordinators continue to be available for participants.

I also revised the PollinatorWatch protocol by encouraging observers to visit each site every 10-14 days. However, this was an unreasonable timeline for many volunteers, so I conclude that it should not be adopted by PollinatorWatch. Instead, I suggest visiting sites monthly or even three times in a season, as in the California Pollinator Project (see Ullmann *et al*., 2010). Keeping in mind that consistency is very important, however, monitoring dates should remain constant from year to year once they have been selected.

Having volunteers record the number of floral units was not the best way to collect plant abundance data because the data were not standardized across all visits or all volunteers. Instead, I recommend using number of stems for each plant in bloom as a standard unit of floral abundance. In this way, PollinatorWatch coordinators can have an indication of stem density and presence/absence of plants across Canada, both of which can be considered in analyses with large data sets.

The PollinatorWatch program might also benefit from utilizing two-person teams, where one person observes and the other records, as in the California Pollinator Project (see Ullmann *et al*., 2010). For safety reasons, Foster-Smith and Evans' (2003) study also utilized volunteers in pairs or small groups in the field. Each person made their own assessments without collaborating with their field partner. Based on a suggestion from one of the volunteers in my study, I recommend this approach for PollinatorWatch, if only as a guideline to volunteers. There's another justification for pairing participants as well: Lovell *et al*. (2009) used the data from two volunteers together as a proxy for a single expert researcher, though this was for sampling invertebrates rather than simply observing them. They suggest that it is possible to compensate for lack of experience by increasing effort of the volunteers.

PollinatorWatch could also improve volunteer retention by providing certification in particular skills (Crall *et al*., 2011). Certification not only provides credibility and a feeling of accomplishment for volunteers, but also improves their long-term sense of commitment to a program (Bell *et al*., 2008).

5.4.1 Simplify Plant Identification

The volunteers spent most of their time at a site identifying the flowering plants. This was evident when I looked at the time periods between an observer's site visits on a given day. Those who were familiar with plant identification could clearly complete their surveys much quicker than those who were still becoming familiar with wildflowers (for example, 45 minutes vs. 2 hours, respectively). I recommend that in future iterations of citizen science monitoring programs, a comprehensive plant identification guide be provided and/or volunteers should place their 1m^2 quadrats over plants with which they are already familiar.

5.4.2 Enhance Quality Control

Based on my research findings, conversations with other researchers and citizen scientists, and a review of similar programs, I recommend the following bee species-groups for a revised PollinatorWatch program:

Bumble bee
Green (or Green/Blue) bee
Honey bee
Large Carpenter bee
Red/Orange bee
Other bee

As body size plays an important role in our understanding of bee ecology, I suggest including small, medium, and large size categories as well.

I also suggest that PollinatorWatch coordinators develop a training workshop for interested volunteers, similar to the day-long program I designed. I recommend including practice field observations in the training, with the support of either experts or experienced observers. The workshop should provide citizen scientists with a chance to seek clarification, receive directed guidance, and experience an observing session while scaffolding their learning before they collect data on their own. An in-person training workshop could serve to produce more invested participants who collect valid, reliable data.

I didn’t thoroughly assess each volunteer’s ability to identify bees in the field and place them in the appropriate species-group. In retrospect, I could have carried out a simple in-class or field test before the end of the training day, or at least before their first day in the field, similar to the training conducted by Foster-Smith and Evans (2003). Based on my experience and after discussion with experts, I suggest that conducting a test in this way would be reasonable and beneficial.

Similar to Genet and Sargent (2003), I suggest using video recordings of bees, posted on the PollinatorWatch website, for volunteer observers to ‘practice’ before collecting data in the field. Such video recordings should represent typical patches of flowers that an observer could visit as they collect data for PollinatorWatch, and collectively the videos should cover a range of habitats (e.g. mixed meadow, garden, roadside) and times within the season. The videos should last for 10 minutes, the recommended time for observing bees in this protocol. Volunteers will be instructed to watch each video and, using data forms identical to those they would use in the field, report both the flowers present and the bees they see visiting flowers. The observers may then input their data directly to the electronic database, so that their information can be compared to independently predetermined responses from bee experts. This could at once serve to provide volunteers with an understanding of the field observation experience and also give PollinatorWatch program coordinators a sense of the expertise of their volunteers. The videos could also serve as an annual refresher for observers (cf. Genet and Sargent, 2003).

In addition to online videos used to practice observing, I recommend that PollinatorWatch develop an online bee quiz to evaluate observer skill, as suggested by Dickinson *et al*. (2010) and Bonter and Cooper (2012). An example of how this could work is provided by the North American Amphibian Monitoring Program. According to the protocol, participants must pass an online ‘Frog Quiz’ annually to ensure that they know how to detect and identify species. If an observer has not sufficiently met the quiz requirements, his/her data is not used for population trend analyses or made publicly available.

The prevalence of hand-held devices, such as smartphones and tablets, provides new opportunities for citizen science programs. Information can be accessed from most locations, so participants can make use of technology even while in the field. Rather than taking field guides and laminated field sheets to observation sites, PollinatorWatch volunteers can use their phones to look up details about bees they observe, find answers to questions, and confirm observations from many examples of photos. Additionally, volunteers can input their data directly into the PollinatorWatch database rather than using paper records. Not only would data entry be more efficient in this way, but the possibility for transcribing errors would be reduced.

5.5 Future Work

The results of my study urge us to consider protocol design for citizen science programs. In future research I encourage an emphasis on strengthening the aspects of bee observation protocols that clearly provide high quality data. The most obvious next step is to carry out a project using only the recommended protocol and parameters laid out previously, and to engage many more volunteers in collecting data. In such a study, experienced volunteers or professionals should collect data side-by-side with novice volunteers (see Fore *et al*, 2001 and Kremen *et al*, 2011) to better assess correlations between the two groups. Such a project should result in a clearer understanding of the quality of citizen science observations and PollinatorWatch can undergo further modifications if necessary.

Like Kremen *et al*. (2011), my sampling design confounded differences in methodology (sampling and observations) with experience level (researcher and amateur). To some extent, this restricts the conclusions that can be drawn concerning discrepancies between the two data sets. Future studies should include observations from both citizen and professional scientists, as well as a collection of specimens, so that methodological differences can be discriminated from experience level.

Following any program adaptations, a longitudinal monitoring study should be carried out and results from citizen science data collection analyzed with a specific goal in mind. Because the work of PollinatorWatch is intended to contribute to a long-term monitoring program, such a study would be best designed with experts from CANPOLIN so that the data can be used by Canada’s pollination researchers and collaborators.

Researchers and experts from CANPOLIN may also benefit from citizen scientists taking a broader survey of habitats. Having only conducted surveys in meadows leaves a number of other pollinator-rich habitats still to explore: gardens, parks, woodlots, and roadsides may yield contrasting results. Future studies can use plant-pollinator associations to further refine site selection recommendations for observers.

In addition to ecological studies and further improving PollinatorWatch, there are other opportunities for enhancing citizen science bee monitoring in Canada. Following Crall *et al*. (2011), social predictors of volunteer success (e.g. age, education, experience, science literacy, attitudes) can be examined. For instance, does self-identified comfort level impact volunteer success with bee identification? Crall *et al*. (2011) found that for invasive plants, self-identified familiarity predicted correct species identification fairly well.

Evaluating the impacts of PollinatorWatch on learning for individuals, their communities, and the program as a whole may reveal new ways to extend the program's reach and contribute to conservation measures.

5.6 Final Thoughts

The aim of this work was to contribute to bee monitoring efforts. My specific focus was to assess and enhance Canada's citizen science pollinator monitoring program so volunteers can play a valuable role in our collective understanding of the tiny creatures we all depend on. I learned that the variety of possible approaches to citizen science can be overwhelming, but when programs are designed well they can increase scientific understanding and engage communities in sharing knowledge. My study validates what citizen science bee observation programs can offer to monitoring ecologists and pollination biologists.

The effort that volunteers put in to citizen science programs is humbling, and my intention was to confirm how their work can be utilized effectively in PollinatorWatch. With some revisions to the protocol and increased participation, my hope is that bee researchers will soon be able to rely on observational data collected through PollinatorWatch.

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Appendix A

Bee Species Collected

Bee species and number of individuals collected by pan-trapping and netting at Royal Botanical Gardens and the ***rare*** Charitable Research Reserve, by site.

Bee name	Royal Botanical Gardens					*rare*						Total individuals
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm	
Andrenidae												
Andrena asteris Robertson[n]	0	0	0	0	0	0	0	1	0	2	0	3
A. hirticincta Provancher[n]	1	0	0	1	0	0	0	0	0	0	1	3
A. nubecula Smith[n]	0	0	0	1	0	0	0	0	0	0	0	1
A. wilkella (Kirby)	0	0	0	0	1	0	0	1	0	0	0	2
Calliopsis andreniformis Smith[p]	0	0	0	0	0	0	1	0	0	0	0	1
Perdita octomaculata Say[n]	0	0	0	0	0	1	0	0	0	0	0	1
Pseudopanurgus rudbeckiae Robertson[n]	0	0	0	1	0	0	0	3	0	0	3	7
Apidae												
Apis mellifera L.	4	2	30	12	57	35	8	47	48	47	18	308
Bombus bimaculatus Cresson	3	0	0	2	0	0	0	0	0	2	0	7
B. citrinus (Smith)[n]	0	0	0	0	0	0	0	4	2	1	1	8
B. fervidus (Fabricius)	0	0	1	1	0	1	1	0	1	0	2	7
B. griseocollis (DeGeer)[p]	0	0	0	1	0	0	0	0	0	0	0	1
B. impatiens Cresson	35	3	34	94	19	28	43	33	13	40	14	356
B. perplexus Cresson[n]	0	0	1	1	0	0	0	0	0	0	0	2
B. rufocinctus Cresson	8	1	10	2	7	7	0	7	0	3	3	48
B. sandersoni Franklin[n]	0	0	0	0	1	0	0	0	0	1	0	2
B. vagans Smith[n]	1	0	0	0	0	0	1	1	0	0	0	3
Ceratina calcarata Robertson	4	38	4	4	3	4	5	9	19	4	44	138

Bee name	Royal Botanical Gardens					*rare*						Total individuals
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm	
C. dupla Say	1	0	4	0	3	6	4	6	5	1	13	43
C. strenua Smith^{p}	0	0	0	0	0	0	0	1	0	0	1	2
Epeolus autumnalis (Cresson)^{n}	0	1	0	0	0	0	0	0	0	0	0	1
Melissodes comptoides Robertson^{n}	0	0	0	0	0	0	0	0	0	0	1	1
M. desponsa Smith	14	0	0	6	1	0	4	4	3	1	4	37
M. druriella (Kirby)	0	1	0	0	0	11	7	1	1	0	1	22
Nomada articulata Smith^{p}	0	0	0	0	0	0	2	0	1	0	0	3
Peponapis pruinosa (Say)^{p}	0	0	1	2	0	0	0	0	0	0	0	3
Triepeolus donatus (Smith)^{n}	1	0	0	0	0	0	0	0	0	0	0	1
Xylocopa virginica L.	2	0	3	3	2	1	0	1	0	0	0	12
Colletidae												
Colletes compactus Cresson^{n}	0	1	0	0	0	0	0	0	0	0	0	1
C. hyalinus Provancher^{n}	0	0	0	0	2	0	0	2	0	0	0	4
C. simulans Cresson^{n}	0	0	0	0	0	0	0	0	0	2	0	2
Hylaeus affinis Smith	2	2	0	14	8	9	14	2	9	1	3	64
H. annulatus L.^{n}	0	1	0	1	0	0	0	0	0	0	0	2
H. hyalinatus Smith^{n}	9	0	0	0	0	0	0	0	0	0	0	9
H. leptocephalus Morawitz	0	0	0	1	0	0	1	0	3	0	1	6
H. mesillae Cockerell	1	3	0	1	1	1	0	2	8	1	1	19
H. modestus Say	10	3	0	1	2	0	7	0	0	0	0	23
Halictidae												
Agapostemon sericeus Förster	1	0	0	1	0	1	0	0	2	2	0	7
A. texanus Cresson^{p}	0	3	0	0	0	0	0	0	0	0	0	3
A. virescens (Fabricius)	0	2	0	12	0	2	3	0	5	2	1	27
Augochlora pura Say^{n}	4	0	0	0	0	0	0	0	0	0	0	4

Bee name	Royal Botanical Gardens					*rare*						Total individuals
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm	
Augochlorella aurata (Smith)	0	13	3	0	2	23	2	24	13	2	4	86
Halictus confusus Smith	0	10	6	10	3	5	11	36	12	10	10	113
H. ligatus Say	0	5	1	9	0	2	13	22	11	2	10	75
H. rubicundus (Christ)	0	0	0	0	0	1	1	1	2	1	0	6
Lasioglossum anomalum (Robertson)	0	21	0	3	0	20	11	17	5	1	27	105
L. imitatum (Smith)	2	0	1	6	0	0	9	1	0	0	0	19
L. leucozonium (Schrank)	0	0	0	1	0	1	9	17	34	3	9	74
L. pilosum Smith	0	11	1	0	0	1	0	0	0	0	2	15
L. tegulare (Robertson)	0	10	0	0	0	0	0	0	2	0	0	12
L. vierecki (Crawford)	0	69	0	0	0	0	1	0	2	0	0	72
L. zonulum (Smith)[p]	1	0	0	0	0	0	1	1	1	0	2	6
Sphecodes atlantis Mitchell	0	8	0	0	0	0	1	0	0	0	0	9
S. banksii Lovell[p]	0	3	0	0	0	0	0	0	0	0	0	3
S. cressonii (Robertson)	0	2	0	0	0	2	0	0	0	0	0	4
S. davisii Robertson	0	1	0	0	0	0	0	0	2	0	0	3
S. dichrous Smith[n]	0	0	0	0	0	0	0	1	0	0	0	1
S. galerus Lovell and Cockerell	0	1	0	0	0	7	0	0	2	0	0	10
S. prosphorus Lovell and Cockerell[n]	1	0	0	0	0	0	0	1	0	0	0	2
Sphecodes sp.1[p]	0	0	0	0	0	8	0	0	0	1	0	9
Megachilidae												
Anthidium manicatum L.	0	0	0	0	0	0	0	1	1	0	0	2
Coelioxys octodentata Say[p]	0	0	0	0	0	0	2	0	0	0	0	2
C. rufitarsis Smith[n]	0	1	0	0	0	0	1	1	0	0	0	3
Heriades carinatus Cresson	3	0	0	0	0	0	0	0	0	0	0	3
Hoplitis pilosifrons (Cresson)[p]	0	0	0	0	0	0	2	0	0	0	1	3
H. spoliata (Provancher)[p]	0	0	0	1	0	0	0	0	0	0	0	1

Bee name	Royal Botanical Gardens					rare						Total individuals
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm	
Megachile brevis Say	0	0	0	0	0	1	0	0	11	0	0	12
M. campanulae Robertson[n]	0	1	0	0	0	0	0	0	0	0	0	1
M. inermis Provancher[n]	1	0	0	0	0	0	0	0	0	0	0	1
M. latimanus Say[n]	0	0	1	0	0	0	1	0	1	1	6	10
M. melanophaea Smith[p]	0	0	0	0	1	0	0	0	0	0	0	1
M. mendica Cresson	0	1	1	0	0	0	0	0	0	0	0	2
M. rotundata (Fabricius)	1	1	0	1	0	0	1	0	0	0	0	4
Osmia pumila Cresson[p]	0	0	1	0	0	0	0	0	0	0	0	1
Total taxa	23	29	17	28	16	24	29	29	28	23	26	

Bees denoted with [p] were collected only from pan-traps and with [n] were collected exclusively from nets

Appendix B

Plant Species Encountered

Mean density (stems/m^2 ± SE) of flowering stems of species counted within fifteen 1m x 1m quadrats at Royal Botanical Gardens and the ***rare*** Charitable Research Reserve, by site.

Plant name	Royal Botanical Gardens					*rare*					
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm
Apiaceae											
Daucus carota L.	4.4 ± 1.2	0	1.9 ± 0.4	2.7 ± 0.5	3.4 ± 0.4	1 ± 0	2.1 ± 0.5	3.7 ± 0.6	4.5 ± 3.2	1.3 ± 0.3	4.8 ± 1.7
Asclepiadaceae											
Asclepias incarnata L. ssp. *incarnata*	4.5 ± 1.5	0	0	0	0	0	0	0	0	0	0
A. syriaca L.	4.5 ± 0.5	0	0	0	3.1 ± 0.9	0	0	1 ± 0	0	0	1 ± 0
Cynanchum rossicum (Kleopov) Borhidi	0	X	0	0	0	0	0	0	0	0	0
Asteraceae											
Achillea millefolium L. ssp. *millefolium*	0	2.3 ± 0.3	5 ± 1.2	55.3 ± 41	0	8.8 ± 3.1	0	0	3 ± 2	0	0
Ambrosia artemisiifolia L.	0	9 ± 5	0	9 ± 3	0	0	30.2 ± 11	0	0	0	1.7 ± 0.3
A. trifida L.	0	0	0	0	0	0	0	0	0	1.6 ± 0.6	0
Arctium lappa L.	1 ± 0	0	0	1.5 ± 0.5	0	0	1 ± 0	1.5 ± 0.5	1 ± 0	1 ± 0	1 ± 0
A. minus (Hill) Bernh. ssp. *minus*	0	0	0	1 ± 0	0	0	0	0	0	0	0
Bidens frondosa L.	1.5 ± 0.5	0	0	0	0	0	0	0	0	9.5 ± 5.5	0
Carduus nutans L. ssp. *nutans*	0	1 ± 0	0	0	0	1 ± 0	1.5 ± 0.5	2 ± 0.3	5 ± 1.3	5 ± 4	1 ± 0
Centaurea nigrescens Willd. ssp. *nigrescens*	0	0	0	X	0	0	0	0	0	0	0
Cichorium intybus L.	0	0	0	3.4 ± 0.9	0	1 ± 0	0	0	0	0	0
Cirsium arvense (L.) Scop.	9 ± 2.7	0	1 ± 0	5 ± 1.8	1 ± 0	1 ± 0	5 ± 2	1.3 ± 0.3	1 ± 0	3.3 ± 1.9	2.3 ± 1

Plant name	Royal Botanical Gardens					*rare*					
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm
C. vulgare (Savi) Ten.	10 ± 3.7	2 ± 0	1.1 ± 0.1	1.2 ± 0.2	0	0	1 ± 0	1 ± 0	1.7 ± 0.7	3.7 ± 0.9	1 ± 0
Conyza canadensis (L.) Cronquist	0	10.1 ± 4.2	0	0	0	93.2 ± 13.3	30.3 ± 9.2	0	2.6 ± 0.9	23.3 ± 4.7	11.5 ± 3.6
Crepis sp.	0	0	0	0	0	0	6 ± 5	0	2.6 ± 0.8	0	0
Crepis tectorum L.	0	0	0	0	0	0	0	0	12.5 ± 0.5	0	0
Erigeron annuus (L.) Pers.	0	7.8 ± 2.6	5 ± 1.4	5.3 ± 1	1.7 ± 0.6	4.3 ± 1.2	12.9 ± 5.3	6 ± 1.3	63 ± 27.6	11 ± 3.3	7 ± 3.2
E. philadelphicus L. ssp. *philadelphicus*	0	0	3.3 ± 1.5	3 ± 0	0	9 ± 0	5 ± 0	8.1 ± 2.8	8.8 ± 6.5	0	1.5 ± 0.5
Eupatorium maculatum L. var. *maculatum*	0	0	0	0	0	0	0	0	0	0	1 ± 0
Euthamia graminifolia (L.) Nutt.	10 ± 0	0	6.1 ± 1.8	18 ± 0	0	14.4 ± 5.6	6.7 ± 3.2	21.5 ± 4.5	6.5 ± 5.5	9.5 ± 7.5	10 ± 2.1
Hieracium scabrum Michx.	1 ± 0	0	0	0	0	0	0	0	0	0	0
Lactuca serriola L.	0	0	0	0	0	0	0	0	3.3 ± 1.3	1.7 ± 0.3	1 ± 0
Lapsana communis L.	0	0	0	0	0	0	0	4.8 ± 1.8	0	0	0
Leucanthemum vulgare Lam.	0	0	6.7 ± 4.2	0	0	0	61.5 ± 36.5	0	27 ± 0	0	24.2 ± 17.7
Rudbeckia hirta L.	0	0	0	X	0	0	0	0	0	0	0
Solidago canadensis L. var. *scabra* (Muhlenb.) Torr. & A. Gray	14.5 ± 12.5	9 ± 7	2.7 ± 1.7	6.3 ± 2.4	20.5 ± 8.5	5.6 ± 1	8.2 ± 2.6	6.3 ± 1.7	9.6 ± 2.5	5.5 ± 2.1	10.2 ± 2.2
S. canadensis L.	0	15 ± 0	5.8 ± 2	12 ± 2.8	12.3 ± 2	5.1 ± 1.4	4.7 ± 0.9	10.9 ± 2.7	8 ± 3.6	5.6 ± 1.2	6.8 ± 2.1
S. gigantea Aiton	0	0	0	0	0	13 ± 0	0	2 ± 0	0	0	0
S. juncea Aiton	0	5.5 ± 2.5	0	12.3 ± 7.9	0	0	0	0	0	0	0
S. nemoralis Aiton ssp. *nemoralis*	0	0	0	0	0	0	14 ± 1	0	16 ± 0	0	0
Sonchus arvensis L. ssp. *arvensis*	3 ± 2	0	0	2 ± 0	0	5 ± 0	0	0	0	4.5 ± 0.5	2.3 ± 0.8
S. oleraceus L.	0	0	0	0	0	2 ± 0	0	0	2 ± 0	0	8 ± 0
Symphyotrichum ericoides var. *ericoides* (L.) Nesom	0	0	2 ± 0	0	3 ± 1.5	3 ± 0	9 ± 0	0	19 ± 0	0	11 ± 0
S. lanceolatum ssp. *lanceolatum* (Willd.) Nesom	1 ± 0	0	0	0	7.5 ± 3.5	12.5 ± 2.5	0	13 ± 6.2	13 ± 7	13.7 ± 8.8	0
S. lateriflorum var. *lateriflorum* (L.) Britton	2.7 ± 0.3	0	1.3 ± 0.3	0	0	0	0	0	0	0	0

Plant name	Royal Botanical Gardens					*rare*					
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm
S. novae-angliae (L.) Nesom	0	0	1 ± 0	0	3.1 ± 0.5	3 ± 1	4 ± 1.5	2 ± 0	4 ± 0	6 ± 0	2 ± 0
S. pilosum var. *pilosum* (Willd.) Nesom	0	0	1.5 ± 0.5	0	2 ± 0	0	2 ± 0	0	7 ± 4	0	4.8 ± 3.1
S. puniceum (L.) A. & D. Love	0	0	0	0	0	4 ± 0.4	12.5 ± 2.9	24.5 ± 9.5	6.5 ± 2.5	0	12.3 ± 4.8
S. urophyllum (Lindl.) Nesom	0	0	4 ± 1.7	0	0	0	8 ± 0	0	0	0	0
Tanacetum vulgare L.	0	0	0	0	0	9.3 ± 3.5	0	0	0	3.7 ± 1	0
Taraxacum officinale G. Weber	1 ± 0	0	0	0	0	0	1.3 ± 0.3	0	0	0	0
Tragopogon pratensis L. ssp. *pratensis*	5 ± 1	0	0	0	1.3 ± 0.3	0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	0
Tragopogon sp.	0	0	0	0	X	0	0	0	0	0	0
Balsaminaceae											
Impatiens capensis Meerb.	0	0	0	0	0	0	0	0	0	2.6 ± 1.4	0
Boraginaceae											
Echium vulgare L.	0	4.5 ± 1.8	0	0	1 ± 0	0	0	0	0	0	0
Brassicaceae											
Berteroa incana (L.) DC.	0	10.2 ± 3.3	0	0	0	0	0	20 ± 0	0	0	0
Diplotaxis tenuifolia (L.) DC.	0	3 ± 0	0	0	0	0	0	0	0	0	0
Erysimum cheiranthoides L. ssp. *cheiranthoides*	0	0	0	0	0	0	0	0	9.3 ± 8.3	18.7 ± 6.2	0
Campanulaceae											
Lobelia inflata L.	0	0	0	0	0	0	0	0	0	0	47 ± 0
Caryophyllaceae											
Arenaria serpyllifolia L.	0	0	0	0	0	0	0	0	60 ± 0	0	0
Cerastium fontanum Baumg.	0	0	0	0	5 ± 0	0	6.7 ± 1.6	0	0	0	4 ± 0

Plant name	Royal Botanical Gardens					*rare*					
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm
Dianthus armeria L.	0	0	0	0	2.8 ± 0.9	0	4 ± 0	0	0	0	0
Saponaria officinalis L.	0	0	0	0	0	4 ± 0	0	0	0	0	0
Silene vulgaris (Moench) Garcke	0	0	0	0	0	0	0	1.7 ± 0.3	0	0	0
Stellaria graminea L.	47.8 ± 17.1	0	0	0	8 ± 0	0	0	0	0	0	0
Convolvulaceae											
Calystegia sepium (L.) R. Br. ssp. *americanum* (Sims) Brummitt	0	0	0	0	0	1.4 ± 0.2	0	0	0	1 ± 0	0
Convolvulus arvensis L.	0	0	0	0	2.8 ± 1.1	0	0	0	0	0	0
Dipsacaceae											
Dipsacus fullonum L. ssp. *sylvestris* (Hudson) Clapham	0	0	2.6 ± 0.8	0	3 ± 0	1 ± 0	2 ± 0.7	1.3 ± 0.2	3 ± 0	0	1 ± 0
Euphorbiaceae											
Euphorbia cyparissias L.	0	0	0	0	0	0	0	0	0	1 ± 0	0
E. esula L.	0	0	0	0	0	0	0	0	0	20 ± 0	0
Fabaceae											
Desmodium canadense (L.) DC.	0	0	0	8 ± 0	0	0	0	0	0	0	0
Lotus corniculatus L.	0	0	0	4 ± 2	0	3 ± 0	50.6 ± 29.2	25.4 ± 5	185 ± 87.8	0	30.1 ± 18.8
Medicago lupulina L.	0	1 ± 0	0	35.2 ± 13.1	4.5 ± 2.5	0	11 ± 2.2	8.1 ± 3.7	21.8 ± 6	8.8 ± 3.5	7.8 ± 3.7
Melilotus alba Medik.	0	3.4 ± 0.6	0	6.3 ± 1.8	16 ± 0	0	0	3 ± 0	0	9 ± 7	0
M. officinalis (L.) Pall.	0	0	0	3 ± 0	0	0	0	0	26 ± 0	0	0
Trifolium hybridum L. ssp. *elegans* (Savi) Asch. & Graebn.	3 ± 0	0	6.3 ± 1.4	3 ± 0.7	0	0	9.5 ± 3.5	0	0	0	0
T. pratense L.	3.8 ± 0.8	0	0	4.4 ± 2.2	8.9 ± 2.9	0	0	2 ± 0	4 ± 0	0	5 ± 0
T. repens L.	0	0	0	56.5 ± 54.5	0	0	0	0	0	0	0

Plant name	Royal Botanical Gardens					*rare*					
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm
Vicia cracca L.	0	0	4.4 ± 0.8	3 ± 1	2.3 ± 0.3	0	3 ± 0	0	0	10 ± 0	0
V. villosa Roth	0	0	4 ± 1	0	0	0	0	0	0	0	0
Guttiferae											
Hypericum perforatum L.	0	14.5 ± 12.5	0	5.9 ± 1.3	3.2 ± 1.2	0	2 ± 0	5.8 ± 3.3	1 ± 0	21.1 ± 10.4	1 ± 0
Lamiaceae											
Clinopodium vulgare L.	0	0	0	0	0	0	3.5 ± 0.5	0	0	0	0
Glechoma hederacea L.	0	0	0	0	0	0	0	105 ± 0	0	0	0
Leonurus cardiaca L. ssp. *cardiaca*	0	0	0	0	0	0	0	0	0	2 ± 0	0
Monarda fistulosa L.	0	21 ± 10.6	11 ± 0	0	24 ± 16.6	0	15.5 ± 7.5	0	0	0	0
Nepeta cataria L.	0	6 ± 0	0	0	0	0	3.7 ± 0.9	3.8 ± 1.5	0	6 ± 0	1 ± 0
Prunella vulgaris L. ssp. *lanceolata* (W.C. Barton) Hultén	5 ± 1	0	22 ± 0	3.5 ± 2.5	0	0	0	0	0	0	0
Teucrium canadense L. ssp. *canadense*	0	0	0	0	0	3 ± 2	0	0	0	0	0
Thymus praecox Opiz ssp. *arcticus* (E. Durand) Jalas	0	0	0	0	0	0	0	12 ± 0	0	0	0
Lythraceae											
Lythrum salicaria L.	0	0	0	0	0	2.3 ± 1	0	0	0	2.3 ± 0.5	5 ± 0
Onagraceae											
Epilobium ciliatum Raf. ssp. *glandulosum* (Lehm.) Hoch & Raven	0	0	1.5 ± 0.5	0	0	0	0	0	2 ± 0	0	0
E. coloratum Biehler	0	0	2 ± 1	0	0	1.5 ± 0.5	0	0	0	2 ± 1	1.9 ± 0.3
E. hirsutum L.	0	0	0	0	0	1.5 ± 0.5	0	0	0	3 ± 0	0
E. strictum Muhelnb. Ex Spreng.	0	0	0	0	0	0	0	0	1 ± 0	3.5 ± 2.5	2.3 ± 0.6

Plant name	Royal Botanical Gardens					*rare*					
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm
Oenothera biennis L.	0	1.5 ± 0.5	0	0	0	4 ± 0	1 ± 0	0	0	2.5 ± 0.5	0
Oxalidaceae											
Oxalis stricta L.	26 ± 24	0	0	0	0	1.5 ± 0.5	0	2 ± 0	0	0	1 ± 0
Plantaginaceae											
Digitalis grandiflora Miller	0	0	0	0	0	0	0	0	2 ± 0	0	0
Plantago lanceolata L.	8.6 ± 3.5	0	0	8.8 ± 1.6	0	9 ± 0	0	0	0	0	0
Ranunculaceae											
Ranunculus acris L.	1 ± 0	0	0	1 ± 0	0	0	0	0	0	0	0
Rosaceae											
Geum aleppicum Jacq.	0	0	1.7 ± 0.3	0	0	0	0	0	0	0	0
G. canadense Jacq.	0	0	0	0	0	0	1.7 ± 0.7	0	0	0	0
Potentilla argentea L.	0	0	0	X	0	0	0	0	0	0	0
P. norvegica L. ssp. *norvegica*	0	0	1.5 ± 0.5	0	0	0	0	0	0	0	0
P. recta L.	0	1 ± 0	3 ± 0	0	1.3 ± 0.2	2.3 ± 1.3	0	2.6 ± 0.7	0	0	0
Rubiaceae											
Galium mollugo L.	0	0	0	0	0	3.4 ± 0.9	4.2 ± 1.8	1.5 ± 0.5	0	8 ± 4.4	0
Scrophulariaceae											
Linaria vulgaris Miller	0	0	0	4 ± 0	9.5 ± 3.7	1 ± 0	11.5 ± 9.2	4 ± 1.5	0	24.3 ± 11.3	4 ± 0
Verbascum blattaria L.	0	0	0	0	1 ± 0	0	0	1 ± 0	3 ± 2	0	0
V. thapsus L.	0	1 ± 0	0	0	0	1 ± 0	1.4 ± 0.2	0	2.3 ± 1.3	1.5 ± 0.5	2 ± 1

Plant name	Royal Botanical Gardens					*rare*					
	Aviary	Butterfly Walk	Pinetum Trail	Princess Point	Rock Chapel	Blair Flats	Grand Trunk Trail	Hogsback Old Field	Indian Woods	Preston Flats	Springbank Farm
Verbenaceae											
Verbena hastata L.	0	0	0	0	0	1 ± 0	0	0	0	7.3 ± 4.8	0
V. urticifolia L.	0	0	0	0	0	3 ± 0.6	1.5 ± 0.5	0	0	3 ± 1	0
Violaceae											
Viola arvensis Murray	0	0	0	0	0	0	0	0	6 ± 0	0	0
Total taxa	22	21	26	32	27	36	39	33	38	39	36

X = present at site but density information was not recorded because the plant was not found within any 1m x 1m quadrats

Appendix C

Participant Reflections on the Observation Process

Following the field season, I was interested in finding out about the observation experience from the volunteers' perspective, particularly what was working well and where improvements could still be made in the observation process and the recording of observations for PollinatorWatch. The purpose was to paint a more complete picture of the observation and data collection process by taking the participants' experience into account. I informally collected qualitative data in conversations with a few key participants, either over coffee or by e-mail. I asked questions to get a sense of the difficulties in distinguishing between the different types of bees, if the training was sufficient, the utility of the resources provided, whether the expectations were reasonable given that they were volunteers, if the length of observation time was sufficient, and whether they would participate in PollinatorWatch on their own. The insight provided by the citizen scientists form part of the recommendations for PollinatorWatch earlier in this paper. However, here is a more thorough review of what I gathered from the conversations.

Training

The hands-on training proved to be both useful and valuable for volunteers. Some participants noted that while the entire process could be taught by videos posted online, they were much more inclined to go through the training in person, especially because they could ask questions and meet other participants. Volunteers noted that it was beneficial to have others around to share information and confirm their own understanding of what they were expected to carry out. Because they practiced observation sessions during the training, some citizen scientists mentioned that it helped to be next to one or two other people so that they could confirm and share identifications. They also noted that they were sure to clarify any uncertainties they had before collecting data on their own.

Bee Identification

Participants felt confident that they could readily distinguish between bees and flies, especially having been through the training workshop. During the field season one observer sent me a photo she took of a bee and a fly foraging at the same time (see below).

However, those who saw wasps visiting flowers were less certain of their identification skills all the time. In those cases, they spent more time observing how an insect held its wings at rest and noting specific body parts like waists and hairs on legs before making a final determination. In hindsight, I could have provided some written descriptions and visual images of differences between flies, wasps, bees, and other flower visitors that volunteers could take into the field. The laminated field sheets only had information about bees but those could have been a good place to include such details.

Two flower visitors: a fly on the left and a bee on the right (photo courtesy of J. Metelka).

Participants found the laminated field sheets useful because they provided example photos and descriptions of bees in each of the species-groups. The field sheets were referred to frequently. Some volunteers would have appreciated even more written descriptions though, and others suggested including an illustrated silhouette of the actual size of each example bee. One participant recommended including arrows that point to particular features on the example photos to highlight areas of interest, similar to what they had seen in the training workshop.

In regards to distinguishing between the various categories of bees, those participants using observation Scheme A found difficulties in demarcating sizes and colours of bees. According to some volunteers, the length of bees' bodies frequently seemed to fall on the border between Small and Medium sizes. And placing bees into a particular colour class was troublesome for some observers when bee bodies had multiple colours.

For those observers using the Scheme B categories, the Other bee group was useful when an insect was obviously a bee but not one that fit into another visible group such as Bumble bee or Green bee.

A final suggestion made by participants was that while their confidence grew through the season, they would have benefitted from having me follow up periodically with refreshers on bee identification, either in person or through e-mail.

Plant Data Collection

For participants, plant identification was aided when I sent out 'what's in bloom' lists regularly. From these lists, one of the volunteers organized flowers by colour before visiting sites so her identification time in the field was decreased.

Some citizen scientists would prefer to count plant stems rather than the number of floral units, as they remarked that it might be a simpler and easier unit of measure. Others appreciated counting floral units, and still others had no preference either way. By counting the number of floral units, volunteers were able to look closely at how each plant grew which helped in identifying the plants.

Using the 1m x 1m quadrat was especially practical for volunteers as it provided a clear boundary within which to record flowering plants and observe bees.

Time Requirements

The PollinatorWatch protocol as it stands now has an open-ended observation time. In this research project, I delineated a time frame for bee observations. Participants appreciated having a specific amount of time for observations. They also appreciated having one period for observations rather than a watch-and-rest, watch-and-rest rotation like other programs (e.g. Urban Bee Gardens).

Other citizen science programs request volunteers to observe a plot for up to 30 minutes (e.g. Great Sunflower Project). Some PollinatorWatch participants said that they could commit to observing for that length of time but only if they were visiting one site rather than three. Other observers felt that a 30-minute time frame would be too long and they may lose count and focus.

Some participants felt as though they would have been able to collect more information if they were observing for more than 10 minutes, but others felt it would have been tedious to sit for longer, especially on hot, sunny days. That said, however, at least one volunteer repeated observations at a site if the weather was acceptable.

In general, it took volunteers 2 hours to travel to and visit three sites. This time commitment was burdensome for those who worked or who didn't have daytime flexibility when the weather was suitable for observing. But some participants noted that if they had more free time, they would have liked to be at each site more frequently and spent a longer time there.

Overall Experiences

Bell *et al*. (2008) found that the two most important aspects of volunteer participation in monitoring programs are the usefulness of their data and socialization with other amateur and professional naturalists. This is evidenced with the volunteers from my research project too, who participated primarily because they wanted to contribute real data to a program, but who also mentioned that they would have liked to be paired with someone while collecting data. By visiting sites with a partner, some participants felt it would have been beneficial for counting 'busy' plots (i.e., when there were many bees visiting flowers, like milkweed) and as a safety measure when sites were more isolated.

The citizen scientists said that they would participate in the PollinatorWatch program on their own even if it weren't for this research project. Many of them spend their time volunteering for other nature-based programs, including Master Gardeners. In general, the volunteers enjoyed their time working on this project. One participant noted, "I had a really good time. It was so nice to relax and count bees." Another citizen scientist commented, "Of all the things I did at ***rare*** last year, that was the volunteering I felt was the most useful. I felt like I made an impact. I felt like I was making a difference, plus I learned a lot."

Appendix D

Sample Observer Field Sheet

Date ☐ dd ☐ mm ☐ yyyy **Time** ☐ start ☐ end **Observer** ☐

Location Name ☐ **Plot Name** ☐

Weather

Sky	☐ sunny	☐ cloudy	☐ overcast	°C	
Wind	☐ windy, steady	☐ windy, gusts	☐ light breeze, steady	☐ light breeze, gusts	☐ calm
Temp.	☐ cold	☐ cool	☐ seasonal	☐ warm	☐ hot

Plants in Bloom

Plant Species or Common Name	# of Floral Units	Notes

Bees Visiting Flowers

Type of Bee	# of Bees	Flowers Visited
Honey bee		
Bumble bee		
Large carpenter bee		
Green bee		
Other bee		

Comments: