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UNDERSTANDING HABITAT EFFECTS ON POLLINATOR GUILD COMPOSITION IN
NEW YORK STATE AND THE IMPORTANCE OF COMMUNITY SCIENCE
INVOLVEMENT IN UNDERSTANDING SPECIES DISTRIBUTIONS

By

Abigail Joy Jago

A thesis
submitted in partial fulfillment
of the requirements for the
Master of Science Degree
State University of New York
College of Environmental Science and Forestry
Syracuse, New York
November 2019

Department of Environmental and Forest Biology

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In loving memory of my Dad

Acknowledgements

I have many people to thank for their help throughout graduate school. First, I would like to thank my major professor, Dr. Melissa Fierke for guiding me through the entomology program as ESF and thank her for giving me the opportunity to earn my master's degree. I would like to thank my committee members, Dr. Matt Schlesinger and Erin White. Erin, thank you for always supporting and guiding me through both fieldwork and this project. Matt, thank you for your help on this project & always keeping our meetings entertaining, it's never a dull moment with you there.

I'd like to thank the New York Natural Heritage Program, and Dorothy Evans, for funding this project & allowing me to use the data to complete my degree. I would especially like to thank Fiona McKinney for always answering my emails, putting me in touch with the right people, & providing quick feedback on all my expense reports. You're awesome! I'd like to also acknowledge the university & the EFB department for academic & economic support during this time in my life.

A huge thank you to Dr. Jacqui Frair, Dr. John Stella, & Dr. Hyatt Greene for all help & patience with statistics & willingness to teach stats in R. I know it's not easy. I'd also like to thank Mark Storrings for help with GIS.

Another big thank you to all my field technicians, Lorenzo Natalie, Kaylee Fierke, Eva Hanan, Amelia Dragone, & Lauren Wallace. You were out there with every day, & I sincerely enjoyed my time with you! You really made the work feel less like work! I would also like to thank the anonymous community scientists who collect specimens in the field & submit photos on

iNaturalist for the Empire State Native Pollinator Survey. A special acknowledgment to Beth Newkirk who worked with me on this project but left the earth she loved so much far too early.

A special thanks to Dr. Karen Sime for being my first mentor, & for the support and encouragement at the beginning of my academic career. You inspired me to study entomology & have always encouraged me to do great things with science.

I'd like to express a big thank you to all my lab mates, Hope Mahon, Mike Jones, Skyler Susnick, Tim Morris, Brittany Rogers, Molly Jacobson, McKenzie Wybron, Jessica Van Splinter, Michelle Volk, Jason Hamidi, plus Eric Swiecki and Dan Sinopoli. We made each other laugh when we felt like crying, listened to each other when we complained, helped each other on all the problems with R and GIS. I appreciate feeling like a little nerdy family when I was with you.

I'm immensely thankful for my friends Paige Ryan, Paula Pickreign, and Ariel Servadio for their emotional support and friendship all these years, but especially during my time in grad school. To Taylor Ricks and Holly Nodzo for always taking care of the pets on all those overnight fieldwork trips! I wouldn't have been able to do that without you!

A special thanks, beyond words to my wife (Maria Sagot) you've seen me through my highs and lows and helped me in ways that you don't even know & always kept moving forward. I love you with all my heart! Lastly, to my mom (Diana Jago). Without your support and inspiration all my life, I would not be where I am today. I love you!

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Abstract

A.J. Jago. Understanding habitat effects on pollinator guild composition in New York State and the importance of community science involvement in understanding species distributions, 115 pages, 12 tables, 19 figures, 2019. Journal of Ecology style guide used.

Concerns regarding pollinator declines have grown recently, yet detection of changes in species richness, abundance, and guild composition are inhibited by a lack of data over space and time. New York State initiated surveys for pollinators in multiple ecoregions and habitat types across NYS to assess current distributions as rarity measures. Sampling took place from May–Aug 2018 with contributions by community scientists. Pollinator richness was influenced by habitat (meadow, roadside, wetland, forest), floral presence and abundance, and interactions between floral abundance and month, but not ecoregion. Research to date on data collection quality by community science volunteers has provided mixed results, thus, data collected by volunteers was evaluated relative to paid field biologists. Results suggest volunteers added valuable data to that collected by paid biologists. Volunteers (both via field collection and digital submissions) increased quantified species richness, of both common and species of conservation interest, and informed where species occurred. This research informs development and implementation of conservation practices.

Key Words: pollinators, conservation, habitat selection, pollinator monitoring, community science, New York State

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Chapter 1: Literature Review

Understanding Biodiversity

The concept of biodiversity has fascinated naturalists and ecologists for centuries (Darwin 1859, Hutchinson 1959, Huston 1979, May 1988). Many research studies, e.g. MacArthur and Wilson (1963), have developed mechanistic explanations to understand patterns and maintenance of diversity. However, in the last few decades, due to widespread environmental changes and human-induced climate change, ecological research has refocused towards how these changes affect worldwide biodiversity (Cardinale et al. 2012).

Why biodiversity is important

In natural environments, biodiversity increases resilience to disturbances in ecosystems (Gaston 2000) and can aid ecosystem functioning (Carpenter et al. 2006, Bartomeus et al. 2013b, Winfree et al. 2018). For example, more diverse ecosystems are more resilient to drought, by stabilizing ecosystem productivity and productivity-dependent services (Isbell et al. 2015, Oliver et al. 2015). From an anthropocentric perspective, biodiversity can positively impact humans physiologically (Balvanera et al. 2001), psychologically (Fuller et al. 2007), and via ecosystem services provided by multiple organisms, such as pollination (Daily et al. 2003, Potts et al. 2016, Sánchez-Bayo and Wyckhuys 2019).

These services are often essential to our survival; however, they are almost always ignored, due to a lack of understanding (Kremen 2005). Nevertheless, based on services organisms provide, we can place an economic value on every individual providing such services, a language understood by most of society. In crop pollination for example, individual pollinators can be given a dollar value for services rendered. This has been successfully shown in Mexico with *Agave* plants (used in production of tequila and mezcal), and the nectivorous bats that pollinate them (Trejo-Salazar et al. 2016). Scientists compiled data on the pollination biology of

Agave plants to demonstrate how many individual bats could feed on a single plant. From there, they put a price on individual bats providing pollination services (Trejo-Salazar et al. 2016).

In reality, it is extremely difficult to assign a monetary value to services that are invaluable (Howarth and Farber 2002, Costanza et al. 2014), and some people often argue that this cannot, or should not, be done. In economics, a classic example is the water and diamonds paradox (Heal 2000). Water is essential to our existence on earth, yet the price is extremely low or free, however, diamonds are frivolous and unnecessary, yet their price far exceeds that of water. In economics, prices are set by supply and demand: if the supply is abundant, prices go down. Diamonds are naturally scarce; thus, prices are high. Along the same line, in places where water is extremely abundant, prices are low.

When we talk about ecosystem services such as pollination, in nature, this service comes free of charge. However, the end products of this service, such as fruits, have a monetary price tag, which can be very cheap, just like water. Economics primarily deals with prices, and at times, prices for goods does not reflect perceived value of those goods (Heal 2000). However, what would the price of those fruits be if pollinating insects suddenly became very scarce, like diamonds? Do we need to put a price on an individual pollinator to conserve them? Do we need to lose something invaluable to make it valuable?

Pollinators, tiny animals that control ecosystems

In the last decade, many studies have indicated pollinators are declining world-wide (Gallai et al. 2009a, Lebuhn et al. 2013, Goulson et al. 2015); however, this has been a hidden problem for a long time (Allen-wardell et al. 1998). It is understood that pollen transfer is near essential for angiosperm reproduction (Ledyard Stebbins 1970, Ollerton et al. 2011), with recent

estimates stating ~90% of all flowering plants rely on animals to facilitate reproduction. With certainty, the earth would not look the same without insect pollinators (Ollerton et al. 2011).

Many generalized adaptations make an insect a pollinator, e.g. elongation of mouth parts to form a proboscis, a generally hairy body, etc. (Crepet et al. 1991, Grimaldi 1999). These adaptations are simple and can make it easy for almost any insect to act as a pollinator. This is beneficial for plants as it increases the number of pollination vectors available. But what really makes an animal an efficient pollinator is found in the amount and frequency of pollen transferred during each floral visit (Herrera 1987). This can depend on the frequency and length of time of each flower visitation (Primack and Silander 1975). Based on these characteristics, bees are the most important pollinators, due to the nature of their foraging behavior and morphological structures specific to flower visitation (Herrera 1987, Michener and Grimaldi 1988). However, many “poor” pollinators who lack certain morphological structures, such as pollen carrying hairs, can make up in efficiency what they lack morphologically by their high abundance, as seen with many floral-visiting Diptera (Ssymank et al. 2008, Orford et al. 2015).

Who are the pollinating insects?

Insects in the Order Diptera are arguably the earliest specialized pollinating insects (Baker 1963, Pellmyr 1992, Larson et al. 2001). Variation observed in their mouthparts has facilitated evolution of a long proboscis. Moreover, their hindwings, modified into halteres, have enabled them to become excellent fliers and facilitated their ability to hover in place (Baker 1963, Larson et al. 2001). Hovering is a trait almost all pollinating animals have in common (Heinrich and Raven 1972, Faegri and van der Pijl 1979). Anthophilia (the attraction to flowers) in Diptera dates to the early Cretaceous (Larson et al. 2001). Fossil flies with pollen on them were members of the taxa Nemestrinidae and Stratiomyomorpha. Extant members of both groups

are frequent flower visitors. Pollinating flies use several different food resources, not just nectar and/or pollen (Kevan and Baker 1983, Larson et al. 2001). Thus, fly-pollinated plants tend to have less showy flowers (i.e. less colorful petals) and instead have a more pungent odor (Dobson and Bergström 2000, Ssymank et al. 2008). For example, the corpse flower (*Amorphophallus* spp.) relies completely on Brachyceran flies for pollination and emits a smell akin to rotting flesh (Kite et al. 1998). The cocoa plant (*Theobroma cacao* L.) attracts midges from the family Ceratopogonidae by emitting an earthy smell that vaguely resembles chocolate (Cope 1962).

Beetles are thought to be the original pollinating insects (Gottsberger 1977). It has been argued that the carpel floral structure evolved in response to beetles consuming the nutritious ovules (Kevan and Baker 1983, Bernhardt 2000, Grimaldi and Engel 2005, Peris et al. 2017b, 2017a). Moreover, many extant Magnoliids (primitive monocotyledons), and a few families of woody Eudicotyledons are pollinated by beetles (Bernhardt 2000). Beetle-pollinated plants have flowers that tend to be bowl shaped, making their floral rewards easily accessible to their bulky visitors (Gottsberger 1977). Since beetles visit flowers chiefly to eat pollen, plants have evolved numerous stamens in response to these gluttonous visitors (Gottsberger 1977).

Insects from the order Lepidoptera are thought to be “poor” pollinators, because they do not visit flowers often and tend to fly long distances between visitations (Primack and Silander 1975, Bell 1985, Herrera 1987) However, there are many plants which are obligately pollinated by moths, e.g. yucca, which is pollinated by the yucca moth (Bull and Rice 1991, Althoff et al. 2012). Regardless of how effective a pollinator they may be, Lepidopterans do have important pollination mutualisms and played a role in the radiation of plants globally.

Bees are likely the most recent pollinators to have evolved, but are now the most important pollinators of angiosperms - and are important drivers of plant diversity on earth

(Primack and Silander 1975, Kevan and Baker 1983, Bell 1985, Herrera 1987, Pellmyr 1992). As a whole, this group visits flowers directly and regularly; thus, they are the most reliable source for plant reproduction (Larson et al. 2001). Many pollination adaptations, such as pollen gathering structures, e.g. scopae, pollen baskets, arose multiple times in the clade Aculeata (Michener and Grimaldi 1988, Crepet and Nixon 1998). The elongated proboscis of long tongued bees, one of the most important adaptations for anthophily and pollination, is found only in the family Apidae (Kevan and Baker 1983).

Extant bees are some of the most efficient foragers, making them important pollinators (Herrera 1987). A major reason for their efficiency is their social behavior (e.g. provisioning nests with food for larvae) (Dukas and Real 1991, Seeley 1997). Evidence from preserved bee nests from the early Cretaceous indicates social behavior in bees and wasps started early in their evolutionary history (Genise and Verde 2000), supporting the idea that social behavior was most likely an enabling mechanism for the family Apidae, the group containing eusocial bees (Genise and Verde 2000). The evolution of social behavior led to more fit offspring, which allowed a more efficient foraging behavior. Most of the ~20,000 species of extant bees world-wide provision their larvae with food collected from flowers, e.g. pollen balls (Gullan and Cranston 2014).

Domestic vs. native pollinators

Benefits we obtain from domesticated pollinators, e.g. honey bees (*Apis mellifera* L., Morse and Calderone 2000) are well known. However, many species of cultivated pollinators in North America are not native to this continent. Pollination services provided by native (i.e. wild) species are less well known, even though their impacts in the ecosystem are significant (Gardner and Ascher 2006, Park et al. 2016). For instance, although domesticated pollinators account for

most crop pollination, native pollinators provide these services to 30–40% of crops (Kremen et al. 2002, Kremen 2005, Greenleaf and Kremen 2006). Moreover, because most domesticated pollinators are non-native, they are more vulnerable to endemic diseases and parasites that native species have evolved with (Murray et al. 2013, Vanbergen et al. 2013). Because native pollinators can be locally abundant and diverse, they can potentially provide pollination services needed to maintain populations of wild plants and crops, even if domesticated pollinator populations decline (Garibaldi et al. 2013, Vanbergen et al. 2013).

Macro-, micro-, and structural-habitat selection

Macrohabitat vs. microhabitat

Pleistocene glacial activity initiated shifts in climate and geology, thus creating what we call ecoregions or macrohabitats (large areas with similar geology, soils, climate, and vegetation, Bailey 1998, Bellows et al. 2006, Corser et al. 2014). Many species have evolved a large range of functional traits, including behavioral, phenological, dispersal, and genetic traits to be able to occupy such landscapes (Violle et al. 2007). Research has shown there is a relationship between traits and macrohabitats, suggesting species are molded by environmental differences (Yates et al. 2014).

Microhabitat (referred to as habitat type in the research reported herein) is found within macrohabitats at a finer scale. A microhabitat can be considered to be nonrandom occurrences of characteristics that simultaneously direct species distributions and abundances within macrohabitats (Dueser and Shuggart 1978, Bellows et al. 2006). Habitat generalist species thrive in a wide variety of landscapes by being, or becoming, flexible with habitat requirements. This enables their presence in a wide range of ecoregions. For these generalist species, macrohabitat selection may be based on specific habitat components found in many different ecoregions

(Morris 1984, Bellows et al. 2006). Specialist species, whose abundances correlate with specific or rare habitat characteristics, are limited in distribution on an ecoregional scale (Dueser and Shuggart 1978, Bellows et al. 2006).

Structural Scale

Animal habitat selection can be influenced by plant species richness and abundance. For example, floral size, shape, scent, and color traits are selected based on pollinator preferences (Rausher 2008, Schiestl and Johnson 2013, Gómez et al. 2015, Reverté et al. 2016). Many studies of habitat selection are at the structural scale, such as tree stands (Wuellner 1999, Buse et al. 2007). Research in small protected areas show notable peaks in bee abundance and species diversity corresponding with blooming patterns of flowering plants found in late spring and summer (Mackenzie and Eickwort 1996, Giles and Ascher 2006). Additionally, bee surveys conducted in southern New York State (NYS), found many soil nesting bees associated with specific soil types (Giles and Ascher 2006). Though Westphal et al. (2008) evaluated bee diversity in different habitats and biogeographical regions in Europe, and found high species richness in open, meadow habitats at lower latitudes. I conducted a large-scale habitat association survey that included a diverse array of native pollinator species (i.e. bees and flies). Work like this would help to understand habitat characteristics associated with pollinator species richness and guild composition at the state level.

Potential causes for pollinator declines

Land-use change

Habitat fragmentation and urbanization are considered the most important threats to pollinators around the world (Potts et al. 2010, Lebuhn et al. 2013, Vanbergen et al. 2013, Vanbergen 2014, Goulson et al. 2015, Gezon et al. 2016). These factors cause pollinators to be

separated from, or lose, nesting and foraging habitats (Kremen et al. 2002, Foley et al. 2005, Ollerton et al. 2014). When distances between floral resources and nesting habitats become larger, foraging insects are at greater risk of mortality. Moreover, lower quality pollination services, due to land-use change and loss in bee phylogenetic diversity, causes a cascading effect leading to lower plant reproduction overall and lower crop yields (Didham et al. 2007, Tylianakis et al. 2008, Grab et al. 2019).

Herbicides and pesticides

Pesticide and herbicide use in agriculture and urban environments is another important cause of pollinator decline (Potts et al. 2010, Goulson et al. 2015, Stanley et al. 2015). Agricultural pests are capable of evolving resistance to chemicals used against them (Tabashnik et al. 2004, Tabashnik and Carrière 2017), thereby leading to the use of more/different chemicals. Furthermore, these chemicals can persist in the environment for a very long time with lethal and sublethal effects on non-target beneficial insects (Potts et al. 2016, McArt et al. 2017). Results from a recent study suggest many risks from pesticides to bees come from residues in non-crop pollen, e.g. contaminated wildflowers (McArt et al. 2017). A growing number of studies confirm pesticide residues are commonly found in pollen and wax in honey bee colonies near agricultural settings (Chauzat et al. 2006, Sanchez-Bayo and Goka 2014, Long and Krupke 2016). Long-term exposure to pesticides can influence immunity to diseases (Pettis et al. 2012), alter foraging behaviors (Stanley et al. 2015), and affect growth and survival of colonies (Whitehorn et al. 2012).

Invasive exotic species

Invasive exotic (IE) species are organisms that have been accidentally, or intentionally, introduced outside of their native range, and their subsequent spread and population growth

impacts biota, ecosystems, and societies at large (Vanbergen et al. 2018). In general, IE species are better competitors for limited resources, e.g. food and space (Lee 2002, Allendorf and Lundquist 2003, Kandori et al. 2009, Davidson et al. 2011). Moreover, they introduce new selective pressures into a local community, altering the evolutionary trajectory of community members (Brown et al. 2002, Fierke and Kauffman 2006, Vanbergen et al. 2018), including disrupting community dynamics, species interactions, and consequently, lowering overall diversity (Pyšek et al. 2012, Kumschick et al. 2015, Stout and Tiedeken 2017). Invasive exotic plants can become permanent members of a community through generalist pollinators visiting them, and then over taking space (mutualism facilitation hypothesis, Richardson et al. 2000, Nienhuis and Stout 2009, Nienhuis et al. 2009, Gillespie et al. 2017). This can cause further declines in native specialist pollinators in favor of generalist or domesticated pollinators.

Disease & parasites

It is widely known that infectious disease spillover events from domesticated livestock pose a threat to human health and welfare (Lloyd-Smith et al. 2009, Quammen 2012). The same threat is true regarding transfer of parasites and viruses from European honeybees to native, North American wild bees (Fürst et al. 2014). Shared floral resources can create hotspots for interspecies disease transmission (McArt et al. 2014, Adler et al. 2018). Deformed wing virus, *Nosema*, and *Varroa* mites are some of the infectious diseases/parasites affecting *A. mellifera* (Neumann and Carreck 2009, Martin et al. 2012) and these also negatively affect native bumble bees (Fürst et al. 2014).

In small populations of native bees, this is problematic. Repeated exposure to source hosts results in multiple spillover events, allowing pathogens to mutate, thus causing frequent outbreaks (Dobson 2004, Murray et al. 2013). Ultimately, small populations dwindle even

further, resulting in local extinction (Dobson 2004). Moreover, phylogenetic relatedness of bee species exacerbates interspecies transmission even more, making naïve native species more vulnerable (Manley et al. 2015). This is especially problematic for *Bombus*, a group with many species already on endangered or at-risk lists (e.g., NYS DEC 2016).

Are these issues mutually exclusive?

Ecological systems are complicated webs with intricate relationships (Tylianakis et al. 2008). Multiple drivers of environmental change act simultaneously causing species distributions to change, or populations to decline, and it becomes difficult to tease apart possible causes. Research focusing on single drivers of change to biodiversity loss has produced mixed results (Carpenter and Brock 2006). Understanding interactive effects among multiple drivers has been a fruitful research topic (Carpenter et al. 2006). Declines in some groups can result in the decline of other groups, leading to cascade effects (Didham et al. 2007, Tylianakis et al. 2008) and no definitive answers.

Pollinators of concern

As a result of all above-mentioned environmental changes, many species of pollinators are on the decline, most notably bumble bees (*Bombus* spp.). Recent research on bumble bee decline in North America have shown declining populations have significantly higher infection levels of *Nosema bombi* Fanthom and Porter, a microsporidian pathogen, and have lower genetic diversity compared to co-occurring populations of non-declining bumble bee species (Cameron et al. 2011).

Other declining, less charismatic pollinator species detected by Bartomeus et al. (2013a) include solitary ground-nesting bees (e.g. *Andrena*, *Melissodes*, and *Colletes*), solitary stem- and cavity-nesting bees (e.g. *Osmia* and *Megachile*), social ground-nesting bees (e.g. *Lasioglossum*

subgenus *Dialictus*), host-plant specialists (e.g. *Peponapis*, some *Andrena* and *Colletes*), and cleptoparasites (e.g. *Coelioxys*, *Epeolus*). Bees from the family Melittidae, the “oil bees,” that collect floral oils instead of pollen for lining brood cells as well as for larval nutrition (Cane et al. 1983), are some of the rarest species native to NYS. Almost all are host-plant specialists and many genera prefer sandy soils for nesting (Michez 2008, Danforth and van Dyke 2015). *Epeoloides pilosula* (Cresson) is likely the most threatened bee species in NYS. This species is a cleptoparasite of *Macropis* (family Melittidae), a genus from the rarest family of bees in NYS (Danforth and van Dyke 2015).

Flies and moths are lesser known, yet important pollinators to both agriculture and natural landscapes. The species *Cynorhinella longinasus* Shannon is a rare endemic hoverfly in northeastern North America (Peterson et al. 1987). Very little is known of the natural history and habitat preferences of this species; however, it is likely to inhabit northern hardwood forests, flying in early to mid-spring. Similar to *C. longinasus*, *Callicera erratica* (Walker) is an extremely rare syrphid fly inhabiting late-successional old growth pine stands in southern NYS (Peterson et al. 1987). Larvae live in water-filled rot-holes or cavities of old living conifers and adults fly from April to mid-June, feeding especially on *Ranunculus* (buttercups) (Thompson 1988). *Schinia bifascia* Hübner is a moth species known in NYS from a single record on the privately-owned Robins Island in 1997 (NYNHP 2017, Schlesinger et al. 2017). The golden aster flower moth, *Schinia tuberculum* Hübner, is also only known from a single NYS location, in the dwarf pine barrens on Long Island in 1999 (NYS DEC 2015, NYNHP 2017). This moth also has historical records in Ithaca, Riverhead, Montauk, and Coram (NYS DEC 2015, NYNHP 2017, Schlesinger et al. 2017).

What can be done to help pollinators?

Current protection for pollinators

In the last decade, efforts have been made to protect pollinators on federal, state, and other protected lands. In 2015, President Obama announced the Pollinator Partnership Action Plan, which created a federal strategy aimed at promoting health and wellness of all pollinators (Vilsack and McCarthy 2016). The USDA and Department of Interior have also worked together to create a practical guide for land owners and managers with a set of stewardship responsibilities (USDA 2015). These documents outline safe use of pesticides, restoration plans for habitats used by pollinators, and identification of certain species.

In NYS, over 30 native pollinator species have been listed as Species of Greatest Conservation Need, ~20 of those were designated as High-Priority (NYS DEC 2015). However, information regarding current distributions and abundance of native species in NYS is limited, outdated, in need of revision for some species, or is unknown for others (NYS DEC 2016). In 2017, the New York Natural Heritage Program (NYNHP) designed a multi-year state-wide study to document current distributions and conservation status of native pollinators in non-agricultural habitats (Schlesinger et al. 2017). This project is proposed as a foundation for development and implementation of future conservation practices (NYS DEC 2016, Schlesinger et al. 2017), and will inform the State Wildlife Action Plan, the state list of Threatened and Endangered species, and federal databases.

Community scientists and conservation research

Current costs of conducting scientific research can be challenging, even more so when study areas are large, or focal organisms are small/rare (Losey et al. 2012). Furthermore, it is difficult to build in the necessary time and effort to cover a large area within the time frame and

budgetary constraints of a research project (Deguines et al. 2012). Thus, over the last decade, scientists have been engaging local community members in scientific endeavors. These community members are called community scientists (formerly termed citizen scientists, Cohn 2008, Bonney et al. 2009, Conrad and Hilchey 2011). Although there have been concerns regarding the quality of data collected by volunteers (Cohn 2008, Kremen et al. 2011, Freitag et al. 2016), evidence suggests non-scientists are capable of increasing the flow of data essential to scientific research (Bonney et al. 2009, Howard and Davis 2009, Silvertown 2009, Dickinson et al. 2010, Kremen et al. 2011, Kullenberg and Kasperowski 2016). Moreover, community scientists can be trained to collect samples with rigor comparable to that of professionals (Fore et al. 2001, Kremen et al. 2011, Kosmala et al. 2016). For example, they can learn about pollinator biology and collection methods from professionals at training workshops (Schlesinger et al. 2017, White et al. 2018).

Another efficient way to involve community members in scientific collection is through the use of technology (Bonney et al. 2009, Dickinson et al. 2010). One example is iNaturalist, a website and app that functions as a portal wherein anyone can sign up and upload photographs to document species presence data. In NYS, the NYNHP project the Empire State Native Pollinator Survey (ESNPS) has a project on iNaturalist where people can document pollinators photographically (Schlesinger et al. 2017). These projects are also useful for obtaining geographic coordinates of obscure or private locations.

With the incorporation of both volunteer surveyors and iNaturalist users, scientists and agencies can potentially extend the scale of their studies; however, the efficiency of these two components in facilitating the temporal and geographical expansion of data collection with appropriate scientific rigor has not been assessed. Quantitative and qualitative analyses of the

quality of data collected by volunteers have provided mixed results (Fore et al. 2001, Conrad and Hilchey 2011, Kosmala et al. 2016, Ballard et al. 2017). Thus, it is important to document and assess how data collected by volunteers (both community scientists and iNaturalist users) contributes to surveys conducted by field biologists.

Outreach & partnership programs

Outreach and educational programs are essential for species conservation management programs and go hand-in-hand with community science involvement (Brewer 2002). Outreach programs are more unidirectional in structure, connecting scientists with audiences by way of seminars, discussions, or workshops (Brewer 2002). A partnership program gives participants a more equal share in a project with researchers, ensuring everyone can make contributions. Contrasting this with an outreach program, a partnership program represents a multidirectional model for sharing information (Brewer 2002).

In a long-term conservation program for green sea turtle nesting habitats in Costa Rica, residents have played a major role in keeping sea turtle eggs safe. Starting out as an education program to teach young children about sea turtles and developing into a partnership program for adults, the project conservationists have been successful in making the local residents feel connected to the turtles (Jacobson and Lopez 1994, Troeng and Rankin 2005). Doing this gives residents the motivation and tools to keep the turtles safe when they leave the water to lay their eggs (Troeng and Rankin 2005). Through research, outreach, and education programs, participants learn first-hand what scientists do, how they do it, and why they do it. Furthermore, by working with local communities, researchers learn how residents relate to the threatened species and habitats they study. In working together, both communities and researchers gain valuable knowledge that can help the natural world (Brewer 2006).

Sustainable land management practices

Land management for conservation efforts is an ongoing challenge, especially in areas of the world where agriculture is an important part of society. NYS, for example, has a thriving agricultural industry (NYS DEC 2016). Because there is no one-size-fits-all for best land management practices, every region is unique. Therefore, historical land use, local demands, and governing regulations and policies should be considered when developing land management practices (Senapathi et al. 2015). The best management practices should be voluntary, cost-effective, and ensure conservation of native animals, such as pollinators (NYS DEC 2016, Schlesinger et al. 2017).

Some management practices encourage farm owners to use Integrated Pest Management (IPM, Kogan 1998), and to add buffer strips of native and naturally occurring vegetation (Ricketts et al. 2004, Biddinger and Rajotte 2015). This would greatly reduce residual pesticides from encroaching on natural environments (Chauzat et al. 2006, Sanchez-Bayo and Goka 2014, McArt et al. 2017), and increase nesting and floral food resource availability for native pollinators (Rissman et al. 2007). However, at times landowner goals conflict with these practices. Additionally, IPM can be expensive at the beginning and can take a while to see results (Tabashnik and Carrière 2017). Moreover, creating habitats for pollinators can reduce the land area available for growing crops.

In large cities, green roofs have become a source of sustenance for pollinators traveling long distances (Tonietto et al. 2011, Hall et al. 2016). Additionally, they can potentially act as stepping stones between larger natural areas within cities, thereby increasing local pollinator diversity (Mayrand and Clergeau 2018, Ksiazek-Mikenas et al. 2019). Changes such as these can secondarily help people, by curbing “heat island” effects (Foley et al. 2005). Research has shown

roadsides (Hopwood 2008, 2013, Rotholz and Mandelik 2013) and powerline corridors provide linear corridors of increased pollinator diversity and abundance (Russell et al. 2005, Wagner et al. 2014) as they tend to be open and free of cover from dominant trees. This can allow shrubs and other flowering plants to flourish, thus providing nutrient resources for pollinators. Many flowering plants, including non-native species, which are visited by many generalist pollinators, also thrive in these highly disturbed habitats (Morales and Traveset 2009, Nienhuis et al. 2009, Vanbergen et al. 2018). Furthermore, levels of disturbance commonly found in these habitats reduce interspecific competition, facilitating higher species coexistence (Southwood et al. 1979, Roxburgh et al. 2004).

Conclusions and project summary

Humans can be motivated to action when food is promised as a reward (Epstein et al. 2008, 2012). The promotion of pollinator conservation is ultimately a food-based incentive. One third of food we consume is made possible via pollinating insects (Klein et al. 2007, Gallai et al. 2009b, Calderone 2012, McArt et al. 2017). Thus, if we make an effort to protect pollinators, we are ensuring our survival into the future (Potts et al. 2016).

With my research, my goal was to provide information on important environmental factors predicting pollinator richness and to better inform land managers on best policies and practices. This information is crucial to protect native pollinating insect species that are in decline. Towards this, I present below two data chapters and a synthesis chapter to elucidate effects of local plant assemblages and landscapes on native pollinator guild composition and to evaluate involvement of community scientists in documenting native pollinators in NYS.

Chapter two is largely analytical, as it aims to associate presence and species richness of native pollinator on protected lands in NYS based on multiple environmental variables, including

local plant assemblages. Many studies on habitat selection are at a local scale, e.g. habitat patches (Wuellner 1999, Buse et al. 2007, Hopwood 2008, Wagner et al. 2014); and though there is one study which looked at ecoregions and habitat types in Europe (Westphal et al. 2008), this has not been done in NYS. By conducting a large-scale habitat association survey that includes a diverse array of native pollinator species, I wished to understand habitat characteristics associated with pollinator species richness, and guild composition in NYS.

Chapter three evaluates data collected by volunteer surveyors and iNaturalist users in documenting presence of pollinators in NYS. Specifically, my aim was to determine if involving community science volunteers in the data collection process contributes positively towards pollinator surveys in NYS. Often, quantitative and qualitative analyses of the quality of data collected by volunteers provide mixed results. Thus, this chapter compares data collected by volunteers (both voucher specimen based and observational based) with surveys conducted by paid field biologists. Chapter four synthesizes pollinating insects in NYS and overall effectiveness of including members of the community in the project.

**Chapter 2: Effects of Local Plant and Landscape Composition on Pollinator Assemblages
in New York State**

Abstract

Habitat models for conservation interests are important in landscape planning, development, and species management; however, information on how species use their habitats at different scales is lacking, especially for pollinators in non-agricultural environments. This study is a state-wide habitat association survey to understand variables associated with pollinator richness, and guild composition. In total, 45 sites across the seven ecoregions of New York State were sampled from May–Aug 2018. At each site, four habitat types (forest, meadow, roadside, and wetland) were sampled using bowl traps and timed targeted hand-netting for pollinators. Independent variables evaluated were ecoregion, habitat, month, floral richness, floral abundance, and interactions between month and floral variables. Pollinator richness (143 Hymenoptera and Diptera target species) was influenced by habitat type, floral presence and abundance, and the interaction between flora abundance and month, but not ecoregion. Pollinator richness was highest in meadow (14.5 ± 2.6 species) and roadside (13.8 ± 2 species) habitats and was strongly positively correlated with both floral richness and abundance across ecoregions and habitat types. This research provides information on environmental factors associated with pollinator richness to inform land managers on development of policies and practices for pollinator conservation.

Key Words: pollinators, habitat selection, ecoregion, conservation, flowering plants

Introduction

Habitat models for species of conservation interest are important in landscape planning, development, and species management (Fleishman et al. 2002, Buse et al. 2007); however, there is a lack of information on how species use habitats at different scales, e.g. landscape versus local habitat. This is especially true for pollinators, which play vital roles ecologically and economically (Potts et al. 2010, Lebuhn et al. 2013). Pollinating insects are essential members of all terrestrial ecosystems and are organisms in need of conservation attention.

Pollinators facilitate and can even control gene flow in flowering plants (Grant 1949, Endress 2011). It is estimated that 70–90% of crop plants are insect-pollinated; thus, they are responsible for a large portion of our food (Kluser and Peduzzi 2007, Marshman et al. 2019). Bees (Hymenoptera: Apidae) are the most important angiosperm pollinators and provide services to both wild plant assemblages and agricultural endeavors (Primack and Silander 1975, Kevan and Baker 1983, Pellmyr 1992, Larson et al. 2001). Insects from three other Orders, true flies (Diptera, Orford et al. 2015), beetles (Coleoptera, Bernhardt 2000), and moths/butterflies (Lepidoptera, Reddi and Bai 1984) are also important pollinators (Rader et al. 2016). Plants depend on both domesticated (European honeybees) and native pollinators, all of which are affected by a range of current and projected environmental issues, e.g., habitat loss, climate change, use of broad-spectrum pesticides, with consequences that lead to overall declines in certain species (Kluser and Peduzzi 2007, Potts et al. 2010, Schweiger et al. 2010, Lebuhn et al. 2013, Vanbergen et al. 2013).

Many species have evolved behavioral, phenological, dispersal, and genetic traits to adapt to and occupy different habitats (Violle et al. 2007). Animal habitat selection can be influenced by plant species richness and abundance. For example, floral size, shape, scent, and color traits

are selected based on pollinator preferences (Rausher 2008, Schiestl and Johnson 2013, Gómez et al. 2015, Reverté et al. 2016). Several studies have documented native bees as more abundant in apple orchards than honey bees (Gardner and Ascher 2006, Park et al. 2010) and that *Bombus* and *Melandrena* bees are equally as efficient pollinators as honey bees (Park et al. 2016).

Research in protected areas show notable peaks in abundance and species diversity corresponding with blooming patterns of flowering plants in late spring and summer (Mackenzie and Eickwort 1996, Giles and Ascher 2006). Giles and Ascher (2006) found many soil nesting bees associated with specific soil types in southern New York State (NYS).

Only one study by Westphal et al. (2008) was found evaluating bee sampling methods at large geographic scales, comparing among ecoregions (large areas with similar geology, soils, climate, and vegetation, Bailey 1998) and habitat types (nonrandom occurrences of characteristics that direct species distributions and abundances, Dueser and Shuggart 1978, Bellows et al. 2006) in Europe. They found the highest bee species richness in German grasslands and the lowest in oilseed rape fields in the United Kingdom.

Specific Research questions and Predictions

This research is part of a larger pollinator study (the Empire State Native Pollinator Survey, ESNPS, 2018-2020) to determine the conservation status of a wide array of native pollinators in non-agricultural habitats over three years. A specific goal was to elucidate if ecoregion and habitat type are important predictors of pollinator guild composition. Further, we wanted to evaluate specific environmental characteristics (ecoregion, habitat type, and floral resource availability) as predictor variables for pollinator species richness and variability in guild composition in NYS.

Methods

Study Area

NYS is a geologically heterogeneous region of northeastern North America covering ~ 141,300 km² where the climate exhibits significant temperature seasonality throughout the year (Corser et al. 2014). The state is divided into seven major ecoregions (Bailey 1998): Great Lakes (GL), High Allegheny Plateau (HAP), Lower New England (LNE), North Atlantic Coast (NAC), Northern Appalachian (NAP), St. Lawrence/Champlain Valley (STL), and Western Allegheny Plateau (WAP) (Table 2.1, Fig. 2.1). NYS has 63% forested cover with considerable regrowth following extensive agricultural clearing during the early 1900s (NYS DEC 2014). Annual precipitation is 75–125 cm, and is uniformly distributed throughout the year (NYS DEC 2014).

Table 2.1. Area (km²) and percent of each terrestrial ecoregion in NYS as well as number (percentage) of sites selected for the ESNPS for sampling in 2018 and the total for the 3-yr study period. Adapted from (Schlesinger et al. 2017).

Ecoregion	Area (km²)	Percent of state	No. Sites in 2018	Total Sites to be Sampled
Great Lakes (GL)	29,922	24%	10	30 (20%)
High Allegheny Plateau (Southern Tier, HAP)	35,248	28%	6	18 (12%)
Lower New England (Southern NY, LNE)	15,362	12%	5	15 (10%)
North Atlantic Coast (NYC/Long Island, NAC)	3,827	3%	4	12 (8%)
Northern Appalachian (Adirondack Park, NAP)	27,053	21%	11	33 (22%)
St. Lawrence/Champlain Valley (STL)	11,514	9%	10	30 (20%)
Western Allegheny Plateau (WAP)	3,010	2%	4	12 (8%)
Total	125,936	100%	50	150

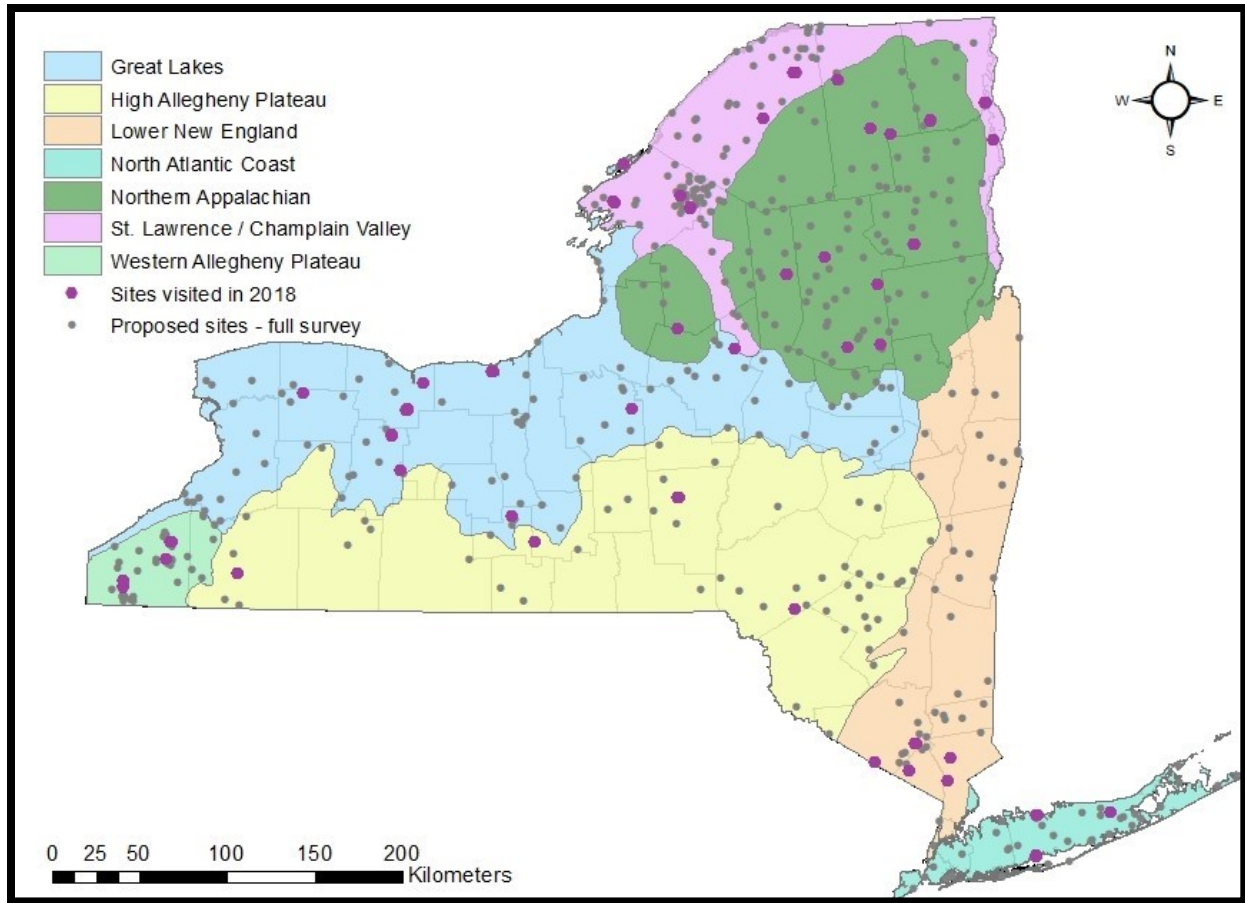


Figure 2.1. The seven terrestrial ecoregions of NYS are areas with similar geology, soils, climate, and vegetation. Sites ($n = 45$) visited from 13-May to 20-Aug 2018 are indicated as well as all proposed/potential with the ~150 targeted sampling sites to be visited throughout the 3-yr span of this project.

Field Sites

Sites in the seven ecoregions of NYS were sampled on protected lands, including those owned by universities, land trusts, and federal, state, and local governments. Number of sites chosen per ecoregion was approximately relative to the size of each ecoregion with larger ecoregions represented by more sites than smaller ecoregions (Table 2.1). As part of the overall ESNPS, a minimum of 150 extensive sites will be surveyed over three years, ~50 sites every year (Fig. 2.1). A Generalized Random Tessellation Stratified (GRTS) spatially explicit sampling methodology (Stevens and Olsen 2003, 2004) was used to maximize geographic spread of

sample locations throughout each ecoregion. This methodology resulted in a set of spatially balanced random points (sites) within protected lands (Fig. 2.2A). Sites were screened using GIS to assess habitat diversity, with a requirement that selected sites have at least two of the three habitat types—forest, wetland, meadow—within 250 m of the random point (Fig. 2.2B), and access was allowed. Points could be moved up to 1,000 m from the random placement to accommodate efficient and economical sampling (Fig. 2.2C). If the proposed site was inaccessible, or landowner information was unavailable, the site was rejected and a site from the “overdraw” from that ecoregion (see below) were screened. For the 2018 season many of the proposed sites in the LNE ecoregion randomly fell in the southern region, with one in the northern region. Unsuccessful attempts to contact the landowner for the point in the northern area were made and finally that site was rejected, resulting in a cluster of sites in the south (Fig. 2.1). However, over the 2019 and 2020 survey seasons, this “gap” will be filled in.

After an initial screening, an additional sampling “overdraw” sites provided backup site options when auto-selected sites were found to be unsuitable in the field, and moving them a reasonable distance nearby did not help. If all four habitat types—forest, wetland, meadow, and roadside—were not present or inaccessible at a site, then additional “bonus” transects were set out in habitat types that were available. This resulted in there always being four transects at every site. No site was visited more than once, i.e. seasonal changes in pollinator guilds over time were beyond the scope of this project.

Due to variability in climate across the state, timing of first sampling was determined by the number of growing degree days (GDD), or thermal heat unit accumulation, in an effort to standardize sampling. For example, since it is warmer earlier in the North Atlantic Coast ecoregion, which includes Long Island and New York City, and warmer later in the Northern

Appalachian, which includes Adirondack State Park, sampling started in North Atlantic Coast sites in May and rotated through ecoregions based on GDD accumulation with sampling occurring last in the Northern Appalachian.

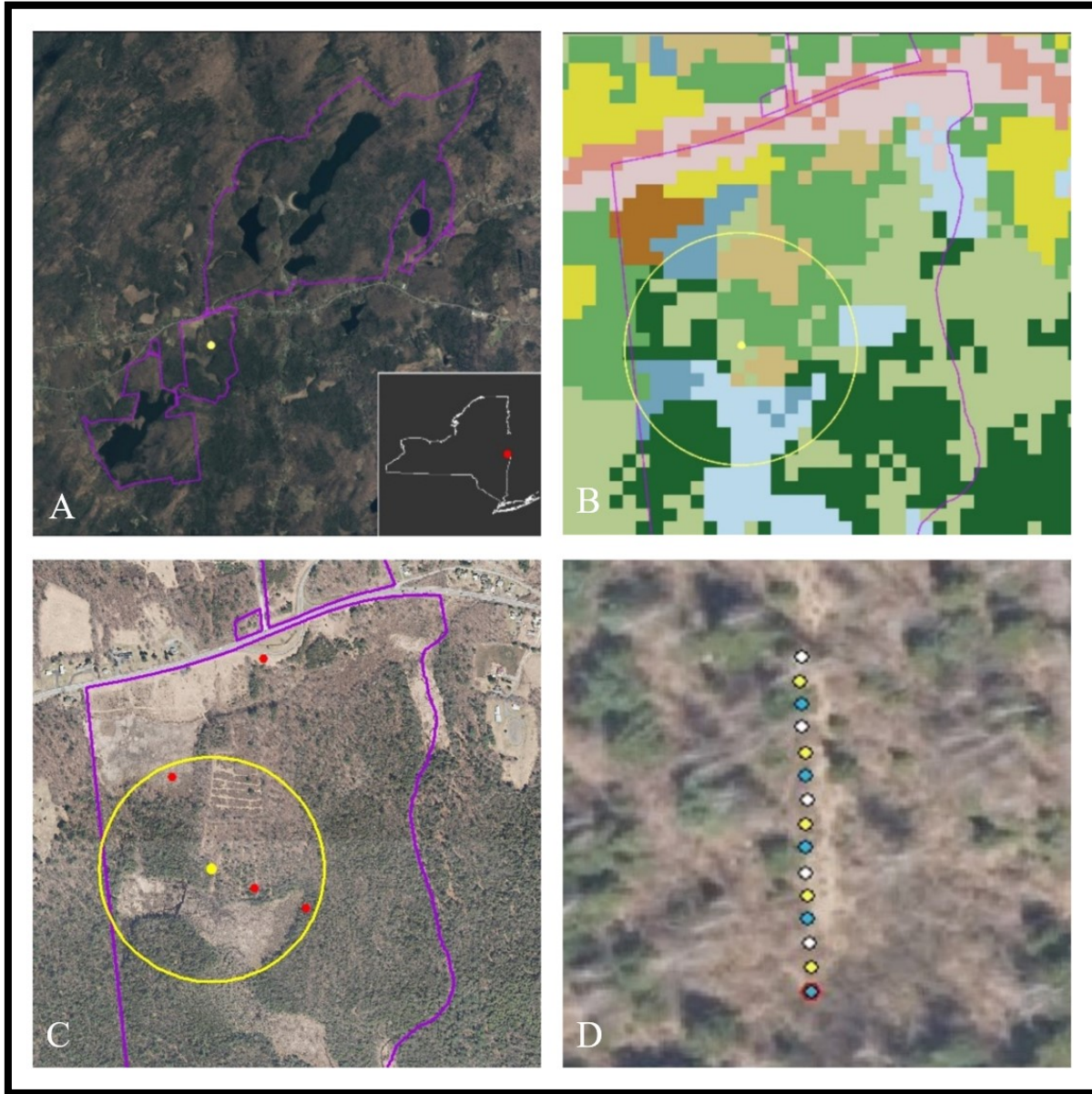


Figure 2.2. Examples of sample site location and selection. A) The yellow dot is a random location within Grafton State Park in eastern NY. B) Landcover and habitat types: green = forests, blue = wetlands, pink = developed, brown = meadow. C) Closer aerial photo of the same location, red dots represent potential sampling locations within a 250 m circle of the initial randomly selected location. From right to left, forest, meadow, wetlands, and roadside. D) Closer aerial photo of the meadow habitat type, illustrating bowl trap layout with each colored dot

representing a trap - the red dot is the original dot from photo C. Adapted from Schlesinger et al. (2017).

Pollinator Sampling

Data were collected from 13-May to 20-Aug 2018, when pollinators were most abundant. To maximize biodiversity captured at each site, two sampling procedures were employed in each habitat type: bowl trapping and timed targeted sweep netting of flowers with pollinating insects from our taxa list with nets (methods modified from Droege 2015, Table 2.2). Sites were sampled when temperatures were $\geq 20^{\circ}$ C, wind was ≤ 2.5 m/s, and it was sunny, partly cloudy, or thinly overcast.

Table 2.2. Taxa (family and genus) collected and analyzed as part of this project. * represents at risk species according to the New York Natural Heritage Program.

Hymenoptera	Andrenidae: <i>Andrena</i> *, <i>Calliopsis</i> *
	Apidae: <i>Anthophora</i> , <i>Apis</i> , <i>Bombus</i> *, <i>Ceratina</i> , <i>Melissodes</i> *, <i>Nomada</i>
	Colletidae: <i>Colletes</i> , <i>Hylaeus</i>
	Halictidae: <i>Agapostemon</i> , <i>Augochlora</i> , <i>Augoclorella</i> , <i>Augochloropsis</i> , <i>Halictus</i> , <i>Lasioglossum</i> , <i>Sphecodes</i>
	Megachilidae: <i>Heriades</i> , <i>Hoplitis</i> , <i>Megachile</i> *, <i>Osmia</i> *
	Melittidae: <i>Macropis</i> *, <i>Melitta</i> *
Diptera	Bombyliidae: <i>Bombylius</i> *
	Syrphidae: 32 genera

Bowl trapping

Within each of the four habitat types, 15 bowls were deployed ~3 m apart for 5 hours during peak flight, typically from ~10:00 am – 3:00 pm along a transect (n = 60 bowls/site) based on methods used by Carboni and Lebuhn (2003) and Droege (2015). Coordinates, dates,

and timing of sampling were noted using the Geopaparazzi application (version 5.5.5, Antonello and Franceschi 2017) on a Samsung Galaxy Tab Active2© (Model number SM-T390, Android version 7.1.1).

We used 96.1 mL painted plastic bowls (Fig. 2.3): UV fluorescent yellow, UV fluorescent blue, and white (Droege 2006). Each bowl was filled half-way with water mixed with several drops of unscented dish soap to break the surface tension. Bowls were placed directly on the ground, alternating colors along the transect (Fig. 2.2D). If the habitat was a wetland, bowls were placed along water edges. All specimens captured in bowl traps were transferred to Whirl-Pak® bags (Nasco) containing 70% ethanol for later sorting and pinning.



Figure 2.3. Bowls used for pollinator sampling. A) UV fluorescent yellow, B) UV fluorescent blue, and C) white bowl traps were placed directly on the ground, alternating colors along transects.

Targeted hand-netting

In each habitat type, two observers spent 30 minutes walking through each of the four habitat types, looking for pollinators and specifically targeting plants in flower. The habitat type to start hand-netting was arbitrarily chosen at every sampling site. An attempt to only catch one representative per species was made, though this was conservatively carried out knowing many species look similar and are difficult to differentiate in the field. All pollinators caught during hand-netting were exposed to cyanide, transferred to plastic pill bottles, and placed in a freezer as soon as possible to preserve for pinning.

Vegetation Sampling

Four fixed area 1 X 1 m plots, two on either side of the bowl transects, were sampled to quantify floral richness and abundance (Fig. 2.4). If flowers were present, a stem count was made, to assess floral abundance. Plants were identified to genus or species to assess floral richness.



Figure 2.4. Four 1 X 1 m plots placed adjacent to bowl sampling transect lines in four habitat types were used to quantify presence of plants (including trees) in flower.

Pollinator Processing

Specimens caught in bowl traps were rinsed with water through a brine shrimp net, blow-dried in a mason jar with a screen for 1–2 min, turned onto a paper towel, and pinned immediately (following methods from Droege 2015). Specimens caught in sweep-nets were kept frozen until being pinned. After pinning, all specimens were placed in boxes based on Order and grouped by site, habitat type, and sampling method. Each site had eight groups of specimens: four habitat types, and two sampling methods. Specimens were individually labeled and sent to experts for identification to the species level for all target pollinators (Hymenoptera at the Danforth lab at Cornell University and Diptera at the Greenwood lab at SUNY Cobleskill). Voucher specimens were housed in the Cornell University Insect Collection in Ithaca, NY and the NYS Museum in Albany, NY.

Statistical Analysis

All statistical analyses were performed in R Studio version 1.1.456 (RStudio 2016). All outliers were kept for data analysis. A t-test was used to compare species richness caught in bowl traps to sweep nets in the MASS package.

A non-metric multidimensional scale analysis (NMDS) was performed on pollinator species, and floral species to visualize how guild composition varied among ecoregions and habitat types. For the overall pollinator matrix of species richness, pollinator species included all species captured in bowls and by sweep netting in all ecoregions and habitat types. A matrix of the top 11 floral taxa was ordinated as vectors in an attempt to find patterns in the distribution of pollinator species. A matrix for floral taxa based on taxon richness by habitat type and ecoregion were made. Because species richness data did not follow a normal distribution, a square root

transformation was used to find the best cluster method. The rank index function in the Vegan R package (Oksanen et al. 2018) was used to compare and rank multiple models. The Manhattan distance was ranked highest and used for all NMDS analyses. The distance matrix and metaMDS functions were performed in the MASS and Vegan packages respectively (Venables and Ripley 2002, Oksanen et al. 2018). All plots were made in the ggplot2 (version 2.5-3) or MASS packages (Wickham 2016).

To further investigate effects habitat and environmental variables had on pollinator species richness, a variance partitioning analysis was performed using the VarPar function in the Vegan R package (Legendre and Legendre 2012, Oksanen et al. 2018). Pollinator species richness was treated as a dependent variable with ecoregion and habitat as independent explanatory variables. This test characterized 1) unique variation explained by each of the components (ecoregion and habitat), 2) correlated variation explained by each two-way interaction, and 3) correlated variation explained by all explanatory variables. To determine significance for each component, partial regressions were carried out based on redundancy analyses (RDA function, Vegan R package).

To further investigate specific variables contributing to variation, a negative binomial regression model was used with pollinator species richness (determined by combining number of species captured in bowls and by hand-netting per site) as a function of ecoregion, habitat type, month, plant richness, plant abundance, and the interactions between month and plant abundance and month and plant richness (global model). Interactions between month and plant abundance and plant richness were evaluated as they represent seasonal vegetation changes. A negative binomial model was selected after testing for goodness of fit on the residual deviance and degrees of freedom. To select the most important variables in the model, a forward selection was

used with 1,000 permutations, using the function Step (Mass package). All variables selected for the final model were plotted using ggplot2 package (version 2.5-3) (Wickham 2016).

Results

Forty-five sites across NYS were visited from 13-May to 20-Aug 2018 (Fig. 2.1, Appendix 1) and included sampling in 33 meadows, 37 wetlands, 44 roadsides, and 45 forests. Note, these numbers vary from expected as extra transects, “bonus” transects, were set out when all four habitat types were not present. There were 1,431 specimens collected, representing 143 unique pollinator species (Appendix 2). Across all sites, there were 1,271 Hymenoptera and 160 Diptera within the focal orders/families and 76 flowering plant taxa (Appendix 3). A total of 89 Hymenoptera species and 54 Diptera species were identified with the top five pollinator species being *Augochlorella aurata* Smith, *Lasioglossum leucozonium* (Schrank), *Ceratina calcarata* Robertson, *Augochlora pura* (Say), and *Toxomerus geminatus* (Say) (Table 2.3 and 2.4).

There was a marginally significant difference in pollinator species richness caught in bowls compared to hand-netting ($t = 1.97$, $df = 63$, $p = 0.053$, Fig. 2.5) with mean number of pollinator species captured in bowls being 19.4 ± 3.2 and 12.4 ± 1.6 via hand-netting. Out of the 143 different species of pollinators, 66 species (46%) were only caught via hand-netting and 15 of those species are of conservation concern. Out of the 143 different species of pollinators, 30 (21%) were only caught in bowls and 10 of those species are of conservation concern. The two bowl traps with the highest species richness were both from meadows in July at two sites that were relatively close together. The hand-net session with highest species richness was from a meadow in a Great Lakes site during May. Bumble bees, in general, were more often found in open habitats, e.g. meadows, roadsides (Table 2.5). Honey bees were also found in mostly open habitats but favored wetlands rather than meadows (Table 2.5).

Table 2.3. Proportion of sites that the five most common pollinators were collected in, by habitat type, in 45 sites across New York State.

Pollinator Taxa	Meadow	Roadside	Wetland	Forest
<i>Augochlorella aurata</i>	40%	25%	11%	7%
<i>Lasioglossum leucozonium</i>	33%	16%	11%	4%
<i>Ceratina calcarata</i>	36%	20%	8%	7%
<i>Augochlora pura</i>	25%	14%	16%	4%
<i>Toxomerus geminatus</i> *	18%	16%	22%	13%

*Order Diptera - all others are Order Hymenoptera.

Table 2.4. Proportion of sites that the top five most commonly collected pollinator species were collected in, by ecoregion, in 45 sites across New York State.

Pollinator Taxa	GL	HAP	LNE	NAC	NAP	STL	WAP
<i>Augochlorella aurata</i>	50%	50%	80%	100%	74%	38%	50%
<i>Lasioglossum leucozonium</i>	100%	100%	80%	50%	82%	50%	75%
<i>Ceratina calcarata</i>	80%	67%	80%	50%	73%	25%	75%
<i>Augochlora pura</i>	90%	100%	60%	50%	91%	38%	50%
<i>Toxomerus geminatus</i> *	60%	100%	80%	75%	82%	25%	100%

*Order Diptera - all others are Order Hymenoptera.

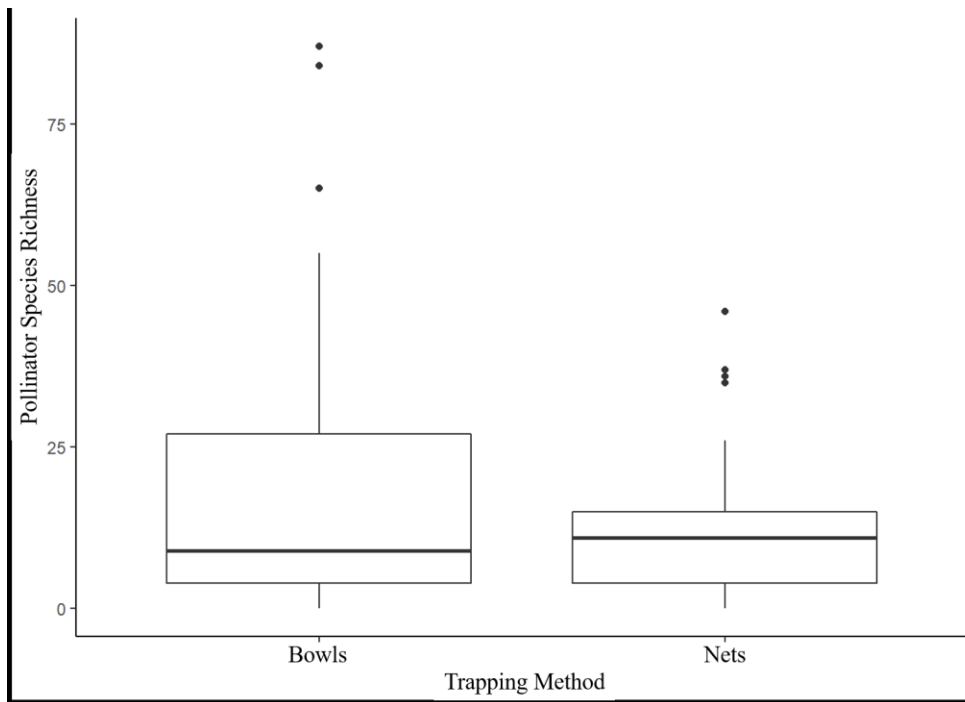


Figure 2.5. There was a marginally significant difference ($p = 0.053$) in pollinator richness between bowl trapping and sweep netting in the 45 field sites across NYS. Dark horizontal bars indicate the sample median.

Table 2.5. Number of honey bees and bumble bees (*Bombus* spp.) and percent of the total number of individuals documented in all habitat types in 45 sites sampled across New York state.

Pollinator Taxa	Meadow		Roadside		Wetland		Forest	
	Number of individuals	Percent of total	Number of individuals	Percent of total	Number of individuals	Percent of total	Number of individuals	Percent of total
<i>Apis mellifera</i>	4	20%	10	50%	6	30%	0	--
<i>B. bimaculatus</i>	4	75%	2	25%	1	12.5%	1	12.5%
<i>B. borealis</i> *•	2	66%	1	33%	0	--	0	--
<i>B. fervidus</i> *°	0	--	1	100%	0	--	0	--
<i>B. griseocollis</i>	4	50%	3	37.5%	1	12.5%	0	--
<i>B. impatiens</i>	8	21%	18	47.4%	11	29%	1	3%
<i>B. perplexus</i> •	0	--	3	75%	1	25%	0	--
<i>B. rufocinctus</i> °	0	--	0	--	1	100%	0	--
<i>B. sandersoni</i> •	3	50%	0	--	3	50%	0	--
<i>B. sp.</i> •	1	50%	0	--	1	50%	0	--
<i>B. ternarius</i> •	0	--	0	--	2	100%	0	--
<i>B. terricola</i> *	0	--	1	50%	1	50%	0	--
<i>B. vagans</i>	8	31%	11	42%	7	27%	0	--

* Indicates species of conservation interest according to NYNHP

• Indicates species was found only via sweep netting

° Indicates species was found only via bowl traps

Across the 45 sites sampled for pollinators, there were 76 flowering plant taxa documented. Ecoregions were significantly different from each other based on floral richness ($F_{6,166} = 3.26$, $p = 0.005$, Table 2.6, Fig. 2.6A) and abundance ($F_{6,166} = 2.97$, $p = 0.009$, Table 2.6, Fig. 2.6B). Northern Appalachian sites had significantly lower floral richness (1.66 ± 0.18) than the Great Lakes (2.99 ± 0.31 , $p = 0.05$), the High Allegheny Plateau (3.44 ± 0.85 , $p = 0.05$), and the St. Lawrence sites (3.22 ± 0.44 , $p = 0.02$). Additionally, Northern Appalachian sites had lower floral abundance than the Great Lakes ($p = 0.05$) and the High Allegheny Plateau ($p = 0.01$) sites. Many of the outliers associated with floral richness and abundance were during the month of June in the Great Lakes and High Allegheny Plateau ecoregions (Fig. 2.6); however, floral richness and abundance by month blocked by ecoregion was not significant.

Habitat types were significantly different from each other based on floral richness ($F_{3,169} = 14.17$, $p > 0.000$, Table 2.6, Fig. 2.7A) and abundance ($F_{3,169} = 24.16$, $p > 0.000$, Table 2.6, Fig. 2.7B). Forest habitats (1.02 ± 1) had significantly fewer species than meadow (4.1 ± 0.6 , $p >$

0.000) and roadside (3.22 ± 0.25 $p > 0.000$) habitats. Wetlands (2.4 ± 0.27) also had significantly fewer species than meadows ($p = 0.0001$). Forest habitats had significantly lower abundance than meadows ($p > 0.000$), roadsides ($p > 0.000$), and wetlands ($p = 0.008$), and wetlands had significantly lower abundance than meadows ($p = 0.02$). The meadow habitat had two major outliers, one in June and the other in August for floral richness (Fig 2.7A). For floral abundance, the meadow habitat also had two major outliers, both in the month of June (Fig. 2.7B).

Based on floral richness by habitat types, months differed significantly from each other ($F_{3,169} = 3.84$, $p = 0.011$, Table 2.6, Fig. 2.7A). There were fewer flowering plant species in May (2.18 ± 0.23) relative to June (3.24 ± 0.36 , $p = 0.03$), and June was marginally significantly higher than July (2.28 ± 0.28 , $p = 0.06$), August did not significantly differ from other months. Based on floral abundance by habitat types, months were also significantly different from each other ($F_{3,169} = 5.77$, $p = 0.0009$, Table 2.6, Fig. 2.7B). There were significantly more flowers present in June (85.5 ± 15.1) relative to both May (47.1 ± 7.6 , $p = 0.05$) and July (37 ± 6.4 , $p = 0.005$), while August (80.2 ± 13) was significantly higher than July ($p = 0.01$). August was marginally significantly different from May ($p = 0.08$). Many of the major outliers occurred in June, however, the month of August also had at least a few as well (Fig. 2.6, Fig. 2.7). The most common plant species were buttercups, clover, garlic mustard, chickweed, and mullein (Tables 2.7 and 2.8).

Table 2.6. Mean flowering plant richness and abundance (based on number of stems) by ecoregion and habitat type by month in 45 sites across NYS. Dashes indicate sampling did not occur in an ecoregion in a particular month.

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>	
	Floral abundance	Floral richness	Floral abundance	Floral richness	Floral abundance	Floral richness	Floral abundance	Floral richness
GL	23.1 ± 6.3	1.7 ± 0.4	112.4 ± 24.0	3.1 ± 0.5	68.9 ± 24.2	4.2 ± 0.6	132.5 ± 28.7	3.8 ± 0.7
HAP	--	--	80.7 ± 38.8	4 ± 1.6	60.3 ± 54.1	1.3 ± 0.8	--	--
LNE	52.4 ± 22.3	3.0 ± 0.7	--	--	57.8 ± 30.0	2.0 ± 1.0	--	--
NAC	111.5 ± 50.3	1.8 ± 0.5	--	--	--	--	--	--
NAP	--	--	21.5 ± 7.4	1.5 ± 0.4	23.8 ± 9.9	1.5 ± 0.3	39.2 ± 11.5	1.9 ± 0.3
STL	--	--	--	--	57.1 ± 25.8	3.0 ± 0.8	81.4 ± 29.6	3.3 ± 1.0
WAP	--	--	61.4 ± 26.0	3.0 ± 1.2	--	--	108.0 ± 49.0	3.0 ± 0.8
Meadow	89.1 ± 89.0	2.4 ± 1.0	96.5 ± 68.1	4.9 ± 2.3	92.1 ± 71.5	3.4 ± 1.5	135.5 ± 89.2	5.3 ± 2.5
Roadside	70.5 ± 46.1	2.7 ± 1.6	64.4 ± 59.9	3.0 ± 1.6	75.3 ± 83.8	3.3 ± 1.9	119.3 ± 76.7	3.8 ± 1.9
Wetland	73.4 ± 75.1	2.1 ± 1.5	82.2 ± 81.1	3.1 ± 1.9	25.6 ± 83.8	1.8 ± 2.0	61.1 ± 76.7	2.3 ± 1.1
Forest	12.6 ± 16.6	1.6 ± 1.3	8.2 ± 14.8	0.7 ± 0.9	7.3 ± 9.0	0.9 ± 1.0	19.0 ± 49.7	1.0 ± 0.9

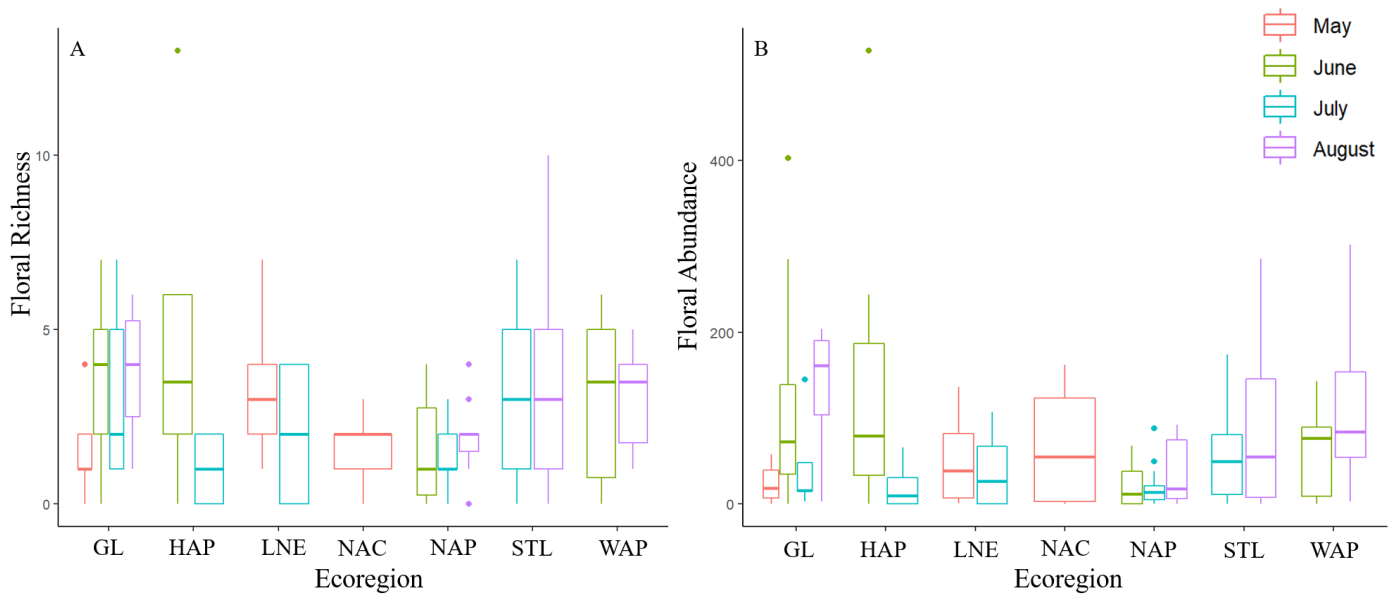


Figure 2.6. A) floral richness and B) abundance (based on counts of stems) by ecoregion and month in 45 sites across NYS. Dark horizontal bars indicate the sample median.

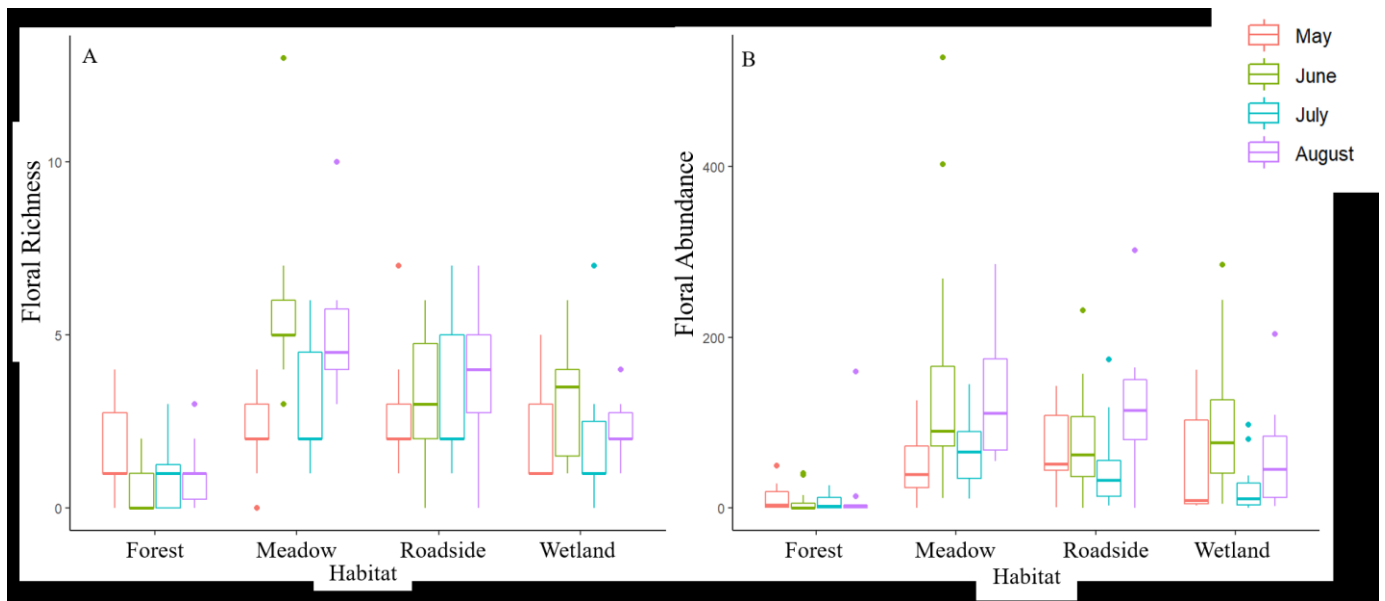


Figure 2.7. A) floral richness and B) abundance (based on counts of stems) by habitat type and month in 45 sites across NYS. Dark horizontal bars indicate the sample median.

Table 2.7. Proportion of the top ten most commonly found plant taxa by habitat type across 45 sites throughout NYS. Dashes indicate a species was not present in a particular habitat type.

Plant Taxa	Meadow (n = 33)	Roadside (n = 44)	Wetland (n = 37)	Forest (n = 45)
Clover (<i>Trifolium hybridum</i> L. & <i>Melilotus officinalis</i> (L.) Pall.)	45%	45%	11%	8%
Buttercup (<i>Ranunculus</i> spp. L.)	67%	50%	24%	40%
Garlic Mustard (<i>Alliaria petiolate</i> (M. Bieb.) Cavara)	33%	11%	11%	2%
Chickweed (<i>Stellaria media</i> (L.) Vill.)	24%	5%	19%	4%
Mullein (<i>Verbascum</i> sp. L.)	18%	7%	16%	4%
Queen Anne's Lace (<i>Daucus carota</i> L.)	18%	23%	3%	--
Violet (<i>Viola</i> sp. L.)	33%	9%	--	4%
Meadowsweet (<i>Spiraea ulmaria</i> (L.) Maxim.)	27%	14%	11%	2%
Jewelweed (<i>Impatiens capensis</i> Meerb.)	6%	7%	10%	--
Raspberry (<i>Rubus</i> sp. L.)	25%	5%	8%	--

Table 2.8. Proportion of the top ten most commonly found plant taxa by ecoregion across 45 sites throughout NYS. Dashes indicate that a species was not present in that ecoregion.

Plant Taxa	GL (n = 10)	HAP (n = 4)	LNE (n = 5)	NAC (n = 3)	NAP (n = 11)	STL (n = 8)	WAP (n = 4)
Clover (<i>Trifolium hybridum</i> L. & <i>Melilotus officinalis</i> (L.) Pall.)	100%	50%	40%	100%	55%	100%	100%
Buttercup (<i>Ranunculus</i> spp. L.)	100%	100%	100%	--	73%	75%	100%
Garlic Mustard (<i>Alliaria petiolate</i> (M. Bieb.) Cavara)	60%	25%	60%	67%	19%	50%	50%
Chickweed (<i>Stellaria media</i> (L.) Vill.)	70%	--	--	--	36%	75%	25%
Mullein (<i>Verbascum</i> sp. L.)	10%	50%	100%	33%	--	--	--
Queen Anne's Lace (<i>Daucus carota</i> L.)	20%	--	20%	--	--	100%	100%
Violet (<i>Viola</i> sp. L.)	90%	25%	40%	33%	9%	25%	--
Meadowsweet (<i>Spiraea ulmaria</i> (L.) Maxim.)	50%	25%	40%	--	27%	88%	25%
Jewelweed (<i>Impatiens capensis</i> Meerb.)	--	--	--	--	27%	13%	75%
Raspberry (<i>Rubus</i> sp. L.)	20%	100%	20%	--	27%	63%	100%

The NMDS analysis using a matrix of 76 flowering plant taxa by the seven ecoregions showed little differentiation in flowering plant assemblages (Fig. 2.8). However, a permutational multivariate analysis using Adonis distance indicated ecoregions were significantly different from each other based on flowering plant assemblages ($R^2 = 0.11$, $F_{6, 1411} = 28.9$, $p = 0.001$, maximum stress = 0.23, Fig. 2.8). Incongruence between the NMDS and Adonis analysis appeared to be related to a high variation associated with flowering plant assemblages among

ecoregions (Fig. 2.8). There was also significant overlap in flowering plant assemblages ($R^2 = 0.04$, $F_{6,1411} = 19.7$, $p = 0.001$, maximum stress = 0.23, Fig. 2.9) among the four habitat types.

Similar non-significant results were also seen using a matrix of 143 pollinator species by the seven ecoregions. There was no difference in pollinator species guild composition among ecoregions ($R^2 = 0.02$, $F_{6,314} = 1.3$, $p = 0.048$, maximum stress = 0.07, Fig. 2.10) nor among the four habitat types ($R^2 = 0.009$, $F_{3,179} = 0.52$, $p = 0.96$, maximum stress = 0.14, Fig. 2.11).

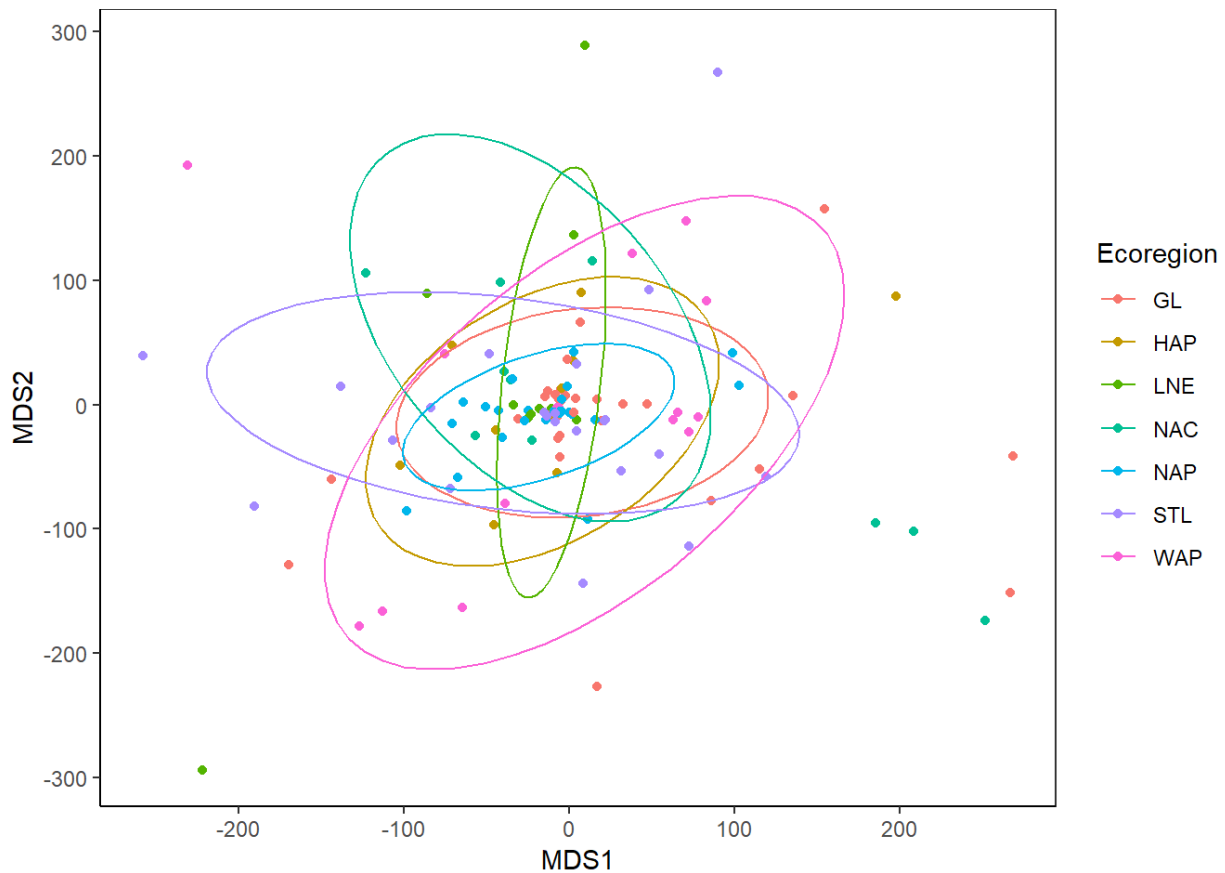


Figure 2.8. NMDS ordination of floral assemblage (76 taxa) by the seven ecoregions indicated overlap in flowering plant assemblages among the 45 sites across NYS.

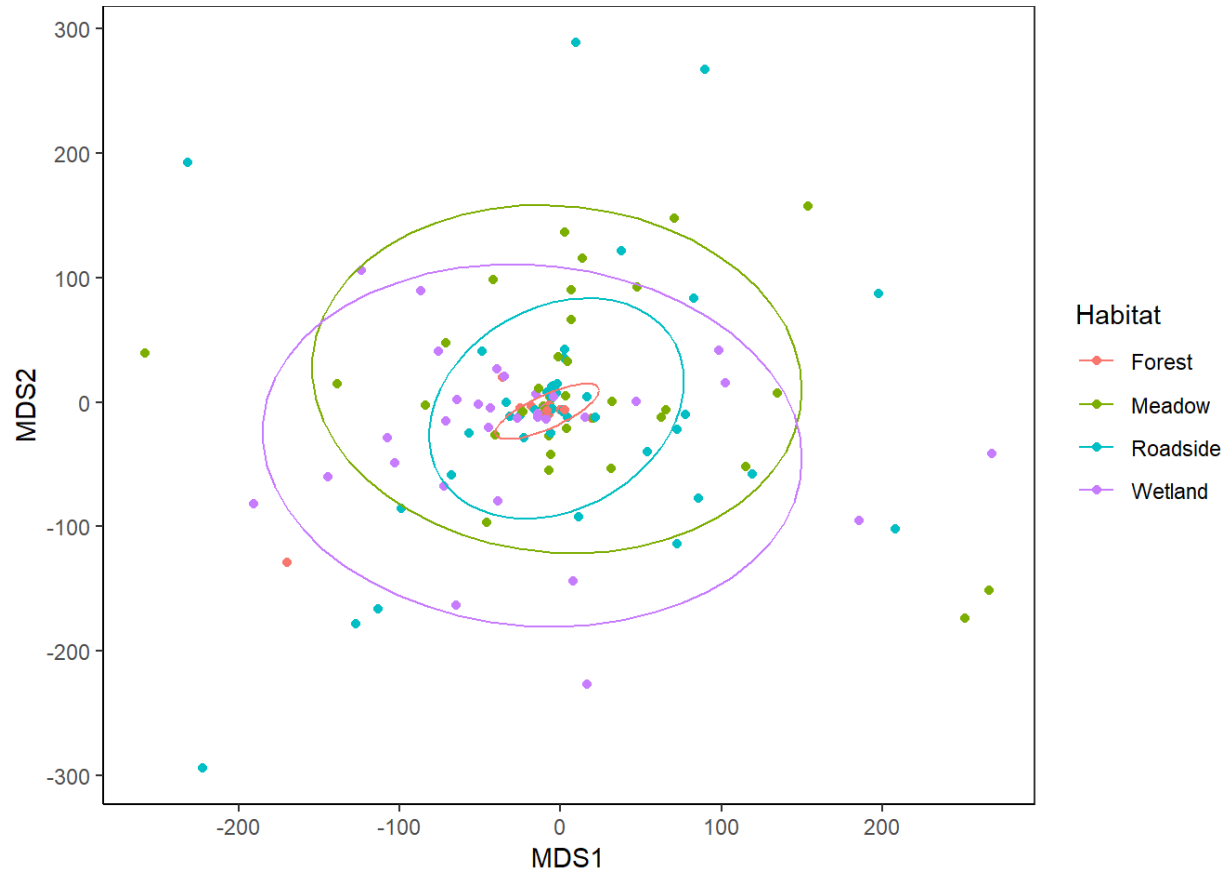


Figure 2.9. NMDS ordination plot of floral assemblage (76 taxa) by the four habitat types revealed flowering plant assemblage composition exhibited little variation among the 45 pollinator sampling sites throughout NYS.

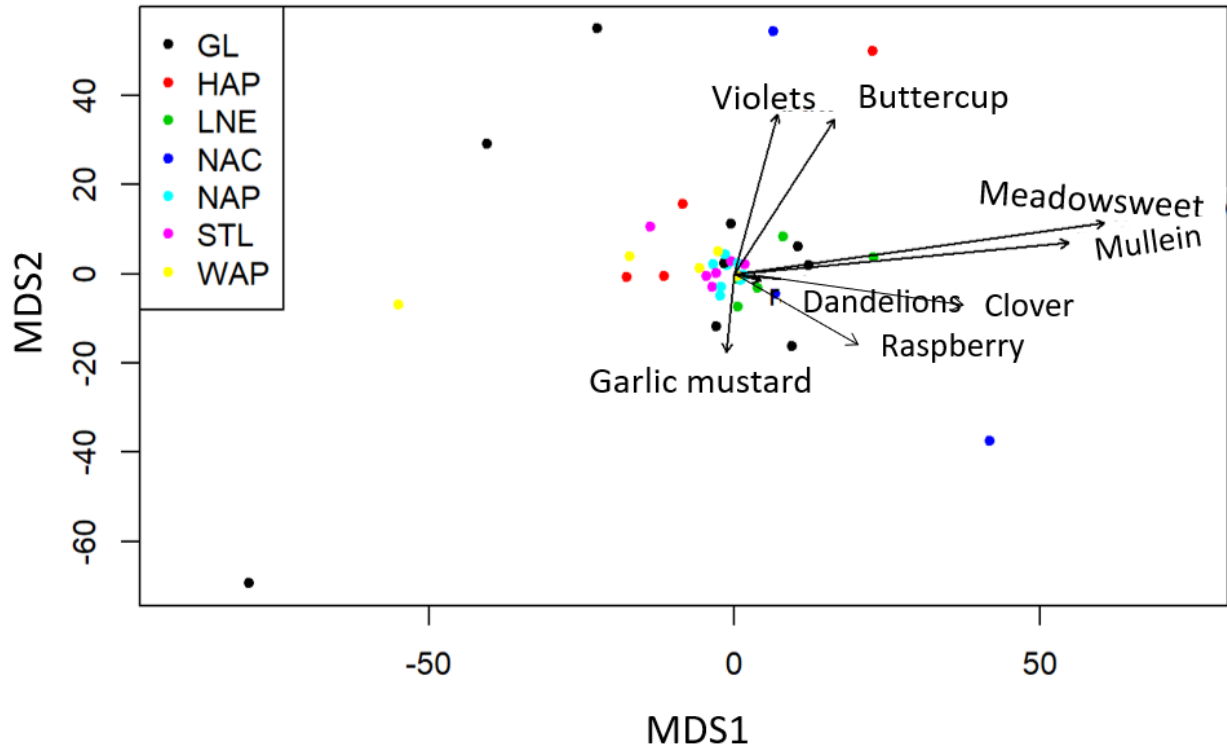


Figure 2.10. NMDS ordination plot of pollinator guild among the seven ecoregions revealed variation across the 45 sites in NYS was not associated with the seven ecoregions. An overlay of the top 11 flowering plants indicate flowering plants associated with axes.

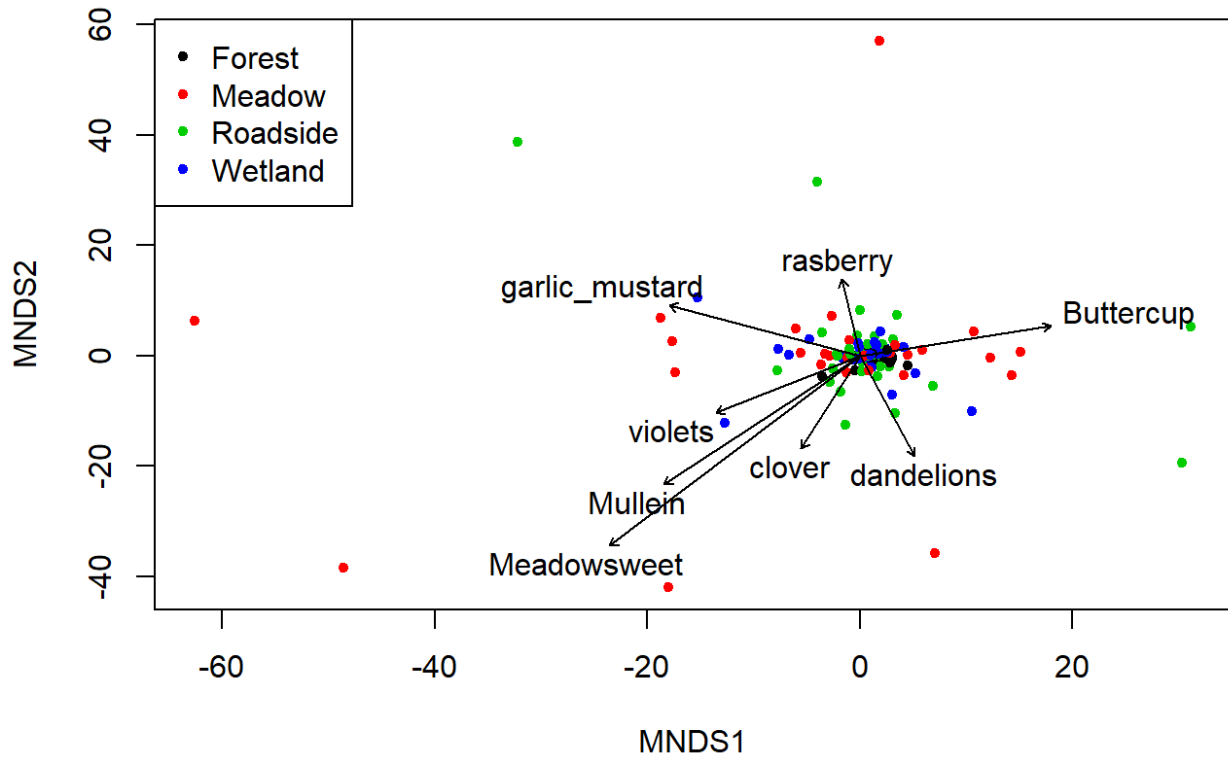


Figure 2.11. NMDS ordination plot of pollinator guild among the four habitat types revealed that the variation across the 45 sites in NYS did not line up with the four habitat types. An overlay of the top 11 flowering plants indicate flowering plants associated with axes.

Based on the variance partitioning analysis, both ecoregion and habitat type together accounted for ~22% of the variation in pollinator species richness ($p = 0.01$, Fig. 2.12). Variation explained by habitat type after controlling for ecoregion was ~20% ($p = 0.005$, Fig. 2.12). Variation explained by ecoregion after controlling for habitat type was not significant, and the variation explained by interactions between ecoregion and habitat type was not significant.

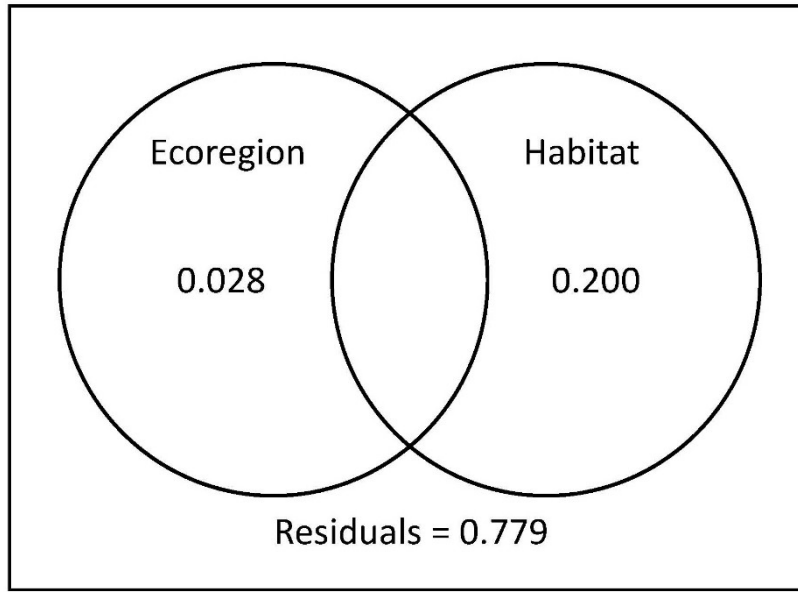


Figure 2.12. Venn diagram showing variance partitioning for pollinator species richness based on ecoregion and habitat type. Habitat type explained most of the variation.

Based on the negative binomial model and model selection, habitat and environmental variables influencing pollinator species richness were habitat type, floral abundance, floral richness, month sampled, the interactions between month sampled and floral abundance, and month sampled and floral richness ($F_{44,55} = 37.2$, $p < 0.001$, Table 2.9).

Table 2.9. Habitat, ecoregion, and temporal variables associated with pollinator species richness in NYS. The degrees freedom, p-values, and AIC values for each of the variables from the global model are presented.

Variable	DF	F-value	p-value	AICc
Month*floral richness	3	0.35	0.81	140.3
Month*floral abundance	3	6.4	0.010	140.5
Floral abundance	1	140.6	0.005	162.7
Floral richness	1	13.5	0.010	222.0
Habitat type	3	5.4	0.010	223.3
Month	3	4.0	0.025	226.7
Ecoregion	6	1.2	0.28	236.7

Ecoregion was not significantly associated with pollinator species richness ($F_{6,49} = 1.20$, $p = 0.32$, Fig. 2.13), though the Northern Appalachian (Adirondacks) had the lowest species richness with < 5 species caught on average across the four habitat types. The two dates of highest species richness statewide were in the Great Lakes ecoregion in June (Fig. 2.13). Meadows (14.6 ± 2.6) and roadsides (13.8 ± 2.0) had the highest pollinator species richness ($F_{3,52} = 5.4$, $p = 0.003$, Fig. 2.14) and were significantly different from forest habitats (4.7 ± 1.1) based on a pairwise comparison (meadow-forest $p = 0.003$, roadside-forest $p = 0.007$). Wetlands were intermediate at 10.4 ± 1.5 species caught. The two dates of highest species richness statewide were in June at roadside and wetland habitats (Fig. 2.14).

Month significantly affected pollinator richness ($F_{3,52} = 4.04$, $p = 0.01$, Fig. 2.15). June with an average of 16 ± 2.7 was not significantly different from May with an average of 12.3 ± 1.6 , however, it was significantly higher than July (7.8 ± 1.7 , $p = 0.02$) and August (8.2 ± 1.3 , $p = 0.03$). The highest species richness in July was from a meadow habitat in the St. Lawrence ecoregion. Additionally, the interaction between month and floral abundance was significant with richness increasing with floral abundance with a peak in the month of June ($R^2 = 0.83$, $F_{7,48} = 38.6$, $p < 0.0001$, Fig. 2.16).

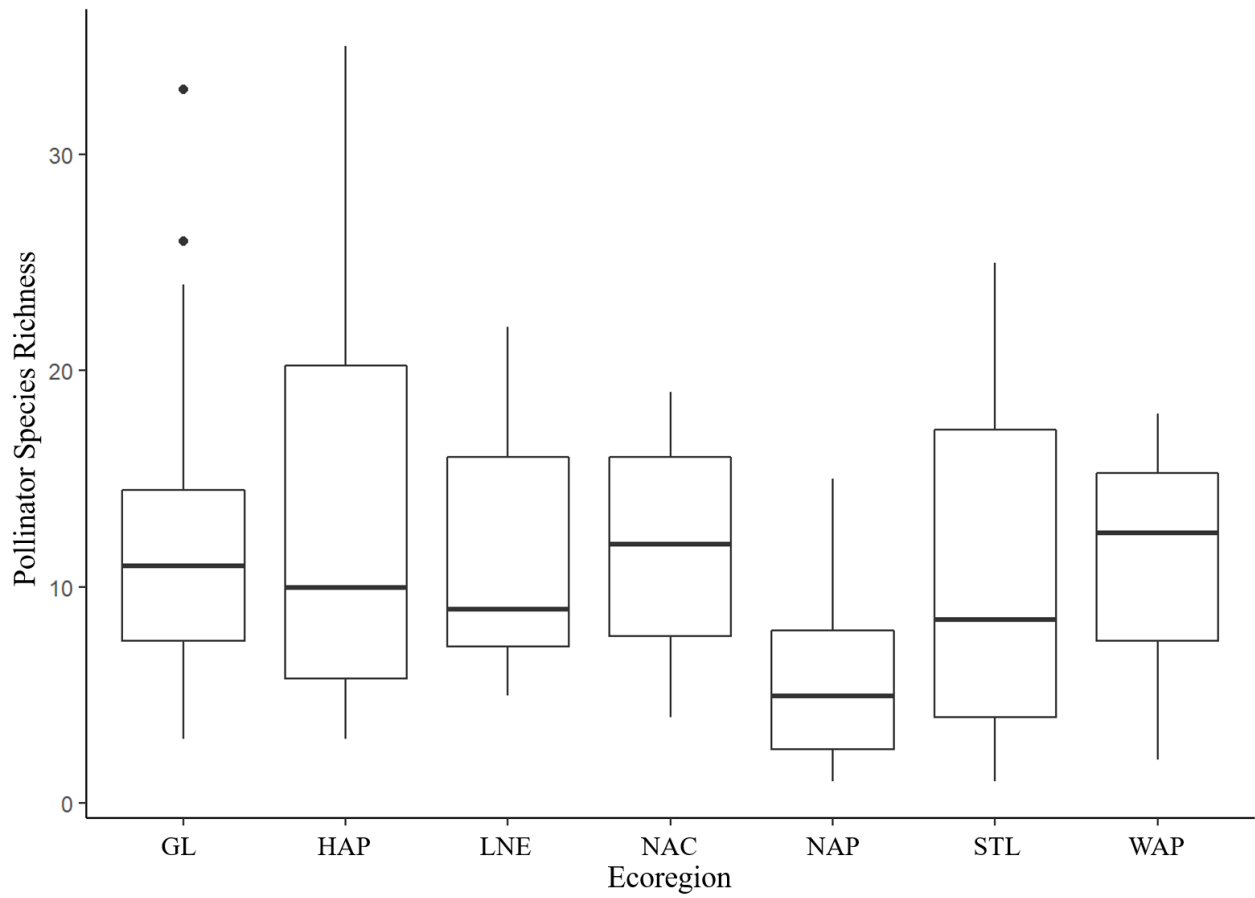


Figure 2.13. Pollinator richness did not vary significantly among ecoregions in 45 sites sampled throughout NYS from 13-May to 20-Aug 2018. Dark horizontal bars indicate the sample median.

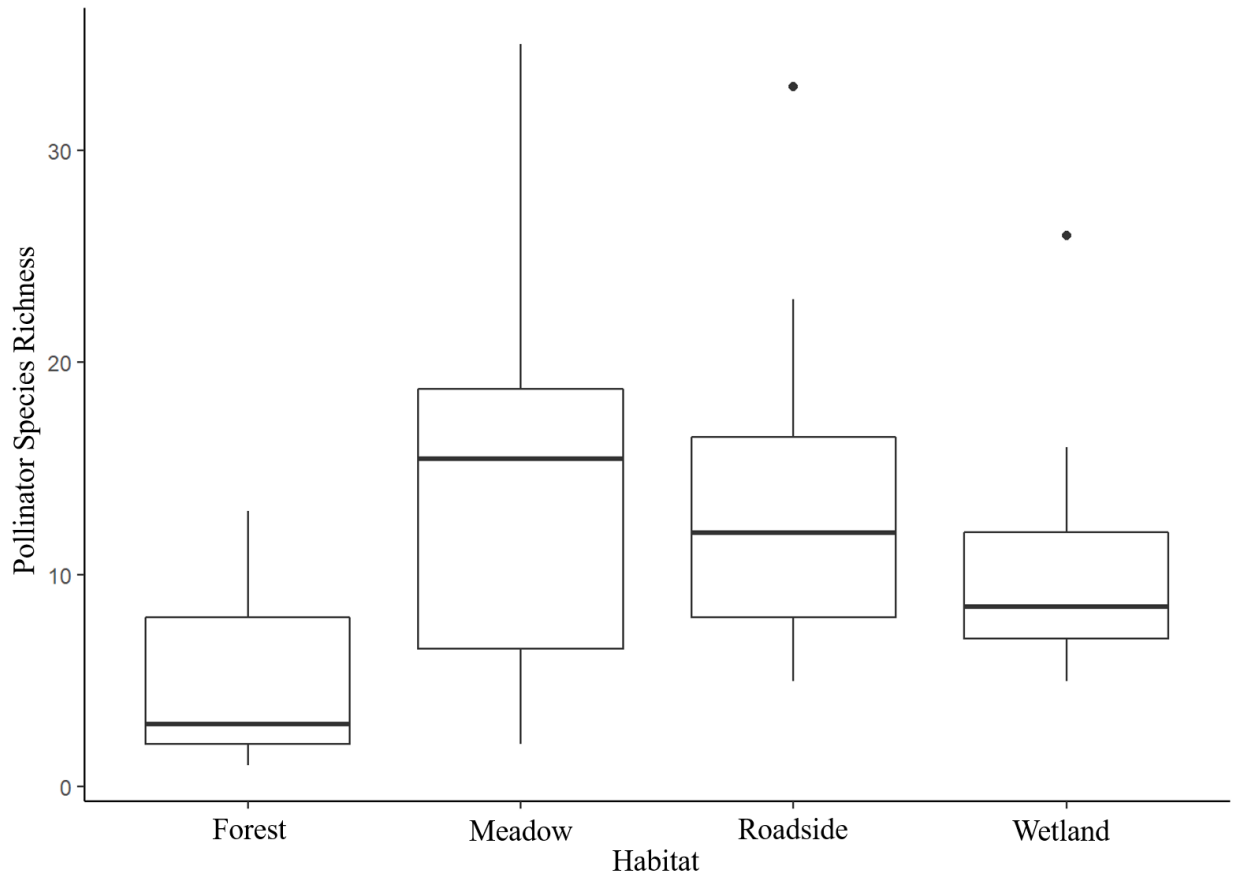


Figure 2.124. Pollinator species richness varied among habitat types in 45 sites sampled throughout NYS from 13-May to 20-Aug 2018. A pairwise comparison revealed meadow and roadside habitats were significantly different from forest habitats. Dark horizontal bars indicate the sample median.

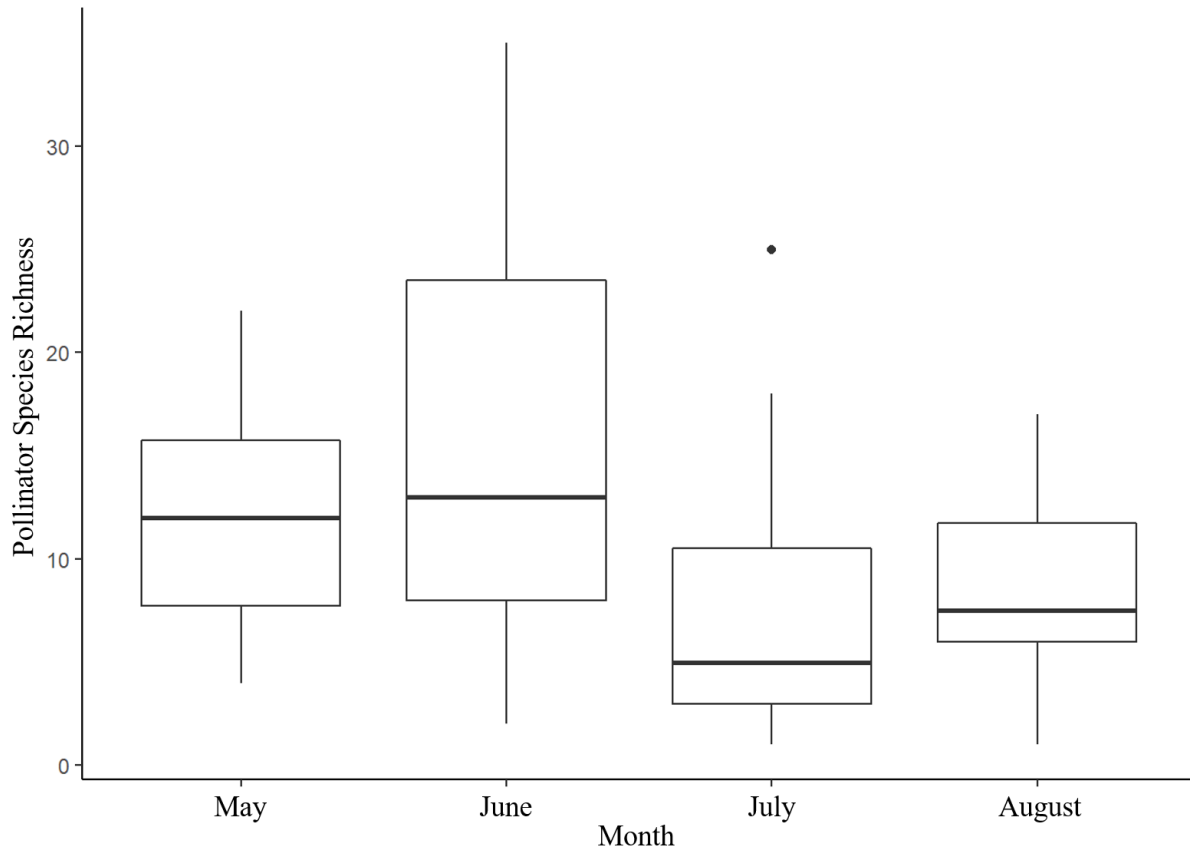


Figure 2.135. Pollinator species richness was highest in June in 45 sites sampled across NYS. A Pairwise comparison revealed June was significantly different from both July and August. Dark horizontal bars indicate the sample median.

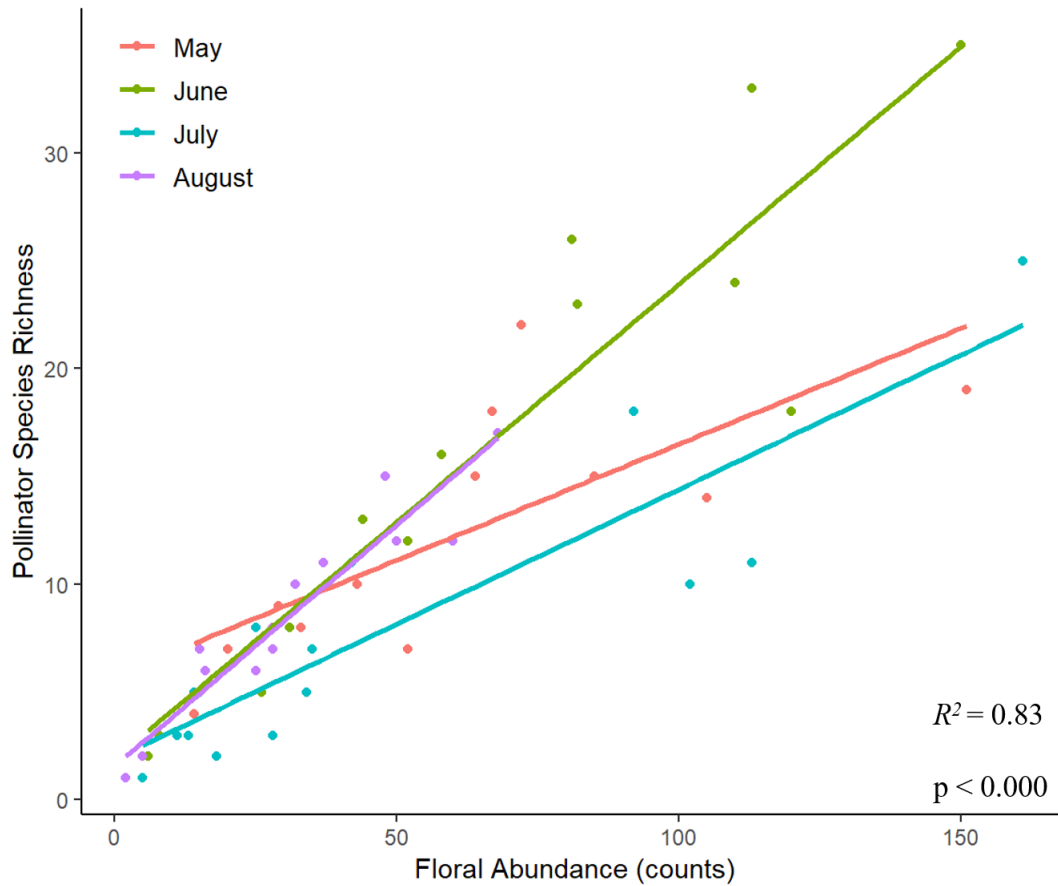


Figure 2.146. There was a significant interaction between month and floral abundance on pollinator species richness in 45 sites sampled across NY from 13-May to 20-Aug 2018. Reported R^2 is for the overall model.

Both floral abundance ($R^2 = 0.72$, $F_{1,54} = 140.5$, $p < 0.0001$, Fig. 2.17) and floral richness ($R^2 = 0.20$, $F_{1,54} = 13.5$, $p < 0.0001$, Fig. 2.18) were important predictors of pollinator species richness with pollinator richness increasing as floral resources increased.

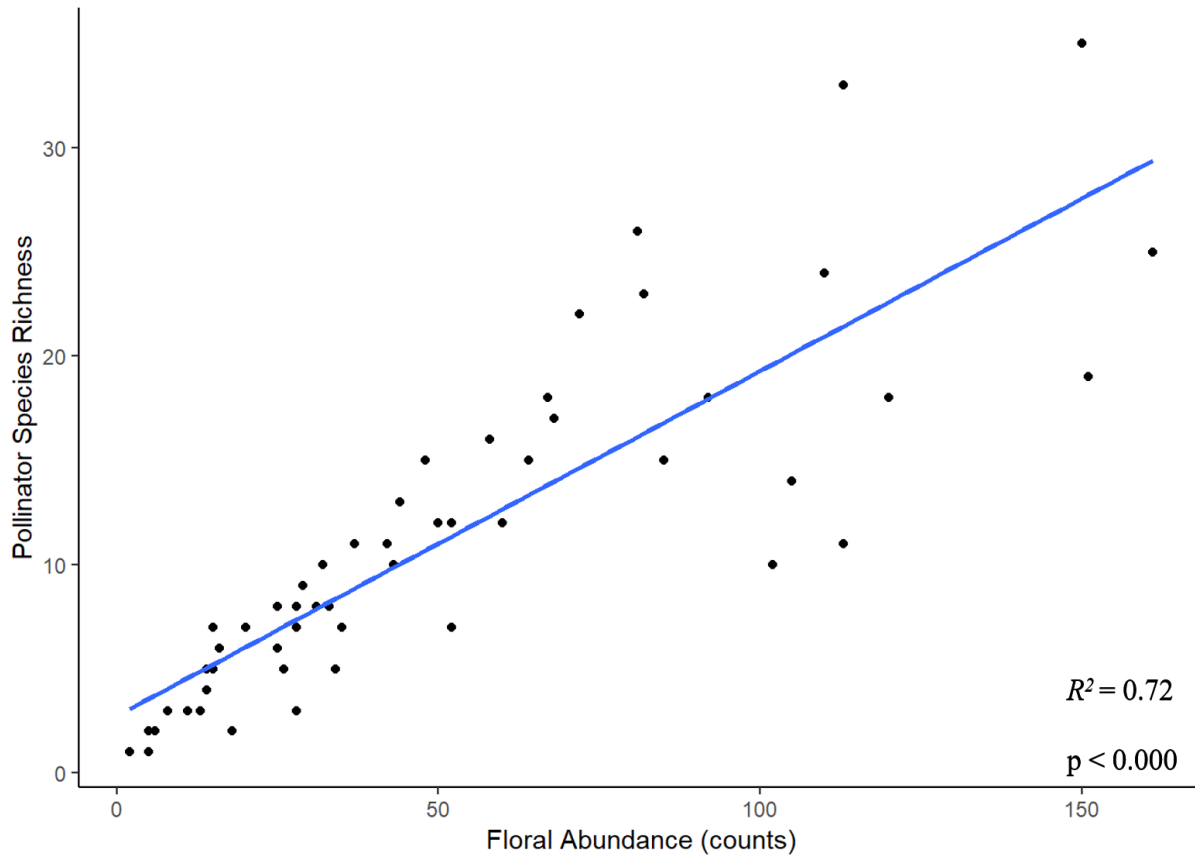


Figure 2.157. Pollinator species richness increased with floral abundance in 45 sites sampled across NY from 13- May to 20-Aug 2018.

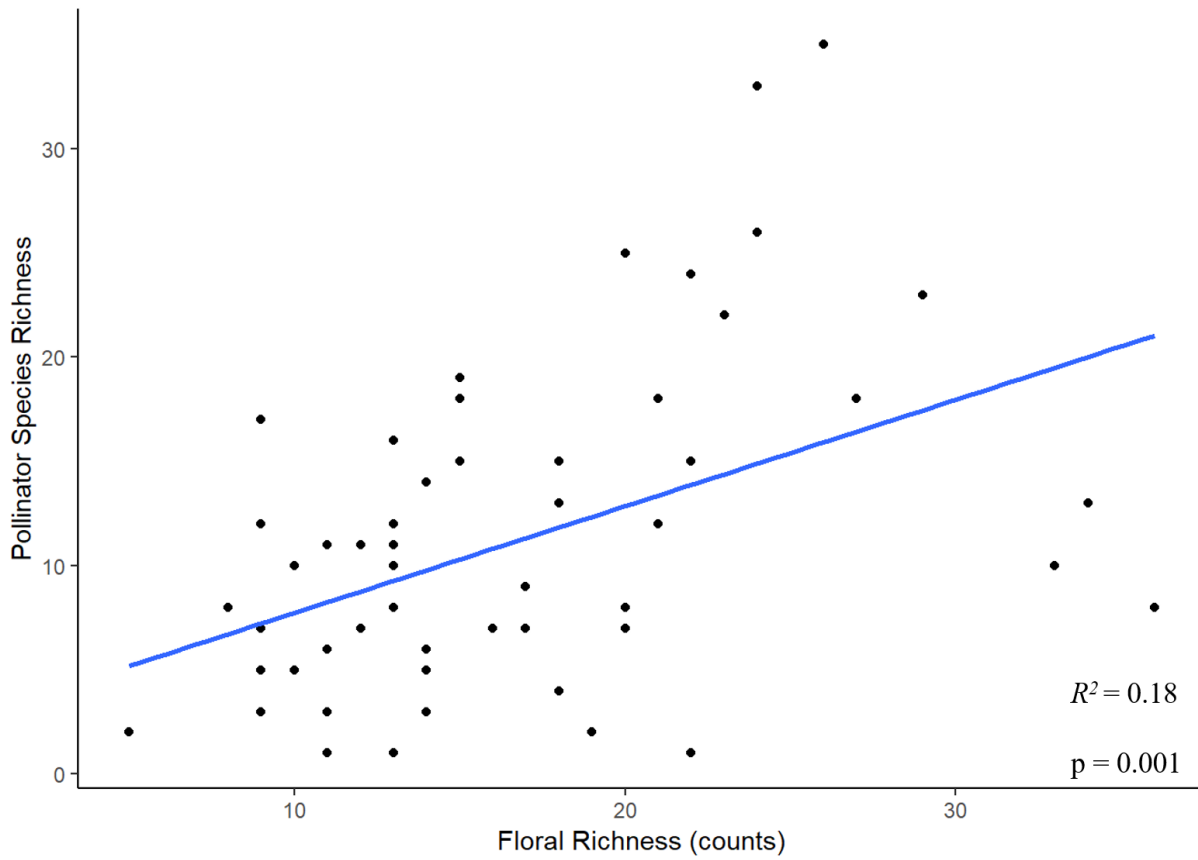


Figure 2.168. Pollinator species richness increased with flowering plant richness in 45 sites sampled across New York from 13-May to 20-Aug 2018.

Discussion

This research indicates pollinator species richness was influenced by habitat type and presence/abundance of flowering plants, as well as the interaction between flowering plants and sampling month. Both sampling methods (bowl traps and sweep netting) are complementary because there is a tendency for both methods to catch different species. We caught 143 different species, 31 which were of conservation interest. Out of the 31 species of conservation interest, 15 were only caught while sweep-netting, i.e. they were not caught in bowls, and 10 were only caught via bowl-traps (Appendix 2). This illustrates that combining passive bowl traps with targeted sweep-netting increased diversity captured.

Species richness of bees found in this study (89 species) is less than what was found in a similar study of bees (144 species) in Black Rock Forest Preserve (Giles and Ascher 2006). That survey was conducted in Orange County, NY and focused on bee species. Their study was conducted in a small area and sampling lasted from 31-March through 16-Oct of 2003. Our study took place from 13-May through 20-August of 2018, thus, their study had a four month longer sampling season than ours did. That study also had 150 bowl traps at each site and utilized wooden trap-nests, a method that caught a rather rare species of Vespid wasp *Zethus spinipes*. Wooden trap-nests were not utilized in our study. Additionally, these researchers opportunistically chose survey sites based on presence of bees. Thus, survey efforts for that study were thorough and captured the entire season, resulting in an accurate quantification of species richness for that preserve. For our study, the sites were only visited once and were scattered statewide, giving a “snapshot” of species distributions each year. Additionally, a handful of taxa (e.g. *Lasioglossum (Dialictus)*, *Nomada* spp., *Sphecodes* spp.) were either only identified to genera or sub-genera due to time constraints for this project and difficulty in identifying to species level.

Bee species richness was also less than what was found in another similar study (278 species) across Europe (Westphal et al. 2008). That survey was conducted in five countries in Europe representing distinct biogeographic regions, with eight sites in each country. The purpose of this study was to compare sampling methods, thus they employed six different methods, thus, the high numbers of bee species would make sense. Additionally, these researchers sampled in agricultural environments, specifically in crop plants that are insect pollinated, this is a habitat that was not a part of our study.

Comparison of dipteran diversity in the present study to those previously conducted presented a significant challenge. Previous research (e.g. Bankowska (1982) and Kearns (2001)) has focused largely on Syrphidae. In a 5-year Syrphid survey in Poland, Bankowska (1982) found a total of 313 species. The most species rich areas were from natural areas rather than urban areas. In the first year of this project, we have found 47 species, representing 32 genera. Kearns (2001) proposed larval food supplies could be more important in producing differences in population sizes among syrphid species and stressed a change in abundance and species composition. Since syrphid larvae are predaceous, the availability of larval food is a key resource and may drive different temporal and spatial patterns in abundance than that observed for bees (Kearns 2001). Since bee larvae are dependent on pollen for food, this would reinforce the idea that different pollinator groups may respond differently to environmental change (Bankowska 1982, Kearns 2001).

Pollinator species richness was best explained by the interaction between month and flower abundance with highest pollinator richness in the month of June. Higher numbers of pollinators in June is likely correlated with a slightly higher floral richness and abundance in June. Other studies also found bee species richness is closely linked to floral diversity and abundance (e.g. Potts et al. 2003, Sargent and Ackerly 2008, Dorn et al. 2010). Furthermore, based on counts, there were more flowering plants in more open habitats (meadows, roadsides, and wetlands) than in forested habitats. The NMDS analysis indicated no difference in flowering plant assemblages by ecoregion or habitat type, suggesting floral abundance and richness are more important and influencing trends seen with pollinators. Furthermore, many of the flowering plant assemblages were dominated by exotic species, that tend to be present at many sites and in many ecoregions.

Results indicate pollinator species richness did not differ by ecoregion. Many wild bees are closely associated with nesting materials, i.e. specific plant species or soil types (Potts and Willmer 1997, Wuellner 1999, Sardiñas and Kremen 2014), which can vary among ecoregions. Potts et al. (2003) found availability of nesting resources influenced ~10% of bee guild composition. Based on this information, it was predicted ecoregion would affect pollinator richness and guild composition. The lack of effects found in this study could be because most sampling efforts were on protected lands with conservation efforts already being implemented. Bates et al. (2011) documented that pollinator guild composition changes along an urbanization gradient, which may extend to this study in that sampling was only carried out in natural environments. Furthermore, only the Great Lakes ecoregion was visited every month throughout the study. All other ecoregions were either visited three out of the four months (NAP), two out of the four months (HAP, LNE, STL, WAP), or only visited one out of the four months (NAC). The phenology of many of the pollinator and floral taxa are not seasonally represented, which may be contributing to the results we found. However, to fully gage this and get a full species list at a site, one would need to sample every two weeks throughout the season (Droege, personal communication). The lack of effects in floral richness and abundance by month, and ecoregion may be confounded by the fact that not all ecoregions were visited every month; however, examining soil composition in addition to quantifying floral resource availability would be an important component to add in future studies.

Most of the pollinators collected and identified are known to be common species that are widespread among ecoregions and habitat types. Locally rare pollinators (ones with a narrow distribution) found during our study, only accounted for a small portion (< 10%) of collected pollinators. It is well known that despite using thorough survey efforts, common and widespread

species are always dominant species in pollinator surveys, and thus, they tend to drive statistical patterns (Giles and Ascher 2006). Moreover, NMDS ordination showed that floral assemblages were not different among ecoregions. Many of the flowering plants found in this study are cosmopolitan or invasive species, occurring across many sites. These plants are known to attract cosmopolitan or generalist pollinators. When a habitat is dominated by invasive plant species, it could increase the distribution of generalist pollinator species at the cost more specialized species (mutualism facilitation hypothesis, Richardson et al. 2000, Prior et al. 2014). Therefore, elucidating these patterns are important to bring awareness to the long-term effects that invasive plant species can have on the distribution and abundance of rare insect pollinators.

Pollinator species richness at 35 species was highest in meadow habitats. Hughes et al. (2000), also found consistently higher number of species in meadow habitats (243 Dipteran species and 203 Hymenopteran species) compared to coniferous forests (159 Dipteran species and 137 Hymenopteran species). However, malaise trapping was used in that study, which is very effective at collecting a large number of insects and is normally deployed for a period of 24–48 hours (Matthews and Matthews 1971, Darling and Packer 1988, Campbell and Hanula 2007). Thus, that study had much higher species richness than our study. Meadows are open and free from dominant tree cover; thus, allowing plants to flourish in the sun.

The roadside habitat type had the second highest number of pollinators at 33 species. This was similar to what Hopwood (2008) found in their study of restored roadside hedges and maintained roadsides. Their results showed that the restored roadsides harbored higher bee species richness (79 bee species) compared to the maintained roadsides (53 bee species). Edge habitats tend to be open, and free of cover from dominant trees. This can mimic meadows in many ways, allowing shrubs and weedy flowering plants to flourish and thus provide abundant

nutrient resources throughout the growing season. Moreover, many flowering plants, including non-native species, which are visited by many generalist pollinators, thrive in these highly disturbed habitats (Morales and Traveset 2009, Nienhuis et al. 2009, Vanbergen et al. 2018). Levels of disturbance commonly found in this habitat type can prevent interspecific competition, facilitating higher species coexistence (Southwood et al. 1979, Roxburgh et al. 2004). However, butterfly and other insect casualties as a result of increased traffic can be a major problem along roadsides (Rao and Girish 2007, Alvarez et al. 2019).

Pollinator declines and future endeavors

With this study, my goal was to provide information on important environmental factors associated with pollinator richness to better inform land managers as they develop best policies and management practices. This information is crucial to protect pollinating insect species that are in decline.

Chapter 3: Evaluating community scientists in pollinator conservation research

Abstract

Incorporation of community science may allow the Empire State Native Pollinator Survey to extend the temporal and geographical range of data collection. The goal of this study was to illuminate on contributions of community scientists to data collected by paid biological technicians. Workshops were held to train volunteers, who could choose to participate via specimen collection (volunteer surveyors) or by observational photos (iNaturalist). Results suggest volunteers contributed valuable data which increased species richness numbers as well as capturing unique species of conservation interest when combined with data collected by paid biologists. This indicates volunteers can extend spatial and temporal ranges of monitoring programs; however, it should be seen as a complement to biological fieldwork.

Key Words: pollinators, ecosystem services, pollinator monitoring, community science, conservation, iNaturalist

Introduction

In the last decade, studies show pollinators are declining world-wide (Gallai et al. 2009a, Lebuhn et al. 2013, Goulson et al. 2015). The consequences of the losses, declines, and changes to pollinator guild composition are not well understood (Potts et al. 2010, Schweiger et al. 2010). In New York State (NYS), > 30 native pollinator species have been listed as Species of Greatest Conservation Need, ~20 of those as High-Priority (NYS DEC 2015). Information regarding the current status of native pollinator species in NYS is limited (NYS DEC 2016). Thus, the New York Natural Heritage Program (NYNHP) has initiated a multi-year state-wide study to document current distribution and status of native pollinators in non-agricultural habitats in NYS (Schlesinger et al. 2017). This project will serve as a foundation for development and implementation of future conservation practices.

Costs for conducting scientific research can be challenging, even more so when study areas are large or focal organisms are small/rare (Losey et al. 2012). Furthermore, it is difficult to incorporate sufficient time and effort to cover a large area within the duration and budget limits of most grant-funded research projects. Thus, over the last decade, scientists have been engaging local community members in scientific endeavors. These community members are called community scientists (formerly termed citizen scientists, Cohn 2008, Bonney et al. 2009, Conrad and Hilchey 2011). Although there have been concerns regarding the quality of data collected by volunteers (Cohn 2008, Kremen et al. 2011, Freitag et al. 2016), evidence suggests non-scientists are capable of increasing the flow of data essential to scientific research (Bonney et al. 2009, Howard and Davis 2009, Silvertown 2009, Dickinson et al. 2010, Kremen et al. 2011, Kullenberg and Kasperowski 2016). Moreover, community scientists can be trained to collect

samples with a rigor comparable to professionals (Fore et al. 2001, Kremen et al. 2011, Kosmala et al. 2016).

Another efficient way to involve community members in scientific collection is with the use of technology (Bonney et al. 2009, Dickinson et al. 2010). One example is iNaturalist, a website and app that functions as a portal. iNaturalist compiles species presence data via georeferenced photographs. In New York, the NYNHP project the Empire State Native Pollinator Survey (ESNPS) has a project on iNaturalist where people can document pollinators photographically (Schlesinger et al. 2017). With the incorporation of both volunteer surveyors and observational iNaturalist users, scientists and agencies can extend the scale of their studies. However, the efficiency and data quality of these two components in facilitating the temporal and geographical expansion of data collection has not been evaluated.

The goal of my research was to compare data collected by community science volunteers, who used different methods, in documenting presence of pollinators in NYS. The specific aim was to determine how involving community science volunteers complements the work of paid technicians conducting pollinator surveys in NYS.

Specific research questions and predictions

For this study, I sought to determine whether involving community scientists yielded more robust results than if only field biologists conducted surveys. Data were collected by iNaturalist users (observational photos only), volunteer surveyors (collected voucher specimens), and by paid field biologists (collected voucher specimens) across NYS. Specifically, I sought to determine whether involving community scientists yielded a larger species presence list and sampled in more areas of the state than if only field biologists conducted surveys. Data were collected by iNaturalist users, volunteer surveyors, and by paid field biologists across NYS.

Methods

Study Area

New York State is a geologically heterogeneous region of northeastern North America comprising ~141,300 km² where the climate exhibits significant temperature seasonal changes throughout the year (Corser et al. 2014). New York State has 63% forested cover with considerable regrowth following extensive agricultural clearing during the early 1900s (NYS DEC 2014). Annual precipitation is 75–125 cm, and is uniformly distributed throughout the year (NYS DEC 2014).

Community Science Participation

Volunteer recruitment

New York Natural Heritage Program personnel contacted partners, colleagues, and community science volunteers from past projects via email. Interested individuals were asked to create a profile on an online registry to stay up to date with the project (<http://signup.com/go/yxaxrgQ>). New York Natural Heritage Program personnel created a public project on iNaturalist and encouraged participation via the iNaturalist website and app (<https://www.inaturalist.org/projects/empire-state-native-pollinator-survey>).

Volunteer training

New York Natural Heritage Program personnel created a participant handbook outlining the field survey protocol, voucher preparation, field data sheets, and data submission (White et al. 2018). They held four public day-long in-person workshops in June and July of 2018 in Wyoming (Western NYS), Franklin (Northern Adirondack region), Albany (Capital Region), and Westchester (Southern NYS) Counties. The workshop curriculum included basic biology, morphology, life histories, and behaviors of Hymenoptera, Diptera, Lepidoptera, and Coleoptera.

New York Natural Heritage Program personnel taught sixty participants how to identify ESNPS focal taxa (Table 3.1) in the field and in the lab. Additionally, participants learned about field protocols and methodologies by practicing outdoors with bowls and hand-nets. Specimen processing and uploading voucher photographs to iNaturalist were also included in the workshop curriculum.

After training, community science volunteers chose to participate via iNaturalist submissions (photographic submissions) or by doing field collections for voucher specimens. The NYNHP provided recommendations of where to obtain equipment needed to complete field surveys and specimen processing to volunteers who chose to collect voucher specimens in the field.

Table 3.1. Focal taxa used in analysis for this project. Focal taxa were species or groups of species on which survey efforts were concentrated. * represents genera of conservation interest according to the NYNHP.

Hymenoptera	<p>Andrenidae: <i>Andrena</i>*, <i>Calliopsis</i>*</p> <p>Apidae: <i>Anthophora</i>, <i>Apis</i>, <i>Bombus</i>*, <i>Ceratina</i>, <i>Melissodes</i>*, <i>Nomada</i></p> <p>Colletidae: <i>Colletes</i>, <i>Hylaeus</i></p> <p>Halictidae: <i>Agapostemon</i>, <i>Augochlora</i>, <i>Augoclorella</i>, <i>Augochloropsis</i>, <i>Halictus</i>, <i>Lasioglossum</i>, <i>Sphecodes</i></p> <p>Megachilidae: <i>Heriades</i>, <i>Hoplitis</i>, <i>Megachile</i>*, <i>Osmia</i>*</p> <p>Melittidae: <i>Macropis</i>*, <i>Melitta</i>*</p>
Diptera	<p>Bombyliidae: <i>Bombylius</i>*</p> <p>Syrphidae: 32 genera, ex: <i>Mallota</i></p>
Coleoptera	<p>Cerambycidae: ~100 species in Lepturinae, ex: <i>Leptura</i></p> <p>Scarabeidae: <i>Trichiotinus</i>*</p>
Lepidoptera	<p>Sphingidae: ~26 species, ex: <i>Hyles</i>, <i>Sphinx</i></p> <p>Noctuidae: <i>Schinia</i>*</p>

Pollinator Sampling by Volunteers and Field Biologists

Field protocols and specimen processing by volunteers and field biologists were based on methods used by Carboni and Lebuhn (2003) and Droege (2015). The primary methods of specimen collection were bowl trapping and targeted netting. Bowl trapping was executed with four transects comprised of 15 blue, yellow, and white bowls filled half-way with soapy water between 9:00 am – 3:00 pm. At each of the sites, an attempt was made to sample four habitat types: meadow, wetland, forest, and roadside. If all habitat types were not present, then volunteer surveyors set out additional transects in habitat types that were present. Additionally, observers

conducted targeted sweep net sessions with insect nets, spending 30 min walking through each sampling location, looking primarily on flowers for bees, flies, beetles, and moths. Volunteer surveyors made an attempt to only catch one representative per species, though this was conservatively carried out knowing many species look similar and are difficult to differentiate in the field. Specimens caught in bowl traps were stored in ethanol, then rinsed, dried, and pinned immediately (following methods from Droege 2015). Specimens caught in hand-nets were kept frozen until they were pinned. Specimens were placed in boxes based on insect Order and grouped by site, habitat type, and sampling method. Volunteers who chose to conduct field surveys collected data from 13-May to 16-Aug 2018.

Pollinator Identification

Specimens collected by volunteer community scientists were sent to NYNHP project managers in Albany, NY. Once there, specimens were labeled, sorted, and distributed to specialists for identification (Hymenoptera at the Danforth lab at Cornell University, Diptera at the Greenwood lab at SUNY Cobleskill, Coleoptera and Lepidoptera by NYNHP personnel). Voucher specimens were housed in the NYS Museum in Albany, NY and the Cornell University Insect Collection in Ithaca, NY. Individuals who chose iNaturalist submitted photographic voucher specimens online and photos were examined by the taxonomic experts from the iNaturalist community which includes taxonomic experts. Photographic submissions with identifiable pollinators collected from 13-May to 20-Aug 2018 were used in data analyses.

Specimens collected by two paid field biologists were from 45 sites in seven ecoregions throughout NYS during the same field season in 2018 (see Chapter 2).

Statistical Analysis

All statistical analyses were performed in R Studio version 1.1.456 (RStudio 2016). To compare unique taxa and species of conservation need collected by community scientists, iNaturalist users, and field biologists, lists were generated, species of conservation interest were indicated, and counts of unique contribution to the project were made.

Bumble bees get a lot of media attention; thus, a comparison was made of only bumble bees. To compare efficiency of field collections by volunteers and iNaturalist submissions in documenting bumble bee species of conservation need and contribution of unique taxa, lists of all bumble bee species found on the project were made, and total numbers of each species were compared. Total number of species of greatest conservation need that were detected by each participating group were compared. Percentage of each species of the total number of bumble bees documented by each participating group were compared. To assess distribution of sampling locations by all participating groups, maps were made using ArcMap (version 10.6.1) (ESRI 2018).

Results

From 13-May to 16-Aug 2018, five volunteer surveyors completed field protocols and collected voucher specimens. Together, these 5 volunteer surveyors visited 78 sites (25 meadows, 23 wetlands, 19 roadsides, 11 forests, and 25 unidentified bonus habitats). They collected a total of 337 specimens representing 102 focal taxa within the focal orders/families, including 266 Hymenoptera, 39 Diptera, 11 Coleoptera, and 15 Lepidoptera. These resulted in a total of 63 Hymenoptera species, 27 Diptera species, 9 Coleoptera species, and 2 Lepidoptera species being identified (Appendix 4). Of the 102 species collected, 22 were unique, i.e. species

collected only by these volunteers, including 8 Hymenoptera, 9 Diptera, 4 Coleoptera, and 1 Lepidoptera.

For the ESNPS iNaturalist project, a total of 470 users participated and posted 1,611 photographic submissions, which included 141 focal taxa. They observed 935 Hymenoptera, 266 Diptera, 85 Coleoptera, and 325 Lepidoptera (Appendix 5) within the orders/families mentioned above with a total of 57 Hymenoptera species, 26 Diptera species, 23 Coleoptera species, and 35 Lepidoptera species identified. Of the 141 species collected, 81 were unique, including 20 Hymenoptera, 9 Diptera, 18 Coleoptera, and 34 Lepidoptera.

Field biologists collected 1,431 specimens, representing 147 pollinator species (Appendix 2), across 45 sites (including 33 meadows, 37 wetlands, 44 roadsides, and 45 forests). There were 1,271 Hymenoptera and 160 Diptera within the focal orders/families with a total of 89 Hymenoptera species and 54 Diptera species identified. Of these, 58 were unique species, 31 Hymenoptera and 27 Diptera. Coleoptera and Lepidoptera were also collected; however, these have not been identified and so are not included in these counts.

Pollinators of conservation interest found

Proportionally, iNaturalist users observed pollinators of conservation interest more often (52%) than community scientists (27%). iNaturalist users tended to document more noticeable species, such as bumble bees and hummingbird moths compared to community scientists and field biologists (Table 3.2, Appendix 4). However, by order, field biologists caught more bee species of conservation interest than both community scientists and iNaturalist users (Table 3.2).

Table 3.2. Number of pollinator species (SR = species richness), number of unique species, and number of species of concern documented by volunteers and paid biologists from 13-May to 20-Aug of 2018 across NYS. Dashes indicate groups not identified for particular methods.

	Volunteer Surveyors (5 volunteers, 65 sites)			iNaturalist (470 users, 1,611 photos)			Field Biologists (team of 2, 45 sites)		
	SR	Unique	Concern	SR	Unique	Concern	SR	Unique	Concern
Hymenoptera									
Andrenidae	11	1	2	3	0	0	24	15	4
Apidae	21	3	6	22	7	4	20	20	3
Colletidae	3	0	0	5	2	0	7	1	0
Halictidae*	14	2	0	10	2	0	16	1	0
Megachilidae	13	1	3	17	9	1	22	12	4
Melittidae	1	1	0	0	0	0	0	0	0
Diptera									
Bombyliidae	3	0	1	2	1	2	4	0	1
Syrphidae	24	9	7	24	8	9	48	26	19
Coleoptera									
Cerambycidae	9	4	7	22	17	21	--	--	--
Scarabaeidae	0	0	0	1	1	1	--	--	--
Lepidoptera									
Noctuidae	1	1	0	4	4	4	--	--	--
Sphingidae	1	0	1	31	30	31	--	--	--
Totals	101	22	27	141	81	73	141**	75**	31**

**Dialictus* (subgenus of *Lasioglossum*) were not identified to species.

**Total is without Coleoptera and Lepidoptera, which are not yet identified from field biologist collections.

Bumble bees found during the project

Close to 47% (437/935) of Hymenopteran images submitted by iNaturalist users were of bumble bees, whereas bumble bees were only 23% (63/266) of specimens collected by community scientists and 8% (101/1341) of specimens collected by field biologists. In field collections, 50% of bumble bee species were caught only via sweep netting (n = 12) with only a few (n = 2) collected in bowls, the passive method of field collection used by both community volunteers and field biologists. The remaining 10 species of bumble bees were caught using more than one method of collection. volunteer surveyors observed bumble bees of conservation interest more often than iNaturalist users, including a species not seen by any other participants in the project (Table 3.3). Of the 47% (437/935) of the submitted bumble bee images by iNaturalist users, 48% (416/671) were of *Bombus impatiens* Cresson, 1863-i.e. they tended to

document many of the same species repeatedly. However, they also documented *B. citrinus*, a bumble bee species not collected by other participants (Table 3.3). Collections by field biologists did not yield any unique *Bombus* species. Honey bees, like bumble bees, were seen by all participating groups. iNaturalist users documented honey bees 184 times out of 776 bee (family Apidae) documentations (24%); which is a much higher number than both volunteer surveyors, who only documented honey bees 5% of the time (5/98) and field biologists, who only documented them 6% of the time (20/359).

Table 3.3. Total number of individual bumble bee (*Bombus* spp.) species and percentage out of total numbers of bumble bees documented by volunteers and field biologists.

	Vol. Surveyors (5 volunteers, 65 sites)		iNaturalist (470 users, 1,611 photos)		Field Biologists (team of 2, 45 sites)	
	Number	Percent	Number	Percent	Number	Percent
<i>B. bimaculatus</i>	5	8%	29	7%	8	8%
<i>B. borealis</i> *	6	9%	5	1%	3	3%
<i>B. citrinus</i> †	0	--	2	0.5%	0	--
<i>B. fervidus</i> *	2	3%	20	4%	1	0.9%
<i>B. flavidus</i> *†	2	3%	0	--	0	--
<i>B. griseocollis</i>	5	7%	119	27%	8	8%
<i>B. impatiens</i>	13	20%	208	48%	38	38%
<i>B. perplexus</i>	7	10%	10	2%	4	4%
<i>B. rufocinctus</i>	0	--	1	0.5%	1	0.9%
<i>B. sandersoni</i>	1	1.5%	0	--	6	6%
<i>Bombus</i> sp.	0	--	0	--	2	11%
<i>B. ternarius</i>	4	6%	26	6%	2	2%
<i>B. terricola</i> *	4	6%	7	1%	2	2%
<i>B. vagans</i>	14	22%	10	3%	26	26%
Total	63		437		101	

*Indicates species of conservation need according to NYNHP. †Indicates unique taxa seen only by one group.

Sites sampled during the field season

Volunteer surveyors sampled in five out of seven ecoregions (Fig. 3.1A). Field biologists sampled in all seven ecoregions (Fig. 3.1C). iNaturalist users submitted data from all seven ecoregions. Moreover, for iNaturalist, there were clusters of submissions in southern NYS around New York City (NYC) and along the I-87 corridor leading to NYC. There were also smaller clusters in the Great Lakes region, around Buffalo, Ithaca, and Rochester (Fig. 3.1B). Workshops were held in Wyoming (Western NY), Franklin (Northern Adirondack region), Albany (Capital Region), and Westchester (Southern NY) Counties (Fig. 3.1D). Despite having a workshop in them, Wyoming and Franklin counties had the least number of visitations from survey participants (Fig. 3.1D). After compiling volunteer surveyor vouchers, iNaturalist user submissions, and field biologist specimens, it appears sampling efforts were concentrated in areas to the east, while areas to the north and west were surveyed less (Fig. 3.1D).

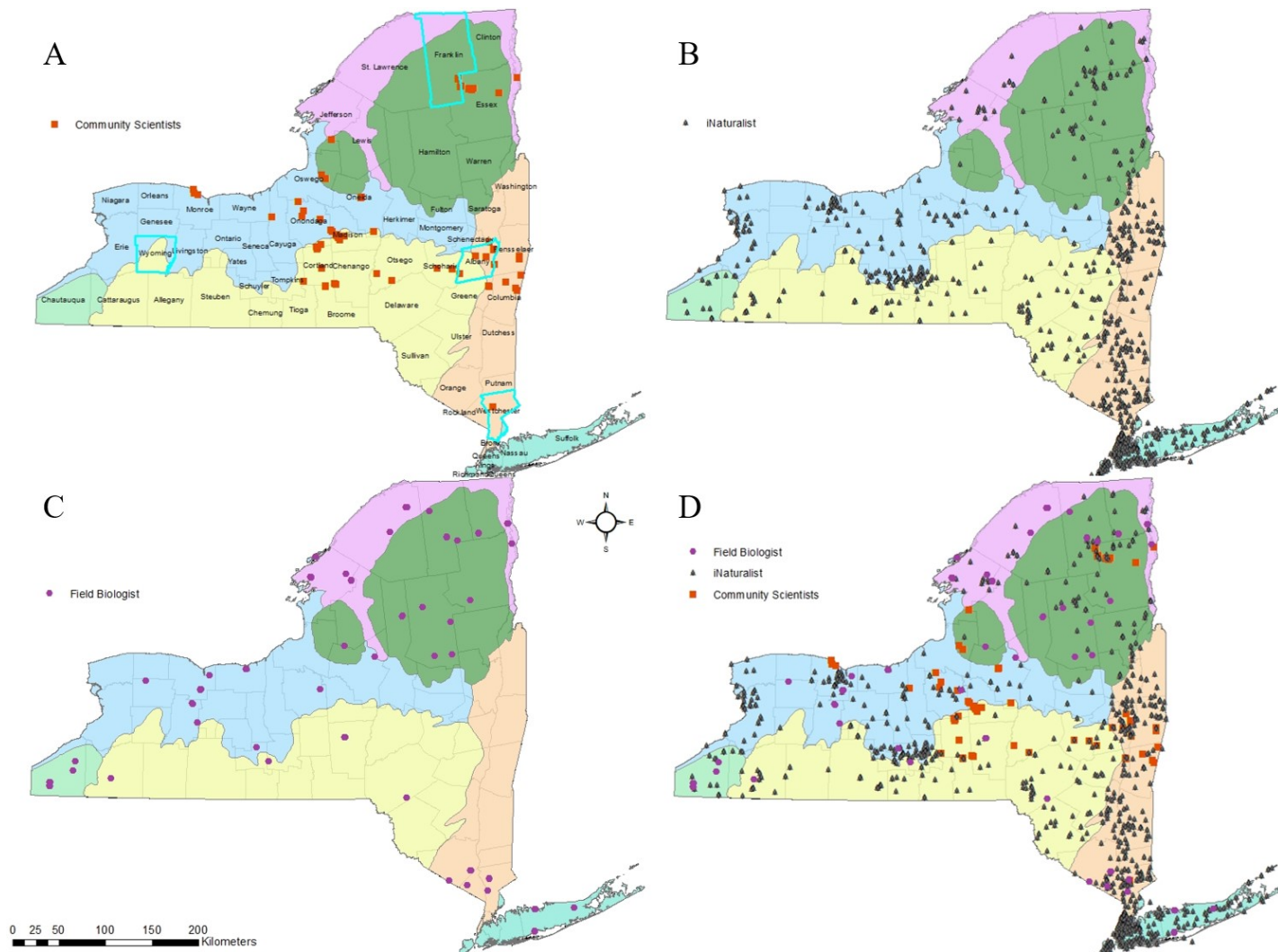


Figure 3.1. Pollinator data gathered across NYS from 13-May to 6-October of 2018. A) Volunteer surveyors conducted field sampling in 81 field sites in five out of seven ecoregions. Workshops were held in Wyoming county (Western NY), Franklin county (Northern Adirondack region), Albany county (Capital Region), and Westchester County (Southern NY).; county outlines in light blue B) iNaturalist users submitted data from all seven ecoregions; there were clusters of many submission in southern NYS around New York City and along the I-87 corridor leading to NYC. There were smaller clusters in the Great Lakes region, around Buffalo, Ithaca, and Rochester. C) 45 field sites were sampled by field biologists during the 2018 field season. D) Considering all sites, much of the state was surveyed; however, areas to the west and to the north were surveyed less.

Discussion

The purpose of this study was to evaluate contributions of volunteer surveyors and iNaturalist photo submissions to the statewide pollinator survey effort. Volunteer surveyors and iNaturalist users added a great deal to data collected by field biologists. iNaturalist users tended to document more charismatic species than both volunteer surveyors and field biologists. Those species tend to be easier to take photos of and identify in photographs (e.g. *Bombus impatiens*).

Field biologists were sent to random locations within protected land, with an attempt to be spatially balanced within ecoregions. Volunteer surveyors and iNaturalist users appeared to be distributing sampling efforts nonrandomly. For example, in the southern NYS region, sites that field biologists were sent to were in the lower portion, near Orange and Rockland counties (Fig. 3.1C). The volunteer surveyors sampled in the upper portion near Albany and Columbia counties (Fig. 3.1A). Together, each participating group provided a thorough survey of that region of NYS (Fig 3.1D). Furthermore, the 2018 field season was the first of three years; thus, the sampling gets balanced geographically over the coming field seasons.

Volunteer surveyors and iNaturalist users both added unique taxa to the study, thereby increasing the number of species detected for the study. iNaturalist users contributed many of the unique moth and beetle species. Moths and beetles are both easy to take pictures of, and easier to identify by pictures. Field biologists contributed the greatest number of unique fly and bee species to the study. Bee and fly species are more difficult to identify in pictures, a voucher specimen is most often required to make a definitive identification. This is especially true for groups like *Andrena* spp. and many flies in the family Syrphidae. Field biologists collected beetle and moth species, but these data were unavailable at the time that this manuscript was being written.

Lasioglossum was the most common pollinator recorded by both volunteer surveyors and field biologists. *Lasioglossum* are small bees, easily overlooked by untrained individuals, and thus more commonly detected using different trapping methods, such as passive bowl traps, but these bees were also caught in nets. iNaturalist volunteers recorded *Bombus impatiens* Cresson, 1863 and *Apis mellifera* L. most frequently. This is expected, since those species are larger and more abundant and easier to document with a camera. The trend of identifying larger charismatic fauna has been seen in other digital community science projects, e.g. Snapshot Serengeti (Kosmala et al. 2016, Swanson et al. 2016). Volunteers for that project were better at identifying iconic mammals (e.g. giraffes, zebras) than identifying lesser known species, e.g. aardwolves, and less distinguishable antelope species (Kremen et al. 2011, Swanson et al. 2016). Additionally, field biologists and the community scientists who attended workshops were asked to avoid collecting honey bees, which were not a taxon of conservation interest. This resulted in field biologists and volunteer surveyors collecting less honey bees. Furthermore, honey bees and bumble bees tend to get a lot of media attention, thus, they can be a focus in cities.

Volunteer surveyors and iNaturalist users documented similar numbers of unique taxa compared to field biologists. Volunteer surveyors used the same field sampling methods as the field biologists, thus, it would make sense that they were collecting similar, less charismatic species as field biologists. Fore et al. (2001) compared data collected between volunteers and biologists, and found ~90% of the variation in their ANOVA models was attributed to differences among sampling sites, not between biologists and volunteers. Kremen et al. (2011) found a strong positive correlation between observational data only collected by volunteers and both netting, and bowl-trapping data only collected by biologists. This suggested that data

collected by volunteers could accurately represent trends in pollinator guild composition, as well as abundance and species richness.

Combining passive traps (bowls) with active capture (nets) allowed field collectors to find more cryptic or rare species that would be harder to see while observing and taking pictures (Kremen et al. 2011). With field surveys, community scientists and field biologists were conservative with collections, i.e. they tried to collect only one representative from each species. This is opposed to iNaturalist users who were documenting species by photos, so causing mortality of insects was not a constraint. However, photographic submissions cannot substitute for abundance, and care must be taken with assuming documentation of particular species. Users can upload pictures of the same individual multiple times and call it more than one observation, thereby inflating numbers and causing issues with analyses. This illustrates that conducting field surveys adds value to results rather than relying only on observational photos. Another problem with relying on iNaturalist users to document rarity and commonness of species is that, species which are easy to identify could seem more common than they actually are, simply because they can be readily identified in photographs.

Locations where iNaturalist users were taking pictures were generally clustered near cities. Volunteer surveyors visited some less accessible areas to sample but were also close to cities. Field biologists visited mostly remote and rural locations to sample. Since volunteer surveyors visited more sites in protected areas with conservation efforts implemented and used a standardized protocol to sample, they had a higher chance of collecting rare and cryptic species. Moreover, urban areas, such as NYC, can support a diverse pollinator guild; however, this is affected by the quality of plants available to them. Other researchers have documented pollinator guild composition changes along an urbanization gradient (Bates et al. 2011), many iNaturalist

users were documenting species along a similar urbanization gradient. This urbanization gradient might explain many of the moth species iNaturalist users documented as many people plant showy, garden flowers to attract pollinators to their backyards. Although many bee, fly, and moth species were documented in and around NYC, mostly common, widespread taxa were being submitted (e.g. honey bees, carpenter bees, *Bombus impatiens* Cresson, 1863).

Sixty people attended at least one workshop training. The most attended workshops were in Wyoming county (Western NY) and in Franklin county (Northern Appalachian region). Interestingly, those two regions had the least number of visits by volunteer surveyors and the least number of photographic submissions from iNaturalist users. Much of the Adirondack region can be essentially inaccessible, making it less desirable for a volunteer to sample. Additionally, there were four workshops held around the state, which meant that some volunteers needed to travel a great distance to attend one. Thus, many of these volunteers were more likely to go back to where they live and document pollinators there. Since many iNaturalist points were clustered around cities, and highways, this indicates users didn't necessarily go far from home to document pollinators. This clustering can be problematic; however, it is something that can be avoided by talking to volunteers at workshops. Talking to volunteers about the importance of reaching the whole state and motivating them to go to more remote places may help cover more area in the future. Additionally, in the following years of this project these workshops will be held in different areas around the state. Thus, would reach more people in different communities.

This study illustrates the importance of conducting biological fieldwork and using volunteer surveyors and digital participants as a complement. Field biologists can visit remote, less accessible sites, while volunteers can provide data from more urban easily accessible places.

Our data indicate volunteers collected valuable species data; thus, involving volunteers can supplement and extend the scale of the study.

The future of community science

Integrating conservation biology research and the public is a good model towards promoting environmental literacy and is essential to the longevity of conservation efforts (Brewer 2002). Furthermore, projects, such as iNaturalist, are useful for obtaining data from urbanized or private locations. This project illustrates volunteers, both observational and specimen based, can collect valuable data, especially in urbanized areas. As a complement to each other, both volunteer surveyors and iNaturalist users together with field biologists were able to reach much of NYS.

Chapter 4: Conclusions

Human driven activities have irreversibly changed large portions of the earth's surface in pervasive ways (Defries et al. 2004). Habitat fragmentation and urbanization are thought to be some of the biggest threats to pollinators around the world (Potts et al. 2010, Lebuhn et al. 2013, Vanbergen et al. 2013, Vanbergen 2014, Goulson et al. 2015, Gezon et al. 2016). Agricultural intensification with pesticide and herbicide application having lethal and sublethal long term effects on pollinators (Kremen et al. 2002, Foley et al. 2005, Potts et al. 2010, Ollerton et al. 2014, Grab et al. 2019) lead to overall declines in certain species (Potts et al. 2010, Schweiger et al. 2010). Since we heavily depend on pollinator services, this in turn affects us. Moreover, lower quality pollination services have been shown to cause a cascading effect on seed dispersal and seed predation, leading to overall lower plant reproduction (Didham et al. 2007, Tylianakis et al. 2008, Grab et al. 2019).

Information on environmental factors predicting pollinator richness can help better inform land managers on best policies and practices. For example, keeping protected land protected and not allowing people to visit certain areas at times of year when pollinators are known to be foraging more may help increase pollinator species richness. This information is crucial to protect pollinating insect species in decline. There are not a lot of data on habitat variables associated with native pollinating species and to protect just one species would not necessarily be economically feasible. Thus, finding out which habitats have the most species and protecting those habitats would be more efficient (Yagerman 1990, Bloomgarden 1995). However, these habitats are part of an integrated landscape and most of those species rich habitats were near forests and wetlands. Which indicates that these pollinators still require habitat heterogeneity to thrive. Thus, if protected land is kept protected, species should thrive. Bates et al. (2011) found that pollinator guild composition changes along an urbanization

gradient, which may illustrate the benefit of management plans that are carried out on protected lands.

Results from this study show that floral abundance and richness were the best predictors of pollinator species richness, which supports what has been found in past research. Potts et al. (2003) found that ~40% of the variation found in bee guild composition was due to floral community characteristics, which supported the notable increase in pollinator species richness and floral richness and abundance in June. Research in protected areas show notable peaks in abundance and species diversity that corresponded with flowering plant blooming patterns found in late spring and summer (Mackenzie and Eickwort 1996, Giles and Ascher 2006).

However, it was difficult to know if ecoregion really affected pollinator species richness, because not every ecoregion was sampled every month and the number of sites was not balanced across months. It would have been easier to tease apart certain factors if the timing of sampling had been more carefully chosen. To a lesser degree, this was seen with habitat types. For example, the only habitat type that was found at almost every site was the forest; every other habitat type was less common. Additionally, having bonus habitat types at sites posed a problem with pseudo-replication and perhaps those transects should have been omitted from analysis.

Some things that I did do differently in the second year compared to the first year of fieldwork, was that I was less conservative with honey bee and the bumble bee (*Bombus impatiens*) collection. I later learned that many other, important species of bees look very similar to these species, and by not collecting them, I could be missing important species documentations. Thus, in the second year of collecting, if I saw them, I collected them.

Many long-term ecological monitoring projects rely on community science volunteers to collect data (Conrad and Hilchey 2011). Results from this project indicate that by incorporating

community scientists, a much broader scope of pollinators across NYS are assessed in one field season, i.e. volunteers do facilitate temporal and geographical expansion of data collection. However, there were still areas of the state that volunteers did not visit, which illustrates the importance of using field biologists to conduct surveys and having data from volunteer surveyors and digital participants as a complement. For this project it would be important for the volunteer surveyors to understand how to properly identify habitat types and to label them as such. Perhaps, also to encourage them to travel to many different areas of NYS, such as different ecoregions. Additionally, by showing the volunteers where the field biologists would be sampling, they can focus their efforts in different areas of the state.

Increasing the number of sites visited was not the only reason to involving community science volunteers. Being able to foster awareness and educate the public about pollinators in tandem was also a major part of this project. Getting people involved in conservation research is a very good way to also spread awareness and educate (Brewer 2006). By volunteering with this project, community scientists learn about many of the pollinator species that NYS is home to, and learn about the habitats that they can be found in. The more people know about a group of species, the more they will want to protect them. Integrating conservation biology research and the public inspires people to take action and is probably more meaningful in the long run than just solely focusing on the research (Brewer 2006).

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APPENDICES

Appendix 1. Sites visited from 13-May to 20-August of 2018

Sites visited	Date visited
Great Lakes	
Genesee	
Oak Orchard Wildlife Management Area	28-June
Jefferson	
Wellesley Island State Park	7-June
Livingston	
Twin Cedars Environmental Area	8-June
Monroe	
Thousand Acre Swamp Preserve	15-June
Mendon Ponds Park	15-August
Oneida	
Penn Mountain State Forest	26-July
Onondaga	
Green Lakes State Park	13-May
Ontario	
Hemlock – Canadice State Forest	17-May
Schuyler	
Finger Lakes National Forest	12-June
Wayne	
Lake Shore Marshes Wildlife Management Area	15-May
High Allegheny Plateau	
Cattaraugus	
Salamanca Public Utilities reservoir	25-June
Chenango	
Pharsalia Wildlife Management Area	11-June
Delaware	
Delaware Wild Forest	18-July
Tompkins	
Connecticut Hill Wildlife Management Area	14-June
Lower New England	
Orange	
Warwick State Forest	29-May
Harriman State Park	19-July
Rockland	
Kakiat County Park	30-May
Westchester	
Teatown Lake Reservation	31-May
Rockerfeller State Park	25-May
North Atlantic Coast	

Suffolk		
Otis Pike Preserve		22-May
Gardiner County Park		23-May
Sunken Meadow State Park		24-May
<hr/>		
Northern Appalachian		
Clinton		
Taylor Pond Wild Forest		20-June
Essex		
Vanderwhacker Mountain Wild Forest		10-July
Franklin		
Debar Mountain Wild Forest		21-June
Deer River State Forest		23-July
Debar Mountain Wild Forest		8-August
Hamilton		
Wilcox Lake Wild Forest		2-August
Siamese Ponds Wilderness Area		11-July
Raquette Lake State Park		9-July
Silver Lake Wilderness Area		12-July
Herkimer		
Fulton Chain Wild Forest		19-June
Lewis		
46-Corners Management Area		6-August
<hr/>		
St. Lawrence/Champlain Valley		
Clinton		
Ausable Marsh Wildlife Management Area		24-July
Essex		
Boquet River Nature Preserve		1-August
Jefferson		
Fort Drum Training Area 14F		3-July
Chaumont Barrens Preserve		16-July
Fort Drum Training Area 13A		2-July
St. Lawrence		
Glenmeal State Forest		9-August
Buckton State Forest		11-August
Buckton State Forest		10-August
<hr/>		
Western Allegheny Plateau		
Chautauqua		
Hatch Creek State Forest		26-June
Boutwell Hill State Forest		29-June
Whalen Memorial State Forest		20-August
North Harmony State Forest		19-August

Appendix 2. List and counts of pollinator species found during study.

Taxonomic grouping	Count of Species
Diptera	159
Asilidae	15
<i>Laphria</i>	15
<i>Laphria sericea</i>	14
<i>Laphria sericeus</i> ^o	1
Bombyliidae	5
<i>Bombylius</i>	2
<i>Bombylius major</i> *•	2
<i>Villa</i>	2
<i>Villa modesta</i> •	1
<i>Villa sp.</i> •	1
<i>Xenox</i>	1
<i>Xenox tigrinus</i> •	1
Conopidae	2
<i>Physocephala</i>	2
<i>Physocephala tibialis</i> †•	2
Syrphidae	137
<i>Anasimyia</i>	1
<i>Anasimyia anausis</i> † ^o	1
<i>Blera</i>	4
<i>Blera badia</i> *†•	1
<i>Blera nigra</i> *†•	3
<i>Chalcosyrphus</i>	13
<i>Chalcosyrphus anthreas</i> *† ^o	1
<i>Chalcosyrphus chalybeus</i> *† ^o	2
<i>Chalcosyrphus nemorum</i> * ^o	6
<i>Chalcosyrphus piger</i> * ^o	2
<i>Chalcosyrphus vecors</i> *†•	2
<i>Cheilosia</i>	1
<i>Cheilosia yukonensis</i> †•	1
<i>Chrysotoxum</i>	1
<i>Chrysotoxum flavifrons</i> †•	1
<i>Copestylum</i>	1
<i>Copestylum vesicularium</i> ^o	1
<i>Dasysyrphus</i>	1
<i>Dasysyrphus venustus</i> †•	1
<i>Eristalis</i>	8
<i>Eristalis arbustorum</i> •	2
<i>Eristalis flavipes</i>	5
<i>Eristalis transversa</i> •	1
<i>Eupeodes</i>	1

<i>Eupeodes americanus/pomus</i> •	1
<i>Eurimyia</i>	2
<i>Eurimyia stipata</i> †•	2
<i>Helophilus</i>	1
<i>Helophilus fasciata</i> •	1
<i>Mallota</i>	6
<i>Mallota bautius</i> *•	2
<i>Mallota posticata</i> *•	4
<i>Melanostoma</i>	1
<i>Melanostoma mellinum</i> †•	1
<i>Meliscaeva</i>	1
<i>Meliscaeva cinctella</i> †•	1
<i>Merodon</i>	2
<i>Merodon equestris</i> •	2
<i>Microdon</i>	1
<i>Microdon ruficrus</i> †°	1
<i>Orthonevra</i>	2
<i>Orthonevra pictipennis</i> †°	2
<i>Parasyrphus</i>	1
<i>Parasyrphus relictus</i> †•	1
<i>Parhelophilus</i>	1
<i>Parhelophilus laetus</i> •	1
<i>Pipiza</i>	1
<i>Pipiza nigripilosa</i> †•	1
<i>Platycheirus</i>	2
<i>Platycheirus scambus</i> †•	1
<i>Platycheirus</i> spp.•	1
<i>Sericomyia</i>	8
<i>Sericomyia chrysotoxoides</i>	8
<i>Somula</i>	2
<i>Somula decora</i> *	2
<i>Sphegina</i>	1
<i>Sphegina keeniana</i> *†•	1
<i>Spilomyia</i>	4
<i>Spilomyia fusca</i> *•	4
<i>Syritta</i>	2
<i>Syritta pipiens</i> •	2
<i>Syrphus</i>	2
<i>Syrphus ribesii</i> †	2
<i>Temnostoma</i>	3
<i>Temnostoma balyras</i> *	3
<i>Toxomerus</i>	53
<i>Toxomerus geminatus</i>	42
<i>Toxomerus marginatus</i>	10

<i>Toxomerus politus</i> •	1
<i>Tropidia</i>	1
<i>Tropidia quadrata</i> †•	1
<i>Xanthogramma</i>	1
<i>Xanthogramma flavipes</i> *†•	1
<i>Xylota</i>	8
<i>Xylota confusa</i> *†°	1
<i>Xylota hinei</i> *†	3
<i>Xylota ouelleti</i> *†•	1
<i>Xylota segnis</i> *†•	1
<i>Xylota subfasciata</i> *†°	2
Hymenoptera	1272
Andrenidae	122
<i>Andrena</i>	100
<i>Andrena algida</i> †°	1
<i>Andrena carlini</i> *	7
<i>Andrena carolina</i> †•	1
<i>Andrena crataegi</i> *•	2
<i>Andrena cressonii</i> •	4
<i>Andrena distans</i> *†°	3
<i>Andrena heraclei</i> †•	2
<i>Andrena hippotes</i> †•	2
<i>Andrena imitatrix</i> †•	1
<i>Andrena mandibularis</i> •	1
<i>Andrena milwaukeensis</i> †•	4
<i>Andrena nasonii</i>	11
<i>Andrena nivalis</i> †•	3
<i>Andrena perplexa</i> †•	1
<i>Andrena personata</i> †	2
<i>Andrena pruni</i> †	6
<i>Andrena robertsonii</i> †	3
<i>Andrena rufosignata</i> †•	1
<i>Andrena rugosa</i> †	5
<i>Andrena</i> spp.	26
<i>Andrena spireana</i> †•	3
<i>Andrena thaspiae</i> •	2
<i>Andrena wilkella</i>	9
<i>Calliopsis</i>	22
<i>Calliopsis andreniformis</i> *°	22
Apidae	359
<i>Anthophora</i>	9
<i>Anthophora furcata</i> †	9
<i>Apis</i>	20
<i>Apis mellifera</i>	20

<i>Bombus</i>	101
<i>Bombus bimaculatus</i>	8
<i>Bombus borealis</i> *•	3
<i>Bombus fervidus</i> *°	1
<i>Bombus griseocollis</i>	8
<i>Bombus impatiens</i>	38
<i>Bombus perplexus</i> •	4
<i>Bombus rufocinctus</i> °	1
<i>Bombus sandersoni</i> •	6
<i>Bombus sp.</i> •	2
<i>Bombus ternarius</i> •	2
<i>Bombus terricola</i> *	2
<i>Bombus vagans</i>	26
<i>Ceratina</i>	167
<i>Ceratina calcarata</i>	80
<i>Ceratina dupla</i>	28
<i>Ceratina mikmaqi</i>	36
<i>Ceratina strenua</i> °	23
<i>Melissodes</i>	6
<i>Melissodes subillata</i>	6
<i>Nomada</i>	56
<i>Nomada spp.</i> †	56
Colletidae	27
<i>Colletes</i>	2
<i>Colletes nudus</i> †•	1
<i>Colletes thoracicus</i> •	1
<i>Hylaeus</i>	25
<i>Hylaeus affinis</i>	10
<i>Hylaeus annulatus</i> °	2
<i>Hylaeus mesillae</i>	4
<i>Hylaeus modestus</i>	8
<i>Hylaeus saniculae</i> °	1
Halictidae	683
<i>Agapostemon</i>	29
<i>Agapostemon sericeus</i>	6
<i>Agapostemon texanus</i> †•	1
<i>Agapostemon virescens</i>	22
<i>Augochlora</i>	49
<i>Augochlora pura</i> •	49
<i>Augochlorella</i>	116
<i>Augochlorella aurata</i>	114
<i>Augochlorella persimilis</i> †°	2
<i>Augochloropsis</i>	7
<i>Augochloropsis metallica</i>	7

<i>Halictus</i>	48
<i>Halictus confuses</i>	9
<i>Halictus ligatus</i>	34
<i>Halictus rubicundus</i>	5
<i>Lasioglossum</i>	424
<i>Lasioglossum coriaceum</i>	35
<i>Lasioglossum (Dialictus spp)</i>	269
<i>Lasioglossum (Evyllaesus spp)</i>	9
<i>Lasioglossum leucozonium</i>	111
<i>Sphecodes</i>	10
<i>Sphecodes spp.</i>	10
Megachilidae	81
<i>Heriades</i>	3
<i>Heriades leavitti</i> †•	2
<i>Heriadesv ariolosa</i> †•	1
<i>Hoplitis</i>	20
<i>Hoplitis pilosifrons</i> °	1
<i>Hoplitis producta</i> †°	11
<i>Hoplitis spoliata</i> †	8
<i>Megachile</i>	20
<i>Megachile centuncularis</i> °	1
<i>Megachile coquilletti</i> †°	1
<i>Megachile frigida</i> •	1
<i>Megachile inermis</i> *•	1
<i>Megachile lapponica</i> •	1
<i>Megachile latimanus</i> *°	1
<i>Megachile mucida</i> †•	2
<i>Megachile relativa</i> *	12
<i>Osmia</i>	38
<i>Osmia albiventris</i> †•	1
<i>Osmia bucephala</i> °	2
<i>Osmia cornifrons</i>	11
<i>Osmia distincta</i> †°	1
<i>Osmia felti</i> *†•	1
<i>Osmia inspergens</i> †•	1
<i>Osmia pumila</i> †	19
<i>Osmia simillina</i> †°	1
<i>Osmia taurus</i> °	1
Grand Total	1431

* Indicates species in need of conservation attention according to NYNHP and Bartomeus et al. 2013a

† Indicates unique species only found by this team

• Indicates a species only found by sweep-netting

° Indicates a species only found with bowl traps

Appendix 3. List and counts of plant taxa found in 45 study sites in NYS.

Taxonomic Grouping	No. Sites Present	Counts of species
Alismatales	3	9
Alismataceae	3	9
<i>Sagittaria latifolia</i> Willd. (broadleaf arrowhead)	3	9
Apiales	18	538
Apiaceae	17	523
<i>Daucus carota</i> L. (Queen Anne's lace)	16	493
<i>Pastinaca sativa</i> L. (parsnip)	1	30
Araliaceae	1	15
<i>Panax trifolius</i> L. (dwarf ginseng)	1	15
Asparagales	19	183
Asparagaceae	12	152
<i>Maianthemum racemosum</i> (L.) Link (false Solomon's seal)	1	7
<i>Scilloideae</i> spp. Miller (grape hyacinth)	11	145
Asphodelaceae	2	15
<i>Hemerocallis fulva</i> (L.) L. (orange day-lily)	2	15
Iridaceae	3	12
<i>Iris</i> spp. L., 1753	1	5
<i>Sisyrinchium</i> spp. L. (blue-eyed grass)	2	7
Orchidaceae	2	4
<i>Goodyera pubescens</i> (Willd.) R.Br. (downy rattlesnake plantain)	1	3
<i>Pogonia ophioglossoides</i> (L.) Ker Gawl. (snakemouth orchid)	1	1
Asterales	25	1393
Asteraceae	25	1393
<i>Arctium</i> spp. L., 1753 (burdock)	1	4
<i>Bellis perinnus</i> (L.) (common daisy)	25	280
<i>Cichorium intybus</i> (L.) (chicory)	4	153
<i>Cirsium</i> spp. Mill. (thistle)	10	147
<i>Echinacea purpurea</i> (L.) Moench (purple coneflower)	7	83
<i>Krigia virginica</i> (L.) Willd (dwarf dandelion)	1	40
<i>Lapsana communis</i> (L.) (nipplewort)	5	105
<i>Rudbeckia. Hirta</i> (L.) (black-eyed Susan)	7	40
<i>Solidago</i> spp. L., 1753 (goldenrod)	12	288
<i>Taraxacum officinale</i> F.H. Wigg. (dandelion)	20	253
Boraginales	2	46
Boraginaceae	2	46
<i>Myosotis scorpioides</i> L. (forget-me-not)	2	46
Brassicales	21	785
Brassicaceae	21	785

<i>Alliaria petiolata</i> (M. Bieb.) Cavara (garlic mustard)	20	782
<i>Hasperis matronalis</i> L. (dame's rocket)	1	3
Caryophyllales	26	733
Caryophyllaceae	22	723
<i>Dianthus</i> spp. L. (grass pink)	3	21
<i>Spergularia ruba</i> (L.) C.Presi (red sandspur)	1	5
<i>Stellaria media</i> (L.) Vill. (chickweed)	18	697
Montiaceae	2	4
<i>Claytonia virginica</i> L. (spring beauty)	2	4
Polygonaceae	2	6
<i>Persicaria virginiana</i> (L.) Gaertn. (jumpseed)	2	6
Cornales	6	98
Cornaceae	6	98
<i>Cornus canadensis</i> L. (creeping dogwood)	6	98
Dipsacales	3	34
Caprifoliaceae	3	34
<i>Lonicera</i> spp. L. (honeysuckle)	3	34
Ericales	16	734
Balsaminaceae	7	354
<i>Impatiens capensis</i> Meerb. (orange jewelweed)	7	354
Ericaceae	5	162
<i>Gaultheria procumbens</i> L. (eastern teaberry)	2	6
<i>Vaccinium</i> spp. L. (blueberry)	3	156
Polemoniaceae	2	213
<i>Phlox</i> spp. L.	2	213
Sarraceniaceae	2	5
<i>Sarracenia</i> spp. L. (pitcher plant)	2	5
Fabales	42	2052
Fabaceae	42	2052
<i>Lathyrus</i> spp. L. (sweetpea)	2	113
<i>Melilotus officinalis</i> (L.) Pall. (sweet clover)	42	965
<i>Trifolium hybridum</i> L. (alsike clover)	42	974
Gentianales	8	23
Apocynaceae	6	20
<i>Asclepias</i> spp. L. (milkweed)	6	20
Gentianaceae	2	3
<i>Centaurium erythraea</i> Rafn. (European centaury)	2	3
Geraniales	6	19
Geraniaceae	6	19
<i>Geranium</i> spp. L.	6	19
Lamiales	22	841
Lamiaceae	6	56
<i>Mentha</i> spp. L. (mint)	2	3
<i>Monarda</i> spp. L. (bee balm)	1	17

<i>Physostegia virginiana</i> (L.) Benth. (obedient plant)	3	36
Orobanchaceae	1	1
<i>Castilleja</i> spp. Mutis. (Indian paintbrush)	1	1
Plantaginaceae	5	137
<i>Linaria vulgaris</i> Mill. (common toadflax)	2	104
<i>Nuttallanthus canadensis</i> (L.) D.A.Sutton (blue toadflax)	1	8
<i>Veronica officinalis</i> L. (common gypsyweed)	2	25
Scrophulariaceae	16	591
<i>Verbascum</i> spp. L. (mullein)	16	591
Verbenaceae	2	56
<i>Verbena hastata</i> L. (blue vervain)	2	56
Liliales	7	110
Colchicaceae	1	14
<i>Uvularia grandiflora</i> Sm. (large flowered bellwort)	1	14
Liliaceae	7	43
<i>Lilium</i> spp. L. (lily)	2	26
<i>Streptopus</i> spp. Michx. (rosybell)	2	6
<i>Tulipa</i> spp. L. (tulip)	3	11
Melanthiaceae	3	53
<i>Trillium</i> spp. L.	3	53
Malpighiales	16	429
Violaceae	16	429
<i>Viola</i> spp. L. (violet)	16	429
Myrtales	11	378
Lythraceae	5	147
<i>Lythrum salicaria</i> L. (purple loosestrife)	5	147
Onagraceae	6	231
<i>Chamaenerion angustifolium</i> (L.) Scop. (fireweed)	5	222
<i>Ludwigia peploides</i> (Kunth) P.H. Raven (floating primrose)	1	9
Ranunculales	45	1478
Berberidaceae	6	9
<i>Podophyllum peltatum</i> L. (may apple)	6	9
Papaveraceae	3	50
<i>Sanguinaria canadensis</i> L. (bloodroot)	3	50
Ranunculaceae	45	1419
<i>Actaea ruba</i> (Ait.) Willd. (red baneberry)	1	12
<i>Anemone hepatica</i> L. (kidneywort)	1	7
<i>Aquilegia canadensis</i> L. (red columbine)	2	54
<i>Caltha palustris</i> L. (marsh marigold)	2	41
<i>Ranunculus</i> spp. L. (buttercup)	45	1305
Rosales	40	1100
Rosaceae	40	1100
<i>Argentina anserina</i> (L.) Rydb. (silverweed)	1	3
<i>Fragaria</i> spp. L. (strawberry)	7	89

<i>Geum aleppicum</i> Jacq. (yellow avens)	1	3
<i>Rosa multiflora</i> Thumb. (multiflora rose)	14	308
<i>Rubus</i> spp. L. (raspberry)	12	320
<i>Spiraea ulmaria</i> (L.) Maxim. (meadowsweet)	19	377
Saxifragales	7	26
Crassulaceae	7	26
<i>Hylotelephium telephioides</i> (Michx.) H. Ohba (Allegheny stonecrop)	7	26
Solanales	1	12
Convolvulaceae	1	12
<i>Ipomoea</i> spp. L., 1753 (morning glory)	1	12
Vitales	3	7
Vitaceae	3	7
<i>Vitis</i> spp. L. (wild grape)	3	7
Grand Total	45	11,028

Appendix 4. List and counts of pollinator species collected by volunteer surveyors from 13-May to 16-Aug of 2018 across NYS.

Taxonomic grouping	Count of species
Coleoptera	11
Cerambycidae	11
<i>Analeptura</i>	
<i>Analeptura lineola</i> *	1
<i>Brachyleptura</i>	
<i>Brachyleptura vagans</i> *†	1
<i>Gaurotes</i>	
<i>Gaurotes cyanipennis</i>	1
<i>Oberea</i>	
<i>Oberea praelonga</i> †	1
<i>Stictoleptura</i>	
<i>Stictoleptura canadensis</i> *	2
<i>Strangulepta</i>	
<i>Strangulepta abbreviate</i> *	2
<i>Trigonarthris</i>	
<i>Trigonarthris proxima</i> *†	1
<i>Typocerus</i>	
<i>Typocerus deceptus</i> *†	1
<i>Typocerus velutinus</i> *	1
Diptera	39
Bombyliidae	3
<i>Bombylius</i>	
<i>Bombylius major</i> *	1
<i>Villa</i>	
<i>Villa modesta</i>	1
<i>Xenox</i>	
<i>Xenox tigrinus</i>	1
Syrphidae	36
<i>Chalcosyrphus</i>	
<i>Chalcosyrphus nemorum</i> *	1
<i>Chalcosyrphus piger</i> *	1
<i>Cheilosia</i>	
<i>Cheilosia pallipes</i> †	1
<i>Epistrophe</i>	
<i>Epistrophe grossulariae</i>	2
<i>Eristalis</i>	
<i>Eristalis arbustorum</i>	2
<i>Eristalis dimidiata</i>	2
<i>Eristalis flavipes</i>	1
<i>Eristalis anthophorina</i> †	1

<i>Eumerus</i>	
<i>Eumerus strigatus</i> †	1
<i>Eupeodes</i>	
<i>Eupeodes americanus</i>	1
<i>Myolepta</i>	
<i>Myolepta strigilata</i> *†	1
<i>Orthonevra</i>	
<i>Orthonevra anniae</i> †	1
<i>Parhelophilus</i>	
<i>Parhelophilus laetus</i>	1
<i>Rhingia</i>	
<i>Rhingia nasica</i>	1
<i>Sericomyia</i>	
<i>Sericomyia chrysotoxoides</i>	1
<i>Sericomyia lata</i> †	3
<i>Somula</i>	
<i>Somula decora</i>	1
<i>Spilomyia</i>	
<i>Spilomyia fusca</i> *	2
<i>Syrphus</i>	
<i>Syrphus torvus</i> †	2
<i>Temnostoma</i>	
<i>Temnostoma balyras</i> *	1
<i>Toxomerus</i>	
<i>Toxomerus geminatus</i>	4
<i>Toxomerus marginatus</i>	2
<i>Xylota</i>	
<i>Xylota annulifera</i> *†	1
<i>Xylota quadrimaculata</i> *†	1
Hymenoptera	266
Andrenidae	32
<i>Andrena</i>	32
<i>Andrena carlini</i> *	1
<i>Andrena crataegi</i> *	2
<i>Andrena cressonii</i>	1
<i>Andrena hippos</i>	1
<i>Andrena mandibularis</i>	1
<i>Andrena nasonii</i>	1
<i>Andrena nubecula</i>	1
<i>Andrena scripta</i> †	1
<i>Andrena</i> sp.	19
<i>Andrena thaspis</i>	1
<i>Andrena wilkella</i>	3

Apidae	98
<i>Anthophora</i>	4
<i>Anthophora terminalis</i>	4
<i>Apis</i>	5
<i>Apis mellifera</i>	5
<i>Bombus</i>	63
<i>Bombus bimaculatus</i>	5
<i>Bombus borealis</i> *	6
<i>Bombus fervidus</i> *	2
<i>Bombus flavidus</i> *†	2
<i>Bombus griseocollis</i>	5
<i>Bombus impatiens</i>	13
<i>Bombus perplexus</i>	7
<i>Bombus sandersoni</i>	1
<i>Bombus ternarius</i>	4
<i>Bombus terricola</i> *	4
<i>Bombus vagans</i>	14
<i>Ceratina</i>	19
<i>Ceratina calcarata</i>	10
<i>Ceratina dupla</i>	4
<i>Ceratina mikmaqi</i>	5
<i>Epeolus</i>	1
<i>Epeolus scutellaris</i>	1
<i>Melissodes</i>	5
<i>Melissodes bidentis</i> †	1
<i>Melissodes bimaculata</i>	1
<i>Melissodes subillata</i>	3
<i>Triepeolus</i>	1
<i>Triepeolus</i> spp.	1
Colletidae	13
<i>Hylaeus</i>	13
<i>Hylaeus affinis</i>	1
<i>Hylaeus annulatus</i>	3
<i>Hylaeus modestus</i>	9
Halictidae	85
<i>Agapostemon</i>	6
<i>Agapostemon sericeus</i>	1
<i>Agapostemon virescens</i>	5
<i>Augochlora</i>	16
<i>Augochlora pura</i>	16
<i>Augochlorella</i>	3
<i>Augochlorella aurata</i>	3
<i>Halictus</i>	19
<i>Halictus confusus</i>	1

<i>Halictus ligatus</i>	14
<i>Halictus poeyi</i> †	2
<i>Halictus rubicundus</i>	1
<i>Halictus</i> spp.	1
<i>Lasioglossum</i>	40
<i>Lasioglossum coeruleum</i>	2
<i>Lasioglossum (Dialictus)</i>	33
<i>Lasioglossum leucozonium</i>	1
<i>Lasioglossum zonulum</i> †	4
<i>Sphecodes</i>	1
<i>Sphecodes</i> spp.	1
Megachilidae	37
<i>Anthidium</i>	4
<i>Anthidium manicatum</i>	1
<i>Anthidium oblongatum</i>	3
<i>Coelioxys</i>	1
<i>Coelioxys sayi</i>	1
<i>Hoplitis</i>	1
<i>Hoplitis pilosifrons</i>	1
<i>Megachile</i>	30
<i>Megachile campanulae</i>	2
<i>Megachile inermis</i> *	9
<i>Megachile lapponica</i>	2
<i>Megachile latimanus</i>	2
<i>Megachile mendica</i>	3
<i>Megachile montivaga</i> *†	2
<i>Megachile relativa</i> *	7
<i>Megachile sculpturalis</i>	3
<i>Osmia</i>	1
<i>Osmia taurus</i>	1
Melittidae	1
<i>Macropis</i>	1
<i>Macropis patellata</i> †	1
<hr/>	
Lepidoptera	15
Noctuidae	2
<i>Alypia</i>	2
<i>Alypia octomaculata</i> †	2
Sphingidae	3
<i>Hemaris</i>	3
<i>Hemaris thysbe</i> *	3
<hr/>	
Grand Total	337

* Indicates species in need of conservation attention according to NYNHP and Bartomeus et al. 2013a

† Indicates unique taxa only found by these volunteers

Appendix 5. List and counts of pollinator species found by iNaturalist users from 13-May to 20-Aug of 2018

Taxonomic grouping	Count of species
Coleoptera	85
Cerambycidae	84
<i>Analeptura</i>	9
<i>Analeptura lineola</i> *	9
<i>Anthophylax</i>	4
<i>Anthophylax attenuates</i> *†	2
<i>Anthophylax cyaneus</i> *†	2
<i>Brachyleptura</i>	2
<i>Brachyleptura brevis</i> †	1
<i>Brachyleptura rubrica</i> *†	1
<i>Centrodera</i>	1
<i>Centrodera decolorate</i> *†	1
<i>Evodinus</i>	4
<i>Evodinus monticola</i> *†	4
<i>Gaurotes</i>	1
<i>Gaurotes cyanipennis</i> *	1
<i>Judolia</i>	9
<i>Judolia cordifera</i> *†	9
<i>Leptorhabdium</i>	1
<i>Leptorhabdium pictum</i> *†	1
<i>Leptura</i>	2
<i>Leptura subhamata</i> *†	2
<i>Pidonia</i>	1
<i>Pidonia ruficollis</i> *†	1
<i>Stenelytrana</i>	3
<i>Stenelytrana emarginata</i> *†	3
<i>Stenocorus</i>	1
<i>Stenocorus schaumii</i> *†	1
<i>Stictoleptura</i>	2
<i>Stictoleptura canadensis</i> *	2
<i>Strangalepta</i>	6
<i>Strangalepta abbreviate</i> *	6
<i>Strangalia</i>	17
<i>Strangalia acuminata</i> *†	1
<i>Strangalia famelica</i> *†	5
<i>Strangalia luteicornis</i> *†	11
<i>Typocerus</i>	21
<i>Typocerus acuticauda</i> *†	2
<i>Typocerus lugubris</i> *†	1
<i>Typocerus velutinus</i> *	18

Scarabaeidae	1
<i>Trichiotinus</i>	1
<i>Trichiotinus assimilis</i> *†	1
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Diptera	430
Bombyliidae	6
<i>Bombylius</i>	6
<i>Bombylius major</i> *	5
<i>Bombylius pygmaeus</i> *†	1
Syrphidae	260
<i>Allograpta</i>	3
<i>Allograpta obliqua</i> †	3
<i>Ceriana</i>	1
<i>Ceriana abbreviata</i> *†	1
<i>Eristalis</i>	92
<i>Eristalis arbustorum</i>	38
<i>Eristalis dimidiata</i>	38
<i>Eristalis flavipes</i>	1
<i>Eristalis tenax</i>	16
<i>Eristalis transversa</i>	35
<i>Eupeodes</i>	1
<i>Eupeodes americanus</i>	1
<i>Lejops</i>	1
<i>Lejops curvipes</i> †	1
<i>Mallota</i>	4
<i>Mallota bautius</i> *	2
<i>Mallota posticata</i> *	2
<i>Merodon</i>	6
<i>Merodon equestris</i> †	6
<i>Milesia</i>	2
<i>Milesia virginensis</i> *†	2
<i>Sericomyia</i>	3
<i>Sericomyia chrysotoxoides</i>	1
<i>Sphaerophoria</i>	1
<i>Sphaerophoria contigua</i>	1
<i>Spilomyia</i>	7
<i>Spilomyia alcimus</i> *†	1
<i>Spilomyia fusca</i> *	4
<i>Spilomyia longicornis</i> *†	2
<i>Syritta</i>	8
<i>Syritta pipiens</i>	8
<i>Temnostoma</i>	2
<i>Temnostoma alternans</i> *†	1
<i>Temnostoma balyras</i> *	1
<i>Toxomerus</i>	131

<i>Toxomerus geminatus</i>	51
<i>Toxomerus marginatus</i>	61
<i>Toxomerus politus</i>	19
Hymenoptera	935
Andrenidae	3
<i>Andrena</i>	3
<i>Andrena hirticincta</i>	1
<i>Andrena nubecula</i>	1
<i>Andrena wilkella</i>	1
Apidae	776
<i>Anthophora</i>	1
<i>Anthophora terminalis</i>	1
<i>Apis</i>	184
<i>Apis mellifera</i>	184
<i>Bombus</i>	437
<i>Bombus bimaculatus</i>	29
<i>Bombus borealis</i> *	5
<i>Bombus citrinus</i> †	2
<i>Bombus fervidus</i> *	20
<i>Bombus griseocollis</i>	119
<i>Bombus impatiens</i>	208
<i>Bombus perplexus</i>	10
<i>Bombus rufocinctus</i>	1
<i>Bombus ternarius</i>	26
<i>Bombus terricola</i> *	7
<i>Bombus vagans</i>	10
<i>Ceratina</i>	1
<i>Ceratina calcarata</i>	1
<i>Melissodes</i>	34
<i>Melissodes bimaculatus</i>	26
<i>Melissodes desponsa</i> †	3
<i>Melissodes druriellus</i> *†	1
<i>Melissodes trinodis</i> †	4
<i>Peponapis</i>	5
<i>Peponapis pruinose</i> †	5
<i>Ptilothrix</i>	5
<i>Ptilothrix bombiformis</i> †	5
<i>Triepeolus</i>	3
<i>Triepeolus lunatus</i>	3
<i>Xylocopa</i>	106
<i>Xylocopa virginica</i> †	106
Colletidae	19
<i>Colletes</i>	9
<i>Colletes inaequalis</i> †	5

<i>Colletes simulans armatus</i> †	1
<i>Colletes thoracicus</i>	3
<i>Hylaeus</i>	10
<i>Hylaeus mesillae cressoni</i>	1
<i>Hylaeus modestus</i>	9
Halictidae	78
<i>Agapostemon</i>	21
<i>Agapostemon sericeus</i>	1
<i>Agapostemon splendens</i> †	1
<i>Agapostemon virescens</i>	19
<i>Augochlora</i>	29
<i>Augochlora pura</i>	29
<i>Augochlorella</i>	3
<i>Augochlorella aurata</i>	3
<i>Halictus</i>	22
<i>Halictus confuses</i>	4
<i>Halictus ligatus</i>	16
<i>Halictus rubicundus</i>	2
<i>Lasioglossum</i>	2
<i>Lasioglossum (Dialictus)</i>	1
<i>Lasioglossum nigroviride</i> †	1
Megachilidae	59
<i>Anthidiellum</i>	1
<i>Anthidiellum notatum</i> †	1
<i>Anthidium</i>	15
<i>Anthidium manicatum</i>	15
<i>Coelioxys</i>	3
<i>Coelioxys coturnix</i> †	1
<i>Coelioxys modestus</i> †	1
<i>Coelioxys octodentatus</i> †	1
<i>Megachile</i>	29
<i>Megachile campanulae</i>	2
<i>Megachile frigida</i>	1
<i>Megachile inermis</i> *	1
<i>Megachile mendica</i>	2
<i>Megachile pugnata pugnata</i> †	3
<i>Megachile rotundata</i> †	1
<i>Megachile sculpturalis</i>	18
<i>Megachile texana</i> †	1
<i>Osmia</i>	4
<i>Osmia bucephala</i>	1
<i>Osmia cornifrons</i>	3
<i>Paranthidium</i>	5
<i>Paranthidium jugatorium</i> †	5

<i>Stelis</i>	2
<i>Stelis louisae</i> †	2
Lepidoptera	325
Noctuidae	18
<i>Schinia</i>	18
<i>Schinia arcigera</i> *†	5
<i>Schinia florida</i> *†	9
<i>Schinia rivulosa</i> *†	3
<i>Schinia trifascia</i> *†	1
Sphingidae	307
<i>Amorpha</i>	11
<i>Amorpha juglandis</i> *†	11
<i>Amphion</i>	11
<i>Amphion floridensis</i> *†	11
<i>Ceratomia</i>	27
<i>Ceratomia amyntor</i> *†	7
<i>Ceratomia undulosa</i> *†	20
<i>Darapsa</i>	23
<i>Darapsa choerilus</i> *†	4
<i>Darapsa myron</i> *†	18
<i>Darapsa versicolor</i> *†	1
<i>Deidamia</i>	10
<i>Deidamia inscriptum</i> *†	10
<i>Dolba</i>	1
<i>Dolba hyloeus</i> *†	1
<i>Eumorpha</i>	23
<i>Eumorpha pandorus</i> *†	23
<i>Hemaris</i>	82
<i>Hemaris diffinis</i> *†	32
<i>Hemaris gracilis</i> *†	1
<i>Hemaris thysbe</i> *	49
<i>Hyles</i>	4
<i>Hyles gallii</i> *†	3
<i>Hyles lineata</i> *†	1
<i>Lapara</i>	8
<i>Lapara bombycoides</i> *†	8
<i>Lintneria</i>	2
<i>Lintneria eremitus</i> *†	2
<i>Manduca</i>	8
<i>Manduca jasminearum</i> *†	1
<i>Manduca quinquemaculata</i> *†	1
<i>Manduca sexta</i> *†	6
<i>Pachysphinx</i>	12
<i>Pachysphinx modesta</i> *†	12

<i>Paonias</i>	51
<i>Paonias astylus</i> *†	4
<i>Paonias excaecata</i> *†	27
<i>Paonias myops</i> *†	20
<i>Smerinthus</i>	12
<i>Smerinthus cerisyi</i> *†	1
<i>Smerinthus jamaicensis</i> *†	11
<i>Sphecodina</i>	6
<i>Sphecodina abbottii</i> *†	6
<i>Sphinx</i>	16
<i>Sphinx chersis</i> *†	3
<i>Sphinx gordius</i> *†	1
<i>Sphinx kalmiae</i> *†	10
<i>Sphinx poecila</i> *†	2
Grand Total	1,611

* Indicates species in need of conservation attention according to NYNHP and Bartomeus et al. 2013a

† Indicates unique taxa only found by these volunteers

Curriculum vitae: Abigail Joy Jago
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Education

Master of Science in Environmental and Forest Biology: Entomology

State University of New York (SUNY) Expected graduation date: Dec 2019
College of Environmental Science and Forestry, Syracuse, NY

Bachelor of Science in Zoology

State University of New York (SUNY) at Oswego, Oswego, NY May 2017

Associate Degree in Psychology

Orange Coast Community College, Costa Mesa, CA May 2010

Research Projects

Master's Thesis – Syracuse, NY

Understanding habitat effects on pollinator guild composition in New York State and the importance of community science involvement in understanding species distribution

- Conduct state-wide surveys to look for rare and/or endangered species of pollinating insects. This project was part of a larger project with NY Natural Heritage Program/DEC. Field and lab work include collecting and taxonomically classifying insects from all major regions in New York State throughout the summer. A major part of this project was working with and training volunteer community scientists to help collect data to include in the project.

Independent Research – Oswego, NY

Comparative analysis of trace metals in the ovipositors of wood-boring sawflies (Hymenoptera)

- Compared concentrations of metals accumulated in the ovipositors of two families of sawflies (Siricidae and Xiphydriidae) using MASS spectrometry to determine if there was a difference between the groups drilling soft wood vs. hard wood tree species.

Independent Research – Oswego, NY

Trace metals in the ovipositors of wood-boring parasitoid wasps (Hymenoptera)

- Investigated the mechanisms behind the acquisition of metals in the ovipositors of parasitoid wasps *Spathius agrili* and *Spathius galinae* (Braconidae) using MASS spectrometry to aid in the development and selection of more efficient biological controls to combat the emerald ash borer.

Grants and Awards

Graduate Student Travel Grant (2018) – \$300. State University of New York College of Environmental Science and Forestry

- Entomological Society of America (ESA) North American meeting poster presentation

Scholarly and Creative Activities Committee Grant (2016) – \$1,000. State University of New York at Oswego

- *Trace Metals in the Ovipositors of Wood-Boring Parasitoid Hymenoptera*

Rise Travel Grant (2016 & 2017) – \$250. State University of New York at Oswego

- North American Symposium for Bat Research (NASBR) poster presentation
- Entomological Society of America (ESA) Eastern Branch meeting poster presentation

Publications

Sagot, M., Schoner, C., **Jago, A.**, Razik, I., Chaverri, G. (2018). The importance of group vocal behavior in roost finding. *Animal Behaviour* 142(1), 157–164.

Synergistic Activities

Research Assistant – Syracuse, NY 05/2017–08/2017

*Foraging behavior of *Tetrastichus planipennis**

- Studied foraging behavior of *Tetrastichus planipennis*, a widely used biological control agent of the invasive emerald ash borer beetle.

Research Assistant – Oswego, NY 05/2017–08/2017

*Seasonal activity of *Castor canadensis* and implications for biodiversity in an artificial pond*

- Studied behavior of beavers throughout the year by trapping them to attach transmitters and perform radio telemetry, as well as catching them on camera traps.

Research Assistant – Dominical, Costa Rica 06/2016 & 01/2017

The role of bioenergetics and cooperation in acoustic signaling in promoting strong social interactions

- Studied whether efficiency in roost search is associated with contact call production using the Spix's disc wing bat (*Thyroptera tricolor*) as a model species. This work resulted in one peer-reviewed article published and another in preparation.

Research Assistant – Oswego, NY 05/2016–08/2016

*Effects of temperature and day length on daily movements and home range of *Glaucomys volans* in the Northeastern United States*

- Studied the foraging behavior of southern flying squirrels and how these change throughout the year trapping them using Sherman traps to attach transmitters in order to perform radio telemetry.

Internship – Oswego, NY 05/2015–05/2017

Agricultural analysis & inspection – Port Authority of Oswego

- Detected fungal toxin contamination in commercially produced grain with Envirologix and Quicksan equipment. To ensure product quality, mold detection tests on wheat, soy, and corn were performed.

Internship – Oswego, NY 05/2014–08/2015

Beekeeping – Hives of Howard

- Maintained logs of hive health, tracked life stages of worker bees and honey production and monitored queen bee reproduction. Created new bee colonies by splitting established healthy colonies and adding new queens. Harvested honey from the bees. Made educational presentations about honey bee biology/behavior with live bees, at local schools and for college classes at SUNY Oswego.

Volunteer – Malaysia and Japan

01/2013–04/2013

Humane Education, Adoption & Rescue Tokushima and Langkawi Animal Shelter & Sanctuary

- Evaluated animals' health and wellness daily. Assisted in surgery of an animal patient to gain beneficial insight on animal care. Helped facilitate a catch, neuter, release program. Held meetings to educate the local community about the importance of spaying and neutering pets.

Professional Meetings

Entomological Society of America – Vancouver, B.C. Canada

11/2018

Jago, A.J., Schlesinger, M.D., White, E.L., Fierke, M.K.

Distribution and species diversity of native pollinators in New York State. *Poster.*

Quest Symposium – Oswego, NY

04/2017

Jago, A.J., Sime, K., Tomascak, P.

Comparative analysis of trace metals in the ovipositors of woodboring sawflies (Hymenoptera: Siricidae & Xiphydriidae). *Oral presentation.*

Entomological Society of America Eastern Branch – Newport, RI

03/2017

Jago, A.J., Sime, K., Tomascak, P.

Comparative analysis of trace metals in the ovipositors of wood-boring sawflies. *Poster.*

North American Society for Bat Research – San Antonio, TX

10/2016

Sagot, M., **Jago, A.J.**, Razik, I., Chaverri, G.

Being Loud Won't Help You Find Your House: Calling behavior and roost finding in *Thyroptera tricolor*. *Poster.*

Entomological Society of America – Minneapolis, MN

11/2015

Attended conference.