BUTTERFLIES AS CHARISMATIC INDICATORS: CAN STUDY OF IMPACT OF ON-FARM HABITAT ENRICHMENT ON BUTTERFLY POPULATIONS PROVIDE INSIGHT ABOUT HABITAT QUALITY FOR OTHER INSECTS?

by

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Abstract

Populations of insect pollinators have been declining precipitously across the Northern Hemisphere, due to disease, insecticide application, and habitat degradation and loss. As a result, crop pollination services are at risk, and the ecological insurance provided by biodiversity is in jeopardy. Regional efforts to combat the decline of pollinator diversity and abundance include the New York State Pollinator Protection Plan to assess regional pollinator health, strategies to enhance wild pollinator habitat, as well as on-farm habitat enhancement strategies to augment pollinator populations in and around crops. One such habitat enhancement strategy involves improving native floral resource availability, which is often positively correlated with pollinator abundance and diversity.

This study tests whether native flower plantings can enhance pollinator abundance and diversity, with emphasis on butterfly (*Papilionoidea*) abundance and diversity, by adding floral resources and land cover heterogeneity to an agricultural landscape. Butterfly abundance and diversity, in turn, were compared to species abundance and richness of other pollinator groups to determine whether they were correlated, and hence whether butterflies could serve as indicators for other pollinators. Experimental plots with two different levels of floral diversity were compared to control plots in a Native Meadow Trial involving three trial areas with three treatments each arranged in a split-plot design. All work took place at the Hudson Valley Farm Hub, a 1,200-acre organic farm complex in Hurley, NY during Summer 2018. Treatment A, a wildflower rich mix, contained 23 species of forbs and one grass. Treatment B contained only 6 forbs and a greater number of grasses. Control plots were left unseeded and allowed to revegetate from a residual agricultural weed seed bank and from the inflow of seeds from the surrounding landscape. Biweekly surveys of flower-visiting insects were conducted between May and

September 2018 and were complemented by surveys of other on-farm habitats. Both seeded treatments had multiple plants flowering throughout the study, while the control plots were dominated by Horseweed (*Erigeron canadensis)* from July – September 2018. Analyses revealed that both seeded treatments attracted significantly more butterflies, bumble bees and honey bees ($p < 0.05$) compared to the control, with Treatment A accounting for more butterflies and bumble bees than treatment B. Rank-abundance analyses indicated treatments A and B attracted similarly structured communities of butterflies compared to the control. However, the butterfly communities in all treatments were dominated by Sulphurs (Family: *Pieridae*). Bray-Curtis indices of similarity revealed that treatment A and B attracted similar butterfly communities, in contrast to controls. For the most botanically diverse treatment (A), butterfly and bumble bee visitation rates were significantly correlated with floral abundance (measured as “a floral rank”). To analyze the capacity of different flower species to attract pollinators, expected visitation rates were calculated based on the proportion of total available floral area each flower species represented over the season. Results indicate that certain flower species, such as Black Eyed Susan and White Clover attract greater than the expected number of pollinator visits throughout the majority of the field season. Other species, such as Celosia and Zinnia, attract fewer than the anticipated number of pollinator visits.

Surveys of the experimental treatments were also compared to other elements of the Farm Hub complex, each of which had unique mixes of cultivated and non-cultivated flowering species. Results from added surveys followed a similar trend: lower floral diversity was associated with lower pollinator diversity. However, their inclusion also added different pollinator species, indicating a role for environmental heterogeneity in supporting overall pollinator diversity. Diverse wildflower meadows offer one means by which land managers and farmers can increase observed pollinator abundance and diversity on agricultural lands.

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INTRODUCTION

Approximately one-fifth of butterflies and skippers in the United States and Canada are in decline (Nash 2004). Habitat loss and habitat fragmentation (Swengel and Swengel 2015; Swengel et al. 2011; Ferster and Vulinec 2010) are among the leading causes of documented declines in butterflies; habitat loss due to agricultural conversion and increased agricultural intensity are seen as the cause of drastic decreases in insect abundance and diversity (Jarvis 2017; Landis 2017). Fifteen to thirty percent of significant crop commodities, produced in New York State, require insect pollination to produce fruit or seed (USDA 2019). Preserving and enhancing pollination services provided by wild insects will require new local and on-farm pollinator management strategies.

Ecologists are working to identify, implement and evaluate land management strategies to support wild pollinators in the agricultural landscape. Like larger fauna, insects are responsive to local habitat quality and landscape variables, but at smaller scales. In the United States and abroad, work has focused on the impact of landscape diversity (Mallinger et al. 2016), flower density (Clark et al. 2007; Davis et al. 2007), and nectar quantity and quality (Barp et al. 2011) on bee and butterfly abundance and diversity. Many findings emphasize the value of native plants (M'Gonigle et al. 2016; Williams et al. 2015; Haaland et al. 2011; Isaacs et al. 2009), while others indicate that native pollinators also use exotic plants as resources, and the relationships between insects and non-native plants are continuously evolving (Ferrero et al. 2013; Shapiro 2002).

While research indicates the positive impacts of increased flower density and landscape diversity on pollinator populations, entomologists and ecologists alike describe multiple challenges. There is inherent risk in making sweeping land management generalizations for diverse insect populations (Bried 2009). However, detailed study of insect communities requires significant financial and human capital. New York State is home to hundreds of insect pollinators, and even study at the regional scale involves entomological expertise and time. In contrast, there 140 butterfly species in New York State that could serve as an accessible and visible ecological indicator to farmers and land managers. Therefore, it may be possible for farmers, land managers and interns to use butterflies as initial indicators of other flower visiting insects in on-farm habitats. There is demand for such a line of inquiry, but the work has only started in New York State.

Here, I provide a brief synopsis of research regarding declines in North American butterfly populations, New York State pollinators, pollinator response to landscape variables, native plants and habitat enhancement strategies, butterflies as ecological indicators and agriculture in New York's lower Hudson Valley Region.

Butterfly declines

There is much concern regarding butterfly population decline and fluctuation, particularly the declines of rare species that have specific habitat requirements. (National Research Council 2007). Most butterfly population studies focus on a single rare and/or charismatic species, such as the Bay Checkerspot (*Euphydryas editha bayensis*) (Ehrlich and Hanski 2004; McLaughlin et al. 2002 as cited in National Research Council 2007), the Regal Fritillary (*Speyeria idalia*) (Ferster & Vulinec 2009) and the Monarch (*Danaus plexippus*) (Gibbs et al. 2006 as cited in National Research Council 2007) as opposed to entire butterfly communities.

Recent studies took place in California (Ferster & Vulinec, 2009), Kansas and the Midwest (Swengel & Swengel 2015; Swengel et al. 2011; Gibbs et al., 2006) and Massachusetts (North American Butterfly Association 2019; Stichter 2012; Clark et al. 2007). The habitats considered by these studies differ from those of Hudson Valley agricultural lands at the focus of this study. In 2017, the New York Natural Heritage Program began surveying some targeted butterfly species in bog and high-elevation habitats in New York State in response to the NYS Pollinator Protection Plan (2016). Yet, there are limited data and analyses available regarding current status of butterflies in New York State, let alone on agricultural and semi-natural habitats that compose much of New York's rural landscape. Study of butterfly populations and conservation strategies has been limited and geographically scattered to date, and this work aims to fill these gaps.

Status of New York State pollinators

Insect communities contribute essential pollination services to approximately 15 - 30 percent of crops (DEC 2019; DEC 2016). In New York, various crops of economic and cultural significance such as apples, strawberries and squash, require insect pollination. While the managed honey bee, *Apis mellifera,* is the most commonly recognized pollinator, New York State is home to approximately 400 bee species, and numerous pollinators from other taxa, including butterflies and moths (*Lepidoptera),* flies (*Diptera*) and beetles (*Coleoptera*).

Abundant and diverse pollinator populations have been shown to increase yield and quality of New York grown crops (Grab et al. 2018; Winfree et al. 2018; Connelly et al. 2015). Given global documentation of insect declines, and the largely unknown status of New York State invertebrates, New York farmers, land managers and conservation scientists are urgently studying mechanisms to (1) support pollinator populations and prevent future declines, (2) leverage wild pollinator diversity to maintain crop production and (3) identify "habitat management strategies" for managed and wild bees and other pollinators (DEC 2016). Since 10

– 15 percent of New York State's landscape is agricultural, we need to better understand the status and behavior of wild pollinators in these habitats (USDA 2018).

Butterflies as ecological indicators

Studying the status of New York State's pollinators will involve a great deal of entomological expertise, time and financial capital. While these may not be prohibitive, leveraging butterflies as indicators provides the opportunity to expand the number of participants in pollinator studies. Compared to more diverse and morphologically similar insect groups, butterfly populations on agricultural and semi-natural habitats represent a relatively manageable group of species to learn. There are only 140 butterfly species in New York and numerous field guides exist. Butterflies are commonly identified as indicators of habitat quality due to their visibility, distinct wing markings and environmental sensitivity (Clark et al. 2007). Butterflies are a recognizable group of insects: distinct wing markings facilitate species identification by citizen scientists, students, interns, volunteers, land managers and farmers. Thus, butterflies can be leveraged as an entry point to the field of entomology. Utilizing butterflies in this on-farm insect study contributes to our understanding of the current impact of regional habitat enhancement projects on the on-farm pollinator community.

Some studies (as cited in Haaland et al. 2011 and Clark et al. 2007) suggest that butterfly abundance and diversity can be used "as a surrogate for *Hymenoptera* …" (Clark et al. 2007). If the positive correlation holds true, then visual butterfly surveys would be a significant means of making initial assessments of pollinator diversity on farm habitats. This study is partially driven by a desire to contribute to a better understanding of relationships between the abundance and diversity of butterflies and the abundance of other flower visiting insects.

Butterfly & pollinator response to local and regional variables

Pollinators are responsive to particular landscape variables (Mallinger et al. 2016; Kremen et al. 2018; Haaland et al. 2011; Isaacs et al. 2009; Davis et al, 2007; Fleishman et al. 2003). Specifically, butterflies are responsive to (1) floral nectar availability, (2) the abundance of larval food plants, and (3) other non-trophic aspects of habitat diversity and quality.

Butterflies respond, both positively and negatively, to multiple floral cues, including color, corolla morphology and petal abscission (Barp et al. 2011). Increased density of suitable nectar-producing flowers in the habitat attracts more butterflies (Clark et al. 2007; Davis et al. 2007). In areas where mowing is a management strategy (e.g. along roadways), frequent mowing decreases floral availability and butterfly abundance (Sybertz et al. 2017; Halbritter et al. 2015). In laboratory studies, decreased nectar quality and quantity resulted in decreases in the number of eggs laid by female butterflies, adult butterfly life span and, hence, reproductive success (Lebeau et al. 2018). Habitat variables that impact floral resources in turn impact butterfly populations.

Many pollinator groups exhibit similar responses to habitat quality as butterflies. Native plants are associated with greater abundance and diversity of wild bees compared to areas with non-native floral resources (Mallinger et al. 2016). Furthermore, evidence indicates that native, perennial flowers in proximity to crops (e.g. via hedgerows) increase the benefits to agriculture provided by insects (Xerces Society 2017; Isaacs et al. 2016).

Pollinators are also responsive to larger scale heterogeneity in the landscape. Mallinger and colleagues (2016) documented greater species richness and abundance of wild bee communities in landscapes with multiple habitat types, (e.g. forest, orchard, grassland). Others take the agricultural “landscape” as the focal scale, where specific land management strategies, such as hedgerows and cultivation, interact. Cole et al. (2017) documented that on-farm areas with greater floral resources had greater abundances of butterflies and bumble bees. Garratt et al. (2017) found that bees and hoverflies were more abundant in hedgerows embedded in an intensively cultivated landscape matrix; hedgerows with more semi-natural habitat nearby had lower abundances of bees. In contrast to the previous results, an off-farm study in the Great Basin, USA found that butterflies are more responsive to small-scale diversity (Mac Nally et al. 2003).

The terms "landscape" and "spatial scale" is vary in meaning across studies of butterflies and pollinators in their habitat. Ultimately, studying insect response to variables at different scales increases understanding of the influence of different landscape characteristics at different spatial contexts. This study focused on observed pollinator populations at the scale of a single 1,200-acre farm in order to contribute to the growing understanding of how butterflies and pollinators respond to different landscape variables at different scales.

Native seed mixes & habitat enhancement

Given the evidence indicating pollinator response to habitat diversity and floral resources within the landscape, ecologists and conservation scientists recommend enhancing the environment to support pollinators. Some strategies include sown wildflower strips (reviewed in Haaland et al. 2011), hedgerows (reviewed in Kremen et al. 2018a), agricultural set asides (Neff et al. 2017), and floral networks (Costanze et al. 2018). In agricultural contexts, there is demand, particularly from farm owners, to document whether abundant and diverse pollinator communities provide spillover benefits to nearby cultivated crops (Grab et al. 2018; Winfree et al. 2018; Blitzer et al. 2012). Research regarding wild pollinator abundance and habitat diversity/habitat enhancement surrounding crops in New York State remains a growing field of study (Grab et al. 2018; Connelly et al. 2015).

Among the most common strategies to support pollinator populations is planting native wildflowers in peripheral, non-crop producing habitats on the farm (Haaland et al. 2011; Isaacs et al. 2009). While the specific location of habitat and resource provisioning is the subject of ongoing study, some trends have emerged. Seed mixes that successfully attract abundant and diverse pollinators are typically: (1) representative of native flowers of the region, (2) provide nectar and pollen resources throughout the growing season, (3) representative of morphologically diverse flower species, (4) habitat appropriate, (5) hardy, perennial varieties that require little ongoing maintenance and (6) a source of overwintering habitat for beneficial insects (Xerces Society 2019; Isaacs et al. 2009). It was with these considerations in mind that the Hawthorne Valley Farmscape Ecology Program established the Native Meadow Trials at the Farm Hub in May 2017.

Agriculture in New York's Lower Hudson Valley

The lower Hudson Valley region, composed of Albany, Columbia, Dutchess, Greene, Orange, Putnam, Rensselaer, Rockland, Ulster and Westchester Counties, is a significant area of agricultural production (Figure 1). In this region, there are nearly 4,000 farms, producing apples, tomatoes, squash, beans, peppers and other insect-pollinated crops as well as other crops that don't require pollination for production of a marketable crop (e.g. cabbage, potatoes and beets). (Vilsack and Clark 2014). In all, agriculture in the lower Hudson Valley region accounts for approximately 15 percent of the region's total land area (Vilsack and Clark 2014). As demands for local, resilient agriculture increase (Donahue et al. 2017), there is opportunity to manage the agricultural landscape for both insect conservation and increased pollination services.

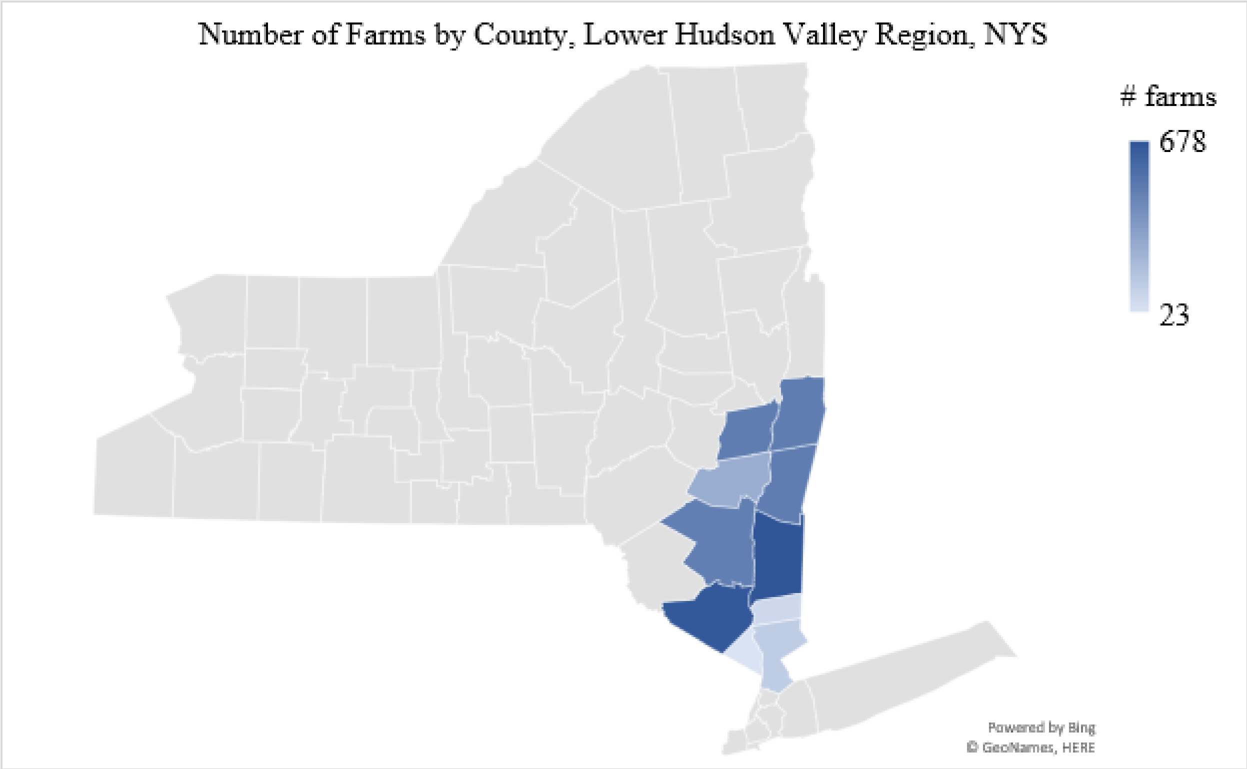

Figure 1. Number of farms by county in the lower Hudson Valley region of New York State. Here, counties in gray, which may have comparable numbers of farms, are outside the region of interest of this study. Data from the 2012 U.S. Census of Agriculture (USDA 2012).

Technological advances, such as GIS and remote sensing technology, have enabled many farms in the United States to increase production without increasing chemical inputs or conversion of greenspace (Esri ArcGIS 2013; Cornell University 2016). While these technologies hold promise, they are neither accessible to the average New York farmer, nor are they specifically marketed to directly benefit pollinator populations.

Research Questions

Considering pollinator declines and increasing demands on agriculture, both regionally and nationally, there is a need for farmers and land managers to quickly assess and remediate changes in pollinator populations. It is with these seemingly conflicting issues of pollinator decline, limited capacity of trained entomologists, and the economic value of regional agriculture, that I approached this study. The design of this study seeks to address one overarching theme: How can the agriculture community quickly and effectively enrich on-farm habitats and survey on-farm habitats (enriched and otherwise) for pollinator abundance and diversity? This study took place at the Hudson Valley Farm Hub in Hurley, NY and provides the opportunity to address these challenges regionally. The research questions of this study are listed below, followed by a brief rationale.

Question 1A: Do Native Meadow treatments at the Farm Hub impact observed butterfly abundance and diversity?

Butterflies are among the insects with documented declines in biodiversity due to habitat degradation and habitat loss. Understanding of the impact of the Native Meadow treatments on observed butterfly abundance and diversity will contribute to the overall understanding how habitat enhancement can provide nectar resources for butterflies.

Question 1B: Do Native Meadow treatments at the Farm Hub impact the observed abundance and diversity of other flower visiting insects?

There is growing concern regarding the impact of declines in managed and wild pollinators on crop production. Flower-visiting insects on the farm can be broadly categorized into two groups: beneficial insects (e.g. pollinators and natural enemies) and pests (e.g. crop damaging insects). Habitat enhancement schemes have the potential either to support crop development and quality by attracting beneficial insects or add to damage crops by attracting pests. Understanding the response of insect populations, both beneficial and pest, to habitat enhancement trials can contribute to our understanding of how to attract different insects to a crop production area.

Question 2: Can butterflies be surrogate measures of other flower visiting insects?

There are about 140 species of butterflies in New York State, compared to approximately 400 wild bee species. Butterflies are also charismatic and ecologically sensitive environmental indicators. Thoroughly conducting surveys of on-farm insects requires immense time and expertise. If butterflies can be a correlate measure for other flower visiting insects, it would provide an entry point for interns, volunteers and farmers to conduct initial pollinator surveys.

Question 3**:** Do different flower species present in on-farm habitats attract flower visiting insects equally?

In order to maximize the potential of seeded flower mixes and naturally occurring flower species in attracting beneficial insects, it is important to understand which flower species attract beneficial insect taxa more than others. Understanding whether or not all flower species present in on-farm habitats are equally attractive could provide insight into how to design flower mixes to attract diverse beneficial insects to the on-farm habitat.

STUDY SITE & FIELD METHODS

Site Description

This study was carried out from May 24, 2018 – September 27, 2018 at the Hudson Valley Farm Hub in Hurley, NY (Center: 41°54'46.6"N 74°05'35.7"W; Figure 2, Table I). Data were collected from three Native Meadow Trials, each containing two treatments and a control. Data were also collected from six additional farm sites to contribute to understanding of pollinator communities across different farm habitats. These sites were as follows: an abandoned Gravel Extraction site, an active Gravel Extraction site, an Herb Garden, a Cut-flower Garden, Wet Meadow Trials and Enriched Hay Fields (seeded in August 2017). The wet meadow sites, enhanced with native seeds, were also sampled throughout the season. All sites were open areas in different farm locations within a 1.8-mile (3 km) radius of the Farm Hub main offices with varying surrounding landscape elements. The Farm Hub lies in the Esopus Creek floodplain, bordered on the west by the Catskill Mountains. Also embedded within this landscape are residential neighborhoods.

Previous Native Meadow Establishment

In May 2017, three replicates of two seed mixes (“treatments”) were established at the Farm Hub. Each trial measured 320 x 200 feet (97.54 m x 60.96 m) and contained three experimental plots measuring 100 x 200 feet (30.48 m x 60.96 m), divided by 10 ft (3.05 m) grass strips. “NMT1,” “NMT2,” and “NMT3” each refer to the locations of these 320 x 200 ft (97.54 m x 60.96 m) trial areas. Treatment A contained 1 species of grass and 23 species of forbs chosen to attract pollinators (Table II). Treatment B contained only 6 forbs and a greater number of native grasses (Table III). Each trial also contained a control plot, “C,” which was left unseeded and allowed to revegetate from a residual agricultural weed seed bank and from the natural arrival of seeds from elsewhere in the landscape. All three treatments were managed equally: no herbicides, fungicides or pesticides were used at any time of site preparation, seeding or growth. The trials were mowed to 8 inches three times during their first year of establishment (2017) and hand weeded twice in early Summer 2018. "NMT1A" and other alpha-numeric abbreviations ending with "A", "B" or "C" refer to a treatment plot at a specific trial location (here, treatment A located in Trial 1). For specific mix proportions and cost, see Appendix A.

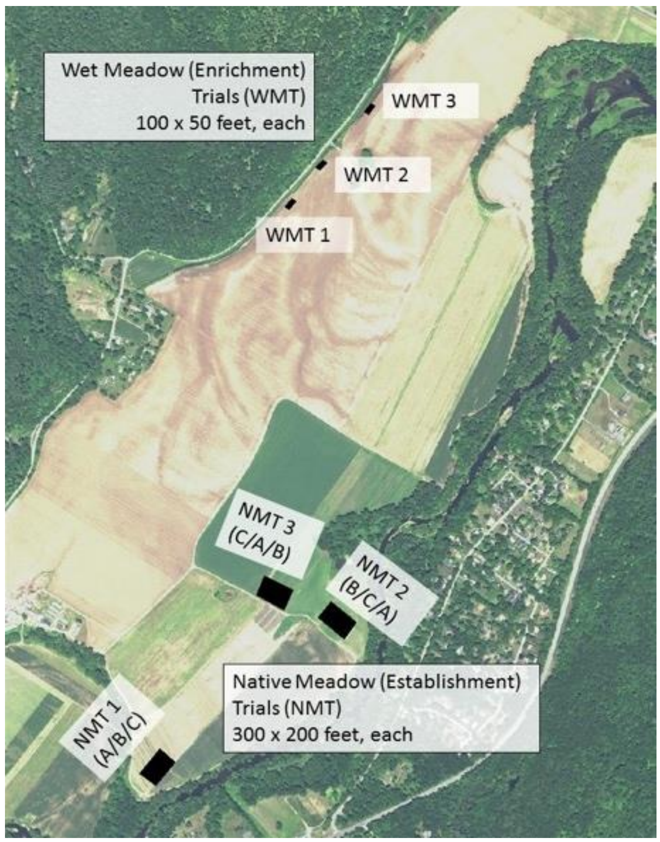

Figure 2. Native Meadow Trial establishment at Hudson Valley Farm Hub. Here, A = treatment A; B = treatment B; C = control. WMT = Wet Meadow trial.

Each site was visited twice a month from June 2018 – September 2018, and once in the last week of May 2018. During each visit, plant species in flower, butterfly species and other insects observed visiting flowering plants at each site were recorded. Surveys were conducted between 08:00 – 17:00 h on days when temperature was greater than 13ºC (55ºF), average wind speeds were less than 16 km/h (10 m/h), and there was no precipitation. During each visit, at each site, flower species, butterfly species and insect visitation to flower data were collected by the author at 10 points along transects within each treatment. Surveys were conducted for 15 – 45 minutes, depending on the density of flowers in bloom.

Table I. Dates and durations of Summer 2018 field surveys. "2*" indicates a field survey that occurred over two days due to weather conditions.

Visit	**Start Date**	**End Date**	**Duration (days)**
1	05/24/18	05/24/18	1
2	06/11/18	06/11/18	1
3	06/26/18	06/26/18	1
4	07/09/18	07/10/18	2
5	07/24/18	07/27/18	2*
6	08/09/18	08/10/18	2*
7	08/20/18	08/20/18	1
8	09/03/18	09/03/18	1
9	09/20/18	09/24/18	2*

Table II. Forbs and grasses included in treatment A native seed mix.

Native Meadow Mix A ("treatment A")	
Common Name	**Scientific Name**
Black Eyed Susan	*Rudbeckia hirta*
Brown Eyed Susan	*Rudbeckia triloba*
Butterfly Milkweed	*Asclepias tuberosa*
Common Milkweed	*Asclepias syriaca*
Dense Blazingstar	*Liatris spicata*
Early Goldenrod	*Solidago juncea*
Joe Pye Weed	*Eupatorium purpureum*
Lance Leaved Coreopsis	*Coreopsis lanceolata*
Lavender Hyssop	*Agastache foeniculum*
Little Bluestem	*Schizachyrium scoparium*
Mistflower	*Eupatorium coelestinum*
Narrowleaf Mountain Mint	*Pycnanthemum tenuifolium*
New England Aster	*Aster novae-angliae*
Ohio Spiderwort	*Tradescantia ohiensis*
Partridge Pea	*Chamaecrista fasciculata*
Purple Coneflower	*Echinacea purpurea*
Purple Prairie Clover	*Dalea purpurea*
Roundhead Lespedeza	*Lespedeza capitata*
Showy Goldenrod	*Solidago speciosa*
Slender Lespedeza	*Lespedeza virginiana*
Smooth Blue Aster	*Aster laevis*
Tall White Beardtongue	*Penstemon digitalis*
Wild Bergamot	*Monarda fistulosa*

Table III. Forbs and grasses included in treatment B native seed mix.

Native Meadow Mix B ("treatment B")	
Common Name	**Scientific Name**
Autumn Bentgrass	*Agrostis perennans*
Big Bluestem	*Andropogon geradii*
Blackeyed Susan	*Rudbeckia hirta*
Canada Wildrye	*Elymus canadensis*
Indiangrass	*Sorghastrum nutans*
Lance Leaved Coreopsis	*Coreopsis lanceolata*
Little Bluestem	*Schizachyrium scoparium*
Partridge Pea	*Chamaecrista fasciculata*
Purple Coneflower	*Echinacea purpurea*
Purple Lovegrass	*Eragrostis spectablis*
Purple Prairie Clover	*Dalea purpurea*
Purpletop	*Tridens flavus*
Slender Lespedeza	*Lespedeza virginiana*
Switchgrass	*Panicum virgatum*

Preparation and Calibration for Field Identification

Field identification methods were established and calibrated in consultation with the Hawthorne Valley Farmscape Ecology Program ("Farmscape Ecology Team") and Dr. Tim McCabe (NYS Museum Entomology Collection).

The Farmscape Ecology Team and I met periodically throughout the season to discuss identification strategies for common plants (seeded and unseeded) in the Native Meadow Trials and other on-farm habitats. Floral rank scores were also calibrated to ensure greater alignment of scores among different observers. If a plant could not be identified in the field at the time of initial observation, a sample and/or photographs of the flower, stem and leaves, (with date and location) were collected and used for consultation with colleagues to provide an accurate identification.

To prepare for insect identification, the Farmscape Ecology Team and I met in April through June to (1) discuss identification strategies for common taxonomic groups, (2) establish a numeric code for varied bee taxa and (3) calibrate identification of common insects. If an insect could not be identified in the field at the time of initial observation, samples and/or photographs, (with date and location) were collected and used for consultation with colleagues to provide accurate identification.

To specifically prepare for butterfly identification in the field, I referenced regional butterfly species in the entomology collection of the NYS Museum from December 2017 – December 2018. If a butterfly could not be identified in the field at the time of initial observation, photographs (with date and location) were used to provide accurate identification.

Flowering plant surveys

Flowering species and their relative abundance were recorded and ranked, respectively, within a 3 ft (approximately 1 m) radius projected 180 degrees in front of the observer for each point. Overall flower abundance was also recorded. Relative scores were assigned based on the following breakdown of percent cover of flowers: “1” = >0 - < 1% cover, “2” = 1 – 10% cover, “3” = 10 – 25% cover and “4” = >25% cover. Only mature flower structures were considered when assigning relative abundance scores.

Flower visitation surveys

At the same 10 points along the transect(s), insect visitors to flowers were recorded within a 6 ft (approximately 2 m) radius projected 180 degrees in front of the observer. For each visitation event, the insect and flower species were recorded. In most cases, insects were identified to family or higher taxon (e.g. *Apocrita* or “wasps”); frequently observed insects were identified to species (e.g. the honey bee, *Apis mellifera* or tarnished plant bug, *Lygus lineolaris*).

Butterfly surveys

Foraging butterflies were recorded to species if observed within a half-circle of 6 ft radius from the sample points during flower visitation surveys. Butterfly species were also recorded if they passed within 12 ft to the left, right, or in front of the observer. Then, I walked the perimeter of each site and recorded the species and number of butterflies present in each plot/location. All encounters were totaled for each location. Since these data could overestimate abundance, butterfly data will be referred to as “[proportion of] butterfly encounters” or “observed abundance” (Pellet et al. 2012; Pollard and Yates 1993).

Additional variables

For each sample location, the following variables were recorded: start and end time, temperature (°C), wind speed (mph) and description of cloud cover. Weather data were gathered by accessing the Farm Hub weather station via https://rainwise.net/weather/eddie12443 at the time of survey in each sample location. These data are available, but not included in analyses.

Data management

Data were assembled into three worksheets: a worksheet documenting insect visitations to flowers, a worksheet documenting relative floral abundance rank and a worksheet documenting butterfly encounters. Butterflies were identified using the *Kaufman Field Guide to Butterflies of North America* (2006). Wildflowers not part of the seed mixes were identified using *Newcomb's Wildflower Guide* (1977). Tables were generated in Microsoft Excel, then transferred to SYSTAT 13 for analysis. Plant, insect and butterfly data were provided to the Hawthorne Valley Farm Farmscape Ecology Team throughout the 2018 field season for periodic review and verification.

Lists of butterfly species encountered in other on-farm habitats are provided (Appendix B). Butterfly encounters for all other on-farm habitats (active Gravel Extraction site, abandoned Gravel Extraction site, Herb Garden, Cut Flower Garden and Wet Meadow trials) are compiled and available in Appendix D.

In order to provide context for results reported in each section, I document and describe the conditions of the Native Meadow Trials in Summer 2018, and overall proportion of insect visitation rates to flowers in different on-farm habitats. "Status of Native Meadow Trials in Summer 2018" and "Overview of Insect-Flower Observations at the Farm Hub" briefly present these results before each research objective is presented.

STATUS OF NATIVE MEADOW TRIALS IN SUMMER 2018

Analytical Methods

Flower visiting arthropods belonging to Hymenoptera, Hemiptera, Orthoptera, Diptera, Coleoptera, Araneae and Odonata were recorded in biweekly surveys. The following subgroups of Hymenoptera were recorded: honey bees (Subfamily: Apinae; *Apis mellifera*), bumble bees (Family: Apidae), sweat bees (Family: Halictidae) and other native bees (Other bees belonging to Apoidea, but not the groups listed previously). The following genera of hoverflies (Subfamily: Syrphidae) were recorded: *Platycherius*, *Taxomerus*, and *Sphaerophoria*. Two other groups of interest: wasps (Suborder: Apocrita) and tarnished plant bugs (*Lygus lineolaris*) were also recorded. Total encounters were recorded during each survey.

Not all the seeded native forbs were present in the Native Meadow Trials in summer 2018, nor were species present in equal amounts. For every flower species present, I converted the relative floral area rank to percent cover, using the following values for percent cover:

Table IV. Assigned percent cover for floral area ranks.

Original Floral Area Rank	Original Range of Cover	Assigned Percent Cover
1	>0 – <1%	0.5%
2	>1 – <10%	5.0%
3	>10 – <25%	17.5%
4	>25 – <100%	62.5%

To identify which sown species were dominant in the native meadows from May 2018 – September 2018, all flower visitations were pooled for all treatments. The sum of flower visitations for each flower species was calculated. The flower species that drew the five greatest numbers of visitation were identified as the "dominant species," these were: Black Eyed Susan, Horseweed (*Erigeron canadensis)*, Lance Leaved Coreopsis, Wild Bergamot and New England Aster. All other flowers were labeled “all others.”

For these dominant species, the duration of flowering was identified as the number of days between the first recorded date of flowering and the last date of recorded flowering. The range of flowering for each of these species was then plotted (Figure 3). While flowers may have begun blooming prior to the “arrival” date and persisted to a date between surveys, this date range marks their presence in the data set.

Between May 2018 – September 2018, I completed nine field surveys in the Native Meadow Trials across 13 days (Table I). For each survey period, treatment and each dominant flower present within a trial, I found the average percent abundance from all sample points. This represents the average percent floral abundance rank of that species in a treatment during that survey.

Documented flowers in the Native Meadow Trials Summer 2018

Forty-nine species of flower were recorded in all of the native meadow treatments. Twenty-nine percent (14 species) were seeded as part of the Native Meadow trial. Twenty-two percent (11 species) were not part of the seed mix but are native to the region. Nearly 50 percent (24 species) were not seeded and are not native to the region. Two of these species (Prairie Coreopsis, *Coreopsis palmata.* and Chicory, *Cichorium intybus*) were included in the Enriched Hay seed mix in nearby fields (Table V - VI).

Table V. Seeded flower species in the Native Meadow Trials observed May 2018 – September 2018. “Y” = seeded, native flower. “

Common Name	**Scientific Name**	**Mix [Y/N]**
Black Eyed Susan	*Rudbeckia hirta*	Y
Brown Eyed Susan	*Rudbeckia triloba*	Y
Butterfly Milkweed	*Asclepias tuberosa*	Y
Early Goldenrod	*Solidago juncea*	Y
Purple Coneflower	*Echinacea purpurea*	Y
Lance-leaved Coreopsis	*Coreopsis lanceolata*	Y
Lavender Hyssop	*Agastache foeniculum*	Y
Mistflower	*Eupatorium coelestinum*	Y
New England Aster	*Aster novae-angliae*	Y
Partridge Pea	*Chamaecrista fasciculata*	Y
Showy Goldenrod	*Solidago juncea*	Y
Smooth Blue Aster	*Aster laevis*	Y
Tall White Beardtongue	*Penstemon digitalis*	Y
Wild Bergamot	*Monarda fistulosa*	Y

Table VI. Non-seeded flowers observed in the Native Meadow Trials May 2018 – September 2018. “N” = not seeded, native flower. “N*” = non-seeded, non-native flower. “N**” = seeded in adjacent field(s).

Common Name	**Scientific Name**	**Mix [Y/N]**
Annual Fleabane	*Erigeron annuus*	N
Carpetweed	*Mollugo verticillata*	N*
Chicory	*Cichorium intybus*	N**
Common Chickweed	*Stellaria media*	N*
Common Smartweed	*Polygonum longiseta*	N
Common Winter Cress	*Barbarea vulgaris*	N*
Yellow Wood Sorrel	*Oxalis europaea*	N
Corn Speedwell	*Veronica arvensis*	N*
Dandelion	*Taraxacum officinale*	N*
Deptford Pink	*Dianthus armeria*	N*
Evening Primrose	*Oenothera biennis*	N
Field Bindweed	*Convolvulus arvensis*	N*
Field Chamomile	*Anthemis arvensis*	N*
Field Mustard	*Brassica rapa*	N*
Field Pennycress	*Thlaspi arvense*	N*
Field Peppergrass	*Lepidium campestre*	N*
Galinsoga	*Galinsoga ciliata*	N*
Goldenrod	*Solidago sp.*	N
Hairy Vetch	*Vicia villosa*	N*
Hedge Mustard	*Sisymbrium officinale*	N*
Horseweed	*Erigeron canadensis*	N
Lamb's Quarters	*Chenopodium album*	N*
Mouse Ear Chickweed	*Cerastium vulgatum*	N*
Mouse Ear Cress	*Arabidopsis thaliana*	N*
Mullein	*Verbascum thapsus*	N*
Oxeye Daisy	*C. leucanthemum*	N*
Philadelphia Fleabane	*Erigeron philadelphicus*	N
Prairie Coreopsis	*Coreopsis palmata.*	N**
Queen Anne's Lace	*Daucus carota*	N*
Red Clover	*Trifolium pratense*	N*
Shepherd's Purse	*Capsella bursa-pastoris*	N
Silvery Cinquefoil	*Potentilla argentea*	N*
Venus's Looking-Glass	*Specularia perfoliata*	N

White Campion	*Lychnis alba*	N*
White Clover	*Trifolium repens*	N**
Wild Radish	*Raphanus raphanistrum*	N*

Period of Flowering

Seeded flowers bloomed at different times in the season, and for different durations. Here, the flowering period of five dominant species in the treatments, Black Eyed Susan, Lance Leaved Coreopsis, Wild Bergamot, Horseweed and New England Aster, are summarized (Figure 3).

Lance Leaved Coreopsis was the first dominant flower to emerge in early June, and it persisted the longest (105 days, approximately 85 percent of the field season). Black Eyed Susan emerged in late June and persisted until September (90 days, 73 percent of the field season). Horseweed was present 58 percent of the season (72 days), Wild Bergamot 33 percent (41 days) and New England Aster 18 percent (22 days). Other species were present, at lower ranks, (discussed next), for the entire duration of the field survey period.

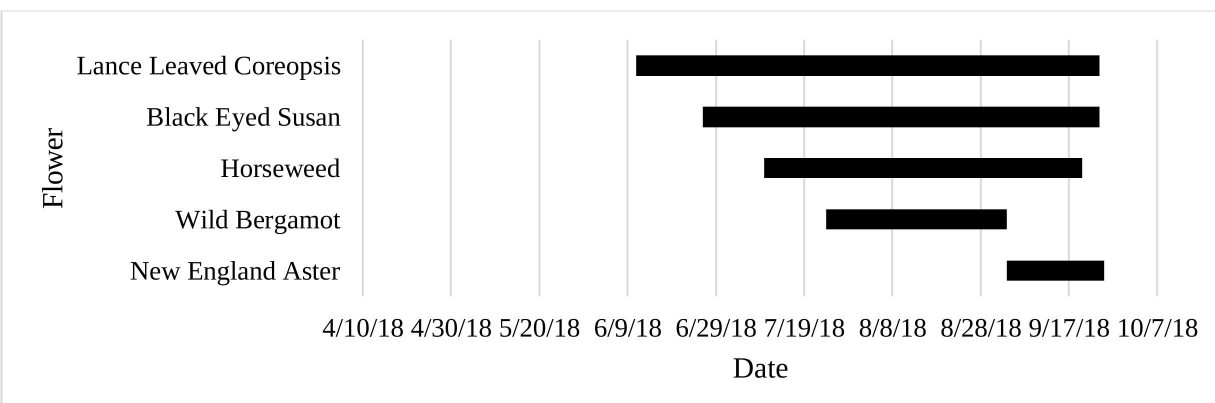

Figure 3. Flowering period of dominant flowers in the Native Meadow Trials. Total days in season: 124. Total sampling days: 13. While flowers may have bloomed before the surveying day, and persisted after September 24, “start” and “end” refer to the start and end of observed flowering in the surveying sequence. Note, dates shown do not represent field survey dates.

Average Floral Abundance

Each flower also differed in its average floral abundance rank throughout the season. Figure 4 - Figure 6 summarize the average percent abundance calculated from floral abundance ranks, see Table IV for each dominant flower in treatments A and B and the control. All other flowers, native and non-native, are grouped as "All others."

In treatment A, Lance Leaved Coreopsis and Black Eyed Susan had the highest observed average floral abundance rank throughout the season. From July 24, 2018 on, the average floral abundance rank of Black Eyed Susan and Lance Leaved Coreopsis declined, while the average rank of New England Aster rose. A similar trend can be observed in treatment B; however, the average floral abundance of Horseweed climbed above 10 percent in the absence of other seeded forbs in the control plots. In both treatments and the control trials, "all other" flowers maintained a relatively constant background floral abundance between 0.5 percent and 5 percent throughout the entire duration of the season.

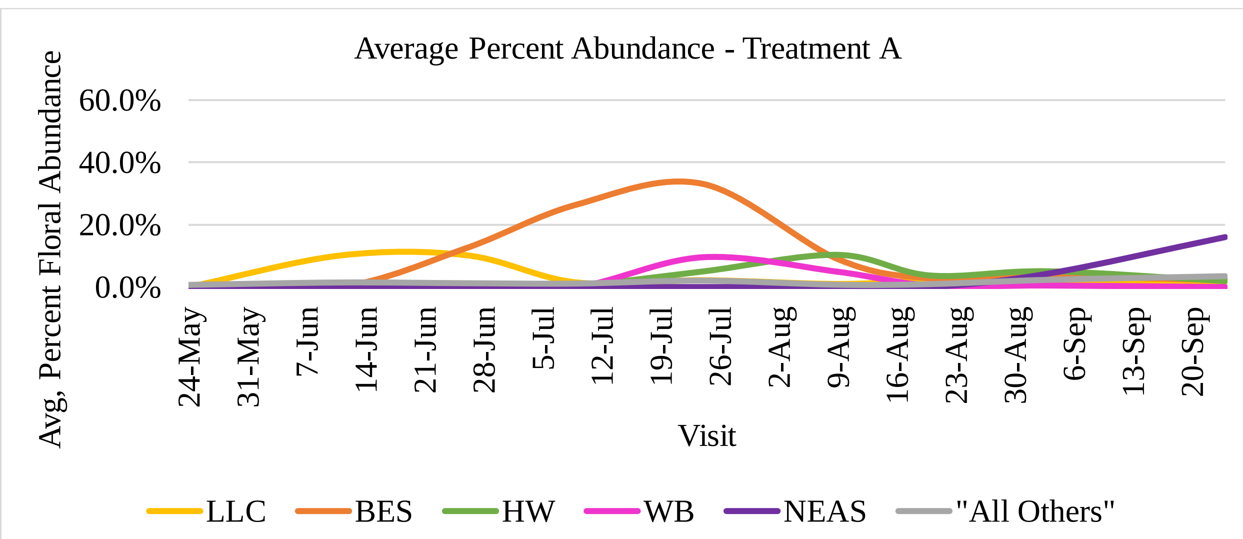

Figure 4. Average percent abundance of dominant flowers in treatment A. "LLC" = Lance Leaved Coreopsis, "BES" = Black Eyed Susan, "HW" = Horseweed, "WB" = Wild Bergamot and "NEAS" = New England Aster. Note, dates shown do not represent field survey dates.

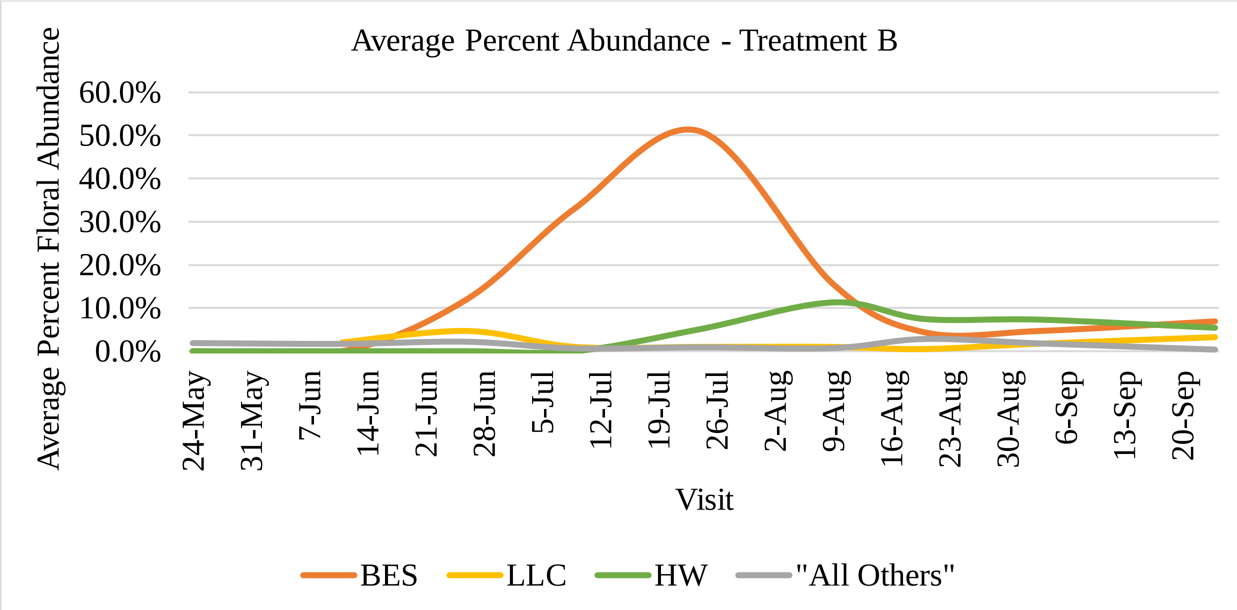

Figure 5. Average percent abundance of dominant flowers in treatment B. “LLC” = Lance Leaved Coreopsis, “BES” = Black Eyed Susan, and “HW” = Horseweed. Note, dates shown do not represent field survey dates.

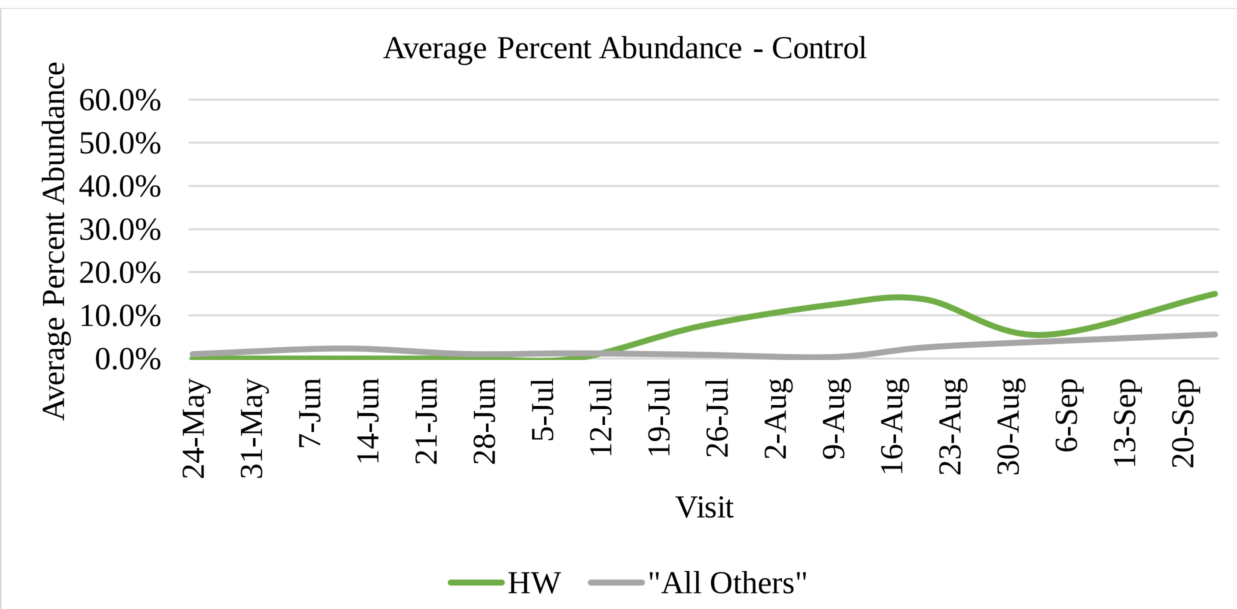

Figure 6. Average percent abundance of dominant flowers in control plots. “HW” = Horseweed.

Overview of Pollinator-Flower Observations at the Farm Hub

Expected vs. Actual Observations per Habitat Type

To verify that the Native Meadow Trials were attracting a greater number of pollinators compared to other farm habitats, all pollinator-flower observations were pooled for June – September 2018 and categorized by habitat. Based on the proportion of total sampled area each habitat type represented during this time frame, expected insect visitations were determined and compared to actual observed visitations (Figure 7). Results indicate that pollinators visited two habitat types more than was to be expected given the relative proportion of the habitat in the data set; these two habitat types were: “Treatments” (Native Meadow Treatment A and B) and “Cultivated” (Herb Garden and Cut Flower Garden).

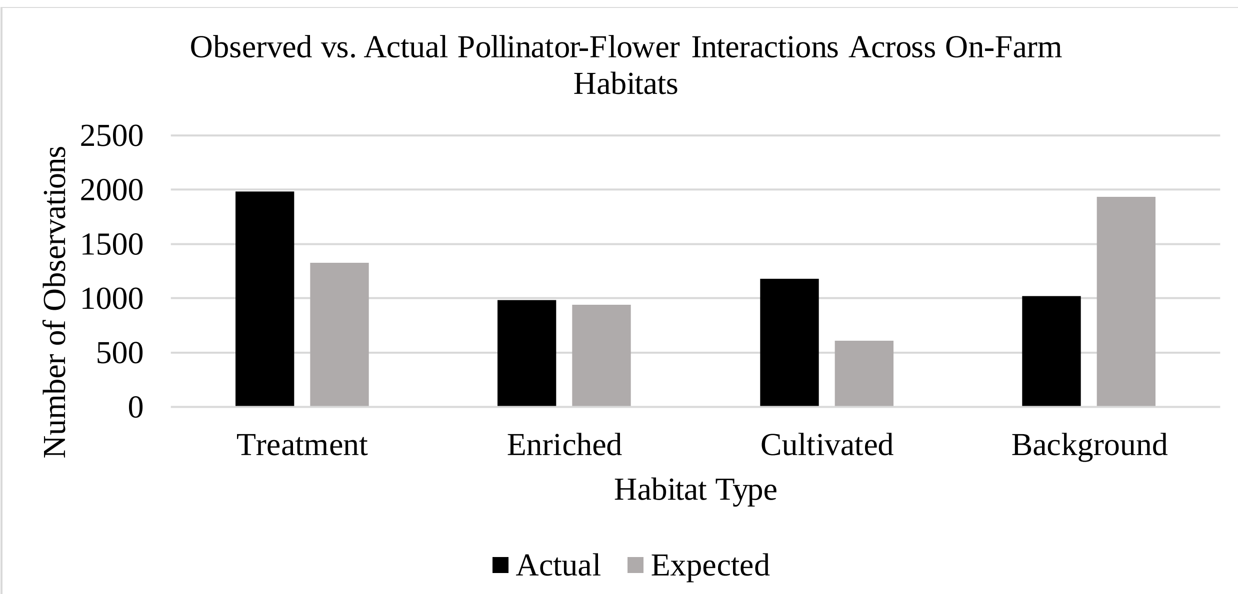

Figure 7. Comparison of expected vs. observed pollinator-flower interactions by habitat type. “Treatment” = treatments A and B in the Native Meadow Trials; “Enriched” = Wet Meadow seed enrichment and Enriched Hay, “Cultivated” = Herb Garden and Cut Flower Garden; “Background” = Native Meadow control, Wet Meadow control and Abandoned Gravel extraction site. (Chi Square Test p-value < 0.01). See Appendix C for method of calculation.

The composition of the insect communities observed visiting flowers in each habitat type also differed. For example, in the Wet Meadows and the Dry Gravel Extraction Site the category “non-Apidae bees” was common. In contrast, bumble bees and honey bees were common in the Enriched Hay fields and the Cut Flower Garden (see Appendix D for composition of observed insect community in each on-farm habitat type).

Given the capacity of the treatments to attract more than the expected number of pollinators, I sought to answer my three primary research questions, restated below:

- Question 1A: Do Native Meadow treatments at the Farm Hub impact observed butterfly abundance and diversity?
- Question 1B: Do Native Meadow treatments at the Farm Hub impact the observed abundance and diversity of other flower visiting insects?
- Question 2: Can butterflies be surrogate measures of other flower visiting insects?
- Question 3**:** Do different flower species present in on-farm habitats attract flower visiting insects equally?

Question 1A. Do Native Meadow treatments at the Farm Hub impact observed butterfly abundance and diversity?

Analytical Methods

Non-parametric tests for normal distribution

Butterfly observation frequency data was assessed for normal distribution. Data were normally distributed.

Observed butterfly abundance and diversity

To identify the impact of Native Meadow treatments on butterfly populations, I conducted three analyses. First, I conducted an ANOVA analysis to compare the observed butterfly abundance across different treatments. Second, I characterized the relative species abundance of butterflies on different treatments with Whittaker Plots (“rank-abundance plots”). Third, I compared the capacity of different trials of treatments to attract similar communities of butterflies using Bray Curtis similarity analysis.

Observations were pooled by treatment for May 2018 – September 2018. Species richness was calculated as the number of species observed per treatment. Total butterfly encounters were compared using ANOVAs using SYSTAT Version 13 (SYSTAT 13^{TM}, SPSS, Chicago, IL).

Relative species abundance was characterized with rank-abundance plots for treatment A, treatment B, and the control sites. Rank-abundance plots were assembled by (1) ranking species in order of abundance, where 1 is the most abundant species, (2) calculating the natural log of the abundance of each species encountered at that location and (3) plotting subsequent points.

Community composition of species attracted to different plots was compared using the Bray-Curtis index of similarity

$$C_N = \frac{2jN}{(aN+bN)}$$

With jN = sum of the lower of the two abundances recorded for species in both sites being compared, aN = number of species found in the first site being compared, and bN = number of species found in the second site being compared. Maximum C_N = 1.0 (all species shared at identical abundances), minimum C_N = 0.0 (no species shared). Pairwise comparisons were made for all nine sites to produce a dendrogram.

Results

I observed 23 species of butterflies over 2,227 total encounters in all Native Meadow Trials. A total of 1,261 encounters and 19 species were recorded in treatment A trials. A total of 681 encounters and 16 species were recorded in treatment B trials. Lastly, a total of 285 encounters and 11 species were recorded in control trials. In all treatments, Clouded Sulphur (*Colias philodice*) (976 total encounters), Cabbage White (*Pieres rapae*) (473), and Orange Sulphur (*Colias eurytheme*) (383) were encountered most often. Butterflies were observed from five families: *Pieridae* (82%), *Papilionidae* (1%), *Nymphalidae* (8%), *Lycaenidae* (1%) and *Hesperiidae* (8%) (Table VII).

Bi-weekly data indicates that the highest frequency of butterfly encounters occurred in the second week of July (07/09/2018; 395 encounters) and the third week of September (09/20/2018; 349 encounters). This aligns with the peak flowering periods of Black Eyed Susan (Survey #4, July 9 - 10) and New England Aster (Field Survey #7-8, September 3, 20 and 24) in the Native Meadow Trials (Figure 8).

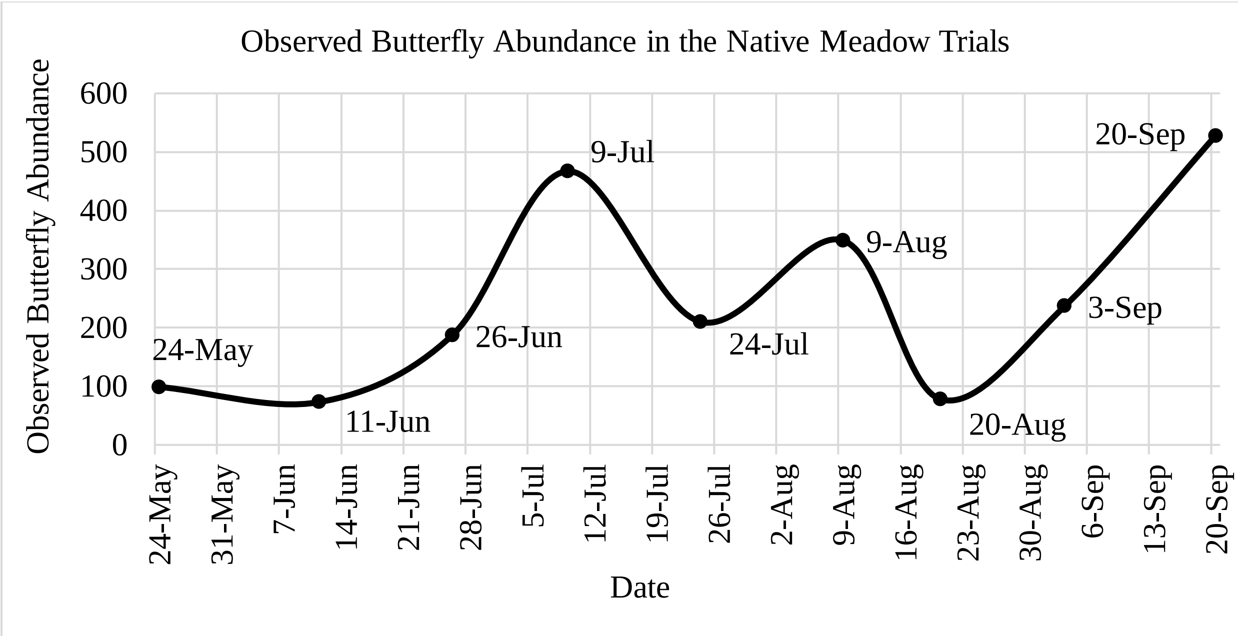

Figure 8. Observed butterfly abundance per field survey May 2018 – September 2018.

Table VII. List and counts of all butterfly species encountered in the Native Meadow Trials May 2018 – September 2018. * indicates a butterfly that is non-native to New York.

Butterfly Species	**Common Name**	**Family**	**Treatment**			**Total**
			A	**B**	**Control**	
Belloria bellona	Meadow Fritillary	*Nymphalidae*	0	1	0	1
Coenonympha tullia	Common Ringlet	*Nymphalidae*	2	0	0	2
Colias eurytheme	Orange Sulphur	*Pieridae*	244	96	43	383
Colias philodice	Clouded Sulphur	*Pieridae*	528	347	101	976
Cupido comyntas	Eastern Tailed Blue	*Lycaenidae*	7	9	2	18
Danaus plexippus	Monarch	*Nymphalidae*	35	12	4	51
Epargyreus clarus	Silver Spotted Skipper	*Hesperiidae*	119	23	8	150
Erynnis baptisiae	Wild Indigo Dusky Wing	*Hesperiidae*	1	0	0	1
Euphyes vestris	Dun Skipper	*Hesperiidae*	3	1	0	4
Limenitis archippus	Viceroy	*Nymphalidae*	4	5	4	13
Lycaena hyllus	Bronze Copper	*Lycaenidae*	1	0	0	1
Lycaena phlaeas	American Copper	*Lycaenidae*	1	0	0	1
Papilio cresphontes	Giant Swallowtail	*Papilionidae*	1	0	0	1
Papilio glaucus	Eastern Tiger Swallowtail	*Papilionidae*	11	4	1	16
Papilio polyxenes	Black Swallowtail	*Papilionidae*	38	14	3	55
Papilio troilus	Spicebush Swallowtail	*Papilionidae*	3	0	0	3
Pholisora catullus	Common Sooty Wing	*Hesperiidae*	5	7	4	16
Phyciodes tharos	Pearl Crescent	*Nymphalidae*	19	9	0	28
*Pieris rapae**	Cabbage White	*Pieridae*	212	148	113	473
Pyrgus communis	Common Checkered Skipper	*Hesperiidae*	0	1	0	1
Speyeria cybele	Great Spangled Fritillary	*Nymphalidae*	27	3	0	30
*Thymelicus lineola**	European Skipper	*Hesperiidae*	0	0	2	2
Vanessa cardui	Painted Lady	*Nymphalidae*	0	1	0	1
		Total	1,261	681	285	2,227

Butterfly encounters by treatment

ANOVA analysis was used to detect if mean butterfly abundance was equal across all treatments and the control. Analysis indicates that butterflies are not attracted to all treatments and the control equally ($F= 6.185$, $df = 2$, $p < 0.05$; Figure 9). Pairwise comparison indicated no significant difference among treatments compared. Visual inspection indicates that more butterflies were observed on treatment A and B plots.

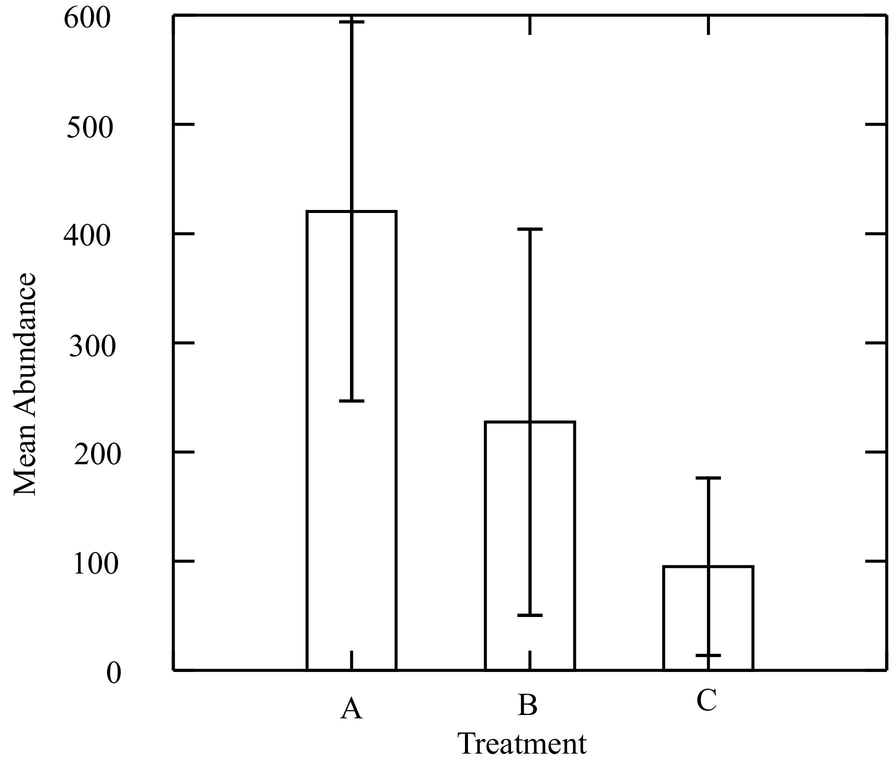

Figure 9. Comparison of butterfly encounters across Native Meadow treatments. "A" = treatment A, "B" = treatment B, "C" = control; bars represent standard errors. Analysis of variance results are presented in Table VII. N = 2,227. Bonferroni pairwise comparisons were not significant at p < 0.05).

Table VIII. Analysis of variance results to accompany Figure 9.

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Treatment	160,602.889	2	80,301.444	6.185	0.035
Error	77,903.333	6	12,983.889		

Butterfly encounters in other on-farm habitats.

Over 80 percent of the butterfly species seen at the Farm Hub during the summer of 2018 were observed in the 4.4 acres that compose the Native Meadow Trials. Given the variation in sampling frequency and lack of replication on other on-farm habitats, formal analysis is not conducted here (see Appendix B for lists of species encountered in different on-farm habitats). Only five additional butterfly species were observed in other farm habitats, shown in Table IX).

Table IX. Butterfly species encountered at other on-farm habitats.

Species Name	Common Name	Location	Count
Panoquina ocola	Ocola Skipper	Herb Garden	1
Vanessa atalanta	Red Admiral	Herb Garden	3
Polites peckius	Peck's Skipper	Wet Meadow trials	3
Polygonia interrogationis	Question-Mark	Active Gravel Extraction	2
Vanessa virginiensis	American Lady	Enriched Hay	1

Relative species abundance of butterflies in the Native Meadow Trials

The number of species I observed in different treatments varied: 19 species were encountered in treatment A, 16 species were encountered in treatment B and 11 species were encountered in control plots. Treatment A attracted 18.75 percent more species than treatment B and 72.73 percent more species than the control.

In each treatment, the top three ranked species belonged to family *Pieridae*: Cabbage white (*Pieris rapae)*, Clouded Sulphur (*Colias philodice*) and Orange Sulphur (*Colias eurytheme*). The slope of the rank-abundance plots in Figure 10 and Figure 11 is relatively gradual, indicating a greater degree of evenness in treatment A and treatment B plots. In the control trials, these three species dominated the community, as illustrated by a steep slope (Figure 12).

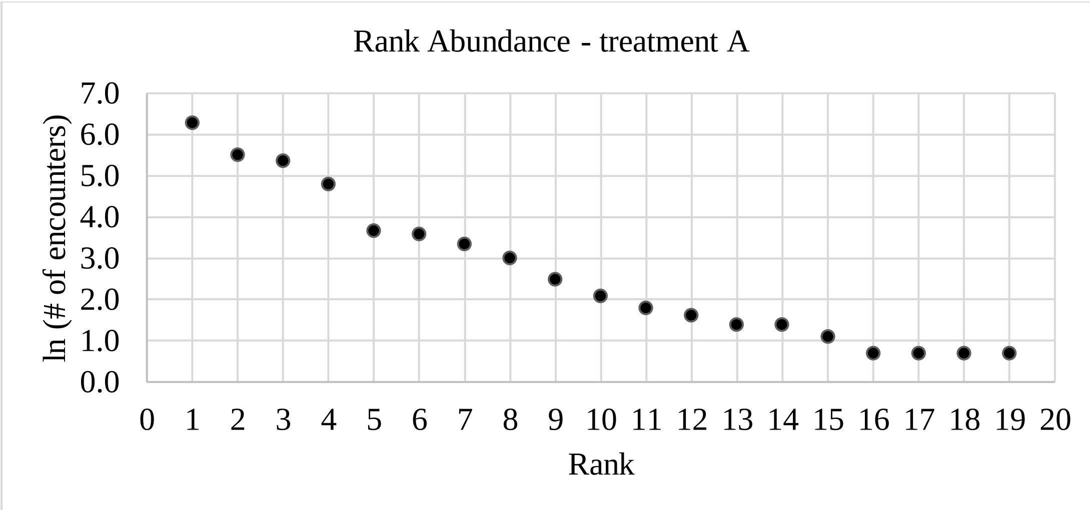

Figure 10. Whittaker Plot (rank-abundance curve) of butterfly species encountered in treatment A. Here, all treatment A trials have been pooled.

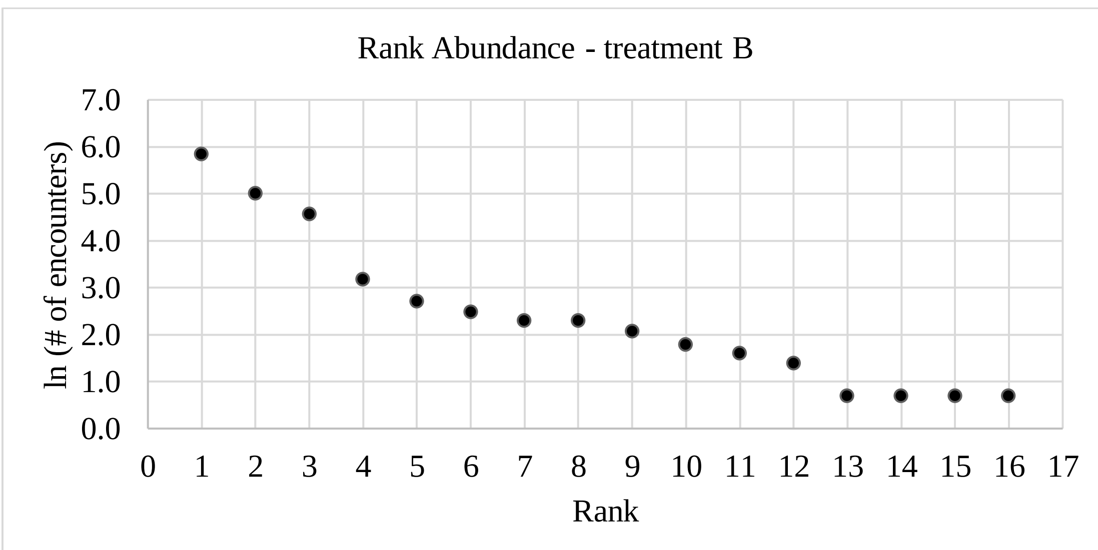

Figure 11. Whittaker Plot (rank-abundance curve) of butterfly species encountered in treatment B. Here all treatment B trials have been pooled.

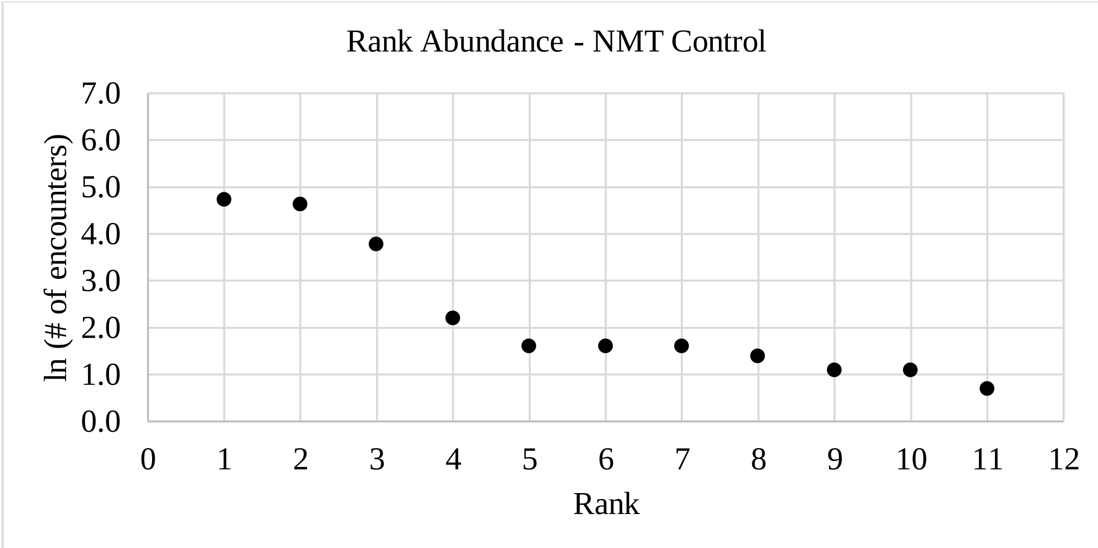

Figure 12. Whittaker Plot (rank-abundance curve) of butterfly species encountered in control plots. Here all Native Meadow control trials have been pooled.

Bray-Curtis analysis of butterfly communities

Bray-Curtis similarity analysis was used to examine the similarities in butterfly communities attracted to the treatments and control plots (Figure 13). Butterfly communities clustered into two communities. In the first cluster (bottom branch), butterfly communities encountered in all A treatments, and one treatment B plot clustered together, indicating that they attracted nearly identical communities of butterflies (i.e. they had high self-similarity). In the second cluster (top branch), butterfly communities encountered in all control treatments and two plots of treatment B had high self-similarity. Butterfly communities encountered in control treatments clustered separately from treatment A, indicating their dissimilarity from the butterfly community encountered in treatments.

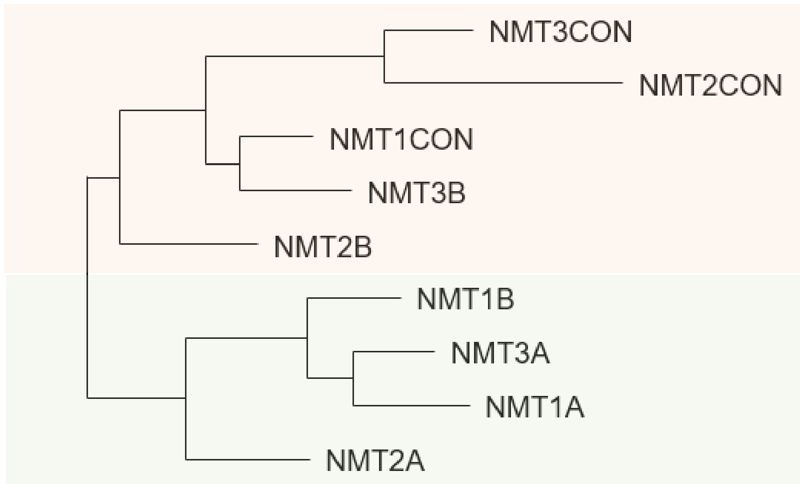

Figure 13. Additive dendrogram for Bray-Curtis similarity analysis of butterfly communities in Native Meadow Trials.

Discussion

Twenty-three species were encountered in the Native Meadow Trials in the Summer 2018 field season. Significantly more butterfly encounters were documented in treatment plots compared to control plots. Observations at the Native Meadow Trials also captured almost all of the species documented on the Farm Hub in Summer 2018. This result was anticipated because of the high native flower density in seed mix A and results documented or reviewed by Clark (2007), Isaacs et al. (2009) and Haaland et al. (2011) verifying that high density of native, perennial flowers are positively correlated with increased butterfly abundance and diversity.

Treatment A attracted more butterfly species compared to treatment B and control. In fact, more than 20 species were observed in the Native Meadow Trials in a single season, indicating that treatment A and treatment B are successfully attracting a variety of butterflies.

The butterfly community in all plots is dominated by generalists belonging to *Pieridae*. The dominance of generalists is typical on chronically disturbed landscapes, such as agricultural lands, and thus is not surprising (Mallinger et al. 2016; Tscharntke et al. 2012; Clark et al 2007). Additionally, this subgroup could have been supported in other life stages by the proximity of cultivated host plants nearby (e.g. broccoli and cauliflower).

Agriculture is often associated with the homogenization of living communities on the landscape (Kremen and Merenlender 2018; Landis 2017). These results suggest that enriched seed mixes can be a possible means to increase observed butterfly diversity at relatively low costs to farmers. However, conserving specialists may require expertise and resources not available to farmers and land managers. Continued research will be required to determine if landscape homogenization can effectively be counterbalanced long-term, in addition to documentation of impacts of larval habitat provisioning for non-generalist species.

Land managers and farmers should consider designing and/or choosing seed mixes with specific insect communities, and their entire life stages, in mind. While the “high floral density” mix here attracted more butterflies, it may be a “moderate floral density” blend that a farm manager may want to use depending on the target insect community. Second, it is possible that habitat enhancement can unintentionally support the adult and/or larval stages of the agricultural pest species of butterflies. For example, Cabbage White larvae feed on cabbage and related plants, Viceroy larva feed on cherry and apple trees, blue and tailed butterfly larva (such as the Eastern Tailed Blue) feed on legumes and Black Swallowtail larva may feed on carrots and celery (Brock and Kaufman 2006). Land managers and farmers will want to consider carefully the placement of crops near areas undergoing habitat enhancement, as well as seek further study regarding biological control adjacent to habitat enhancement sites.

The methods used in this study have inherent limitations. First, the visual surveys document butterfly encounter rate only, and do not directly estimate population size.

Additionally, surveys at the height of vegetation limit observation of species with different flight behavior, such as those that perch under leaves or on stems (Pellet et al. 2012). Also, there is sampling bias against smaller, less conspicuous species. Lastly, visual survey only assesses the adult stage of different species and does not measure the capacity of enriched seed mixes to impact fitness traits (e.g. oviposition, larval survival) of local butterfly populations. The butterfly community observed in Summer 2018 represents just a small snapshot into the regional community and does not measure population changes in response to other variables such as climate patterns. To address such limitations, future on-farm studies of butterfly populations should consider using mark-recapture population assessments, chrysalis and caterpillar surveys and other fitness indicators over multiple seasons.

Question 1B. Do Native Meadow treatments at the Farm Hub impact observed abundance and diversity of other flower visiting insects?

Analytical Methods

Non-parametric tests for normal distribution

Observation frequency data was assessed for normal distribution for the following groups of pollinators: bumble bees, honey bees, non-Apidae bees (including sweat bees), wasps, and hoverflies. Data were not normally distributed, so non-parametric means tests (Kruskal-Wallis) were used in place of ANOVAs using SYSTAT Version 13 (SYSTAT 13^{TM}, SPSS, Chicago, IL).

Observed abundance of flower visiting insects

In order to identify potential impact of Native Meadow treatments on abundance and diversity of other pollinator groups, I first isolated the following taxa from all recorded flower visitations: *Andrena* (mining bees), Apidae (honey bees and bumble bees), Apocrita (wasps), *Ceratina* (small carpenter bees), Chrysididae (cuckoo wasps), *Eucera/Melissodes/Peponapis* (long horned bees), Halictidae (sweat bees), Hesperiidae (skippers), *Lassioglossum* (sweat bees), *Lasioglossum/Halictus* (indistinguishable sweat bees), Lycaenidae (gossamer-winged butterflies), Megachilidae (solitary bees), moths, Nymphalidae (brushfoot butterflies), Papilionidae (swallowtail butterflies), Pieridae (white and Sulphur butterflies), Syrphidae (hoverflies), and Xylocopini (large carpenter bees). The following non-pollinator groups were also isolated: lady beetles (all types, all ages; Family: Coccinellidae) and tarnished plant bugs (*Lygus lineolaris*) because of their potential agricultural significance as natural predators or pests respectively.

Analysis of observed butterfly abundance is represented in the previous section (Objective 1A). Observations were pooled into broader taxonomic groups for May 2018 – September 2018. Here, total flower-visiting insect encounters were compared for the following groups of interest: bumble bees and honey bees, non-Apidae bees (taxa listed above pooled for analysis), hoverflies, wasps, lady beetles (all types, all ages) and tarnished plant bugs.

Community composition of the treatment and control sites were compared using the Bray-Curtis index of similarity (explained above under Question 1A). Pairwise comparisons were made for all nine sites to produce a dendrogram.

Results

Bumble bee encounters

During my surveys, I encountered 551 bumble bees in the Native Meadow Trials. In trials of treatment A, I encountered 414 bumble bees. In trials of treatment B and the control, I encountered 124 and 13 bumble bees respectively. Bumble bees are not visiting each plot equally; ($p < 0.05$; Figure 14); Bonferroni pairwise comparisons were not significant at $p < 0.05$, but visual inspection shows greater abundance of bumble bees on treatment A.

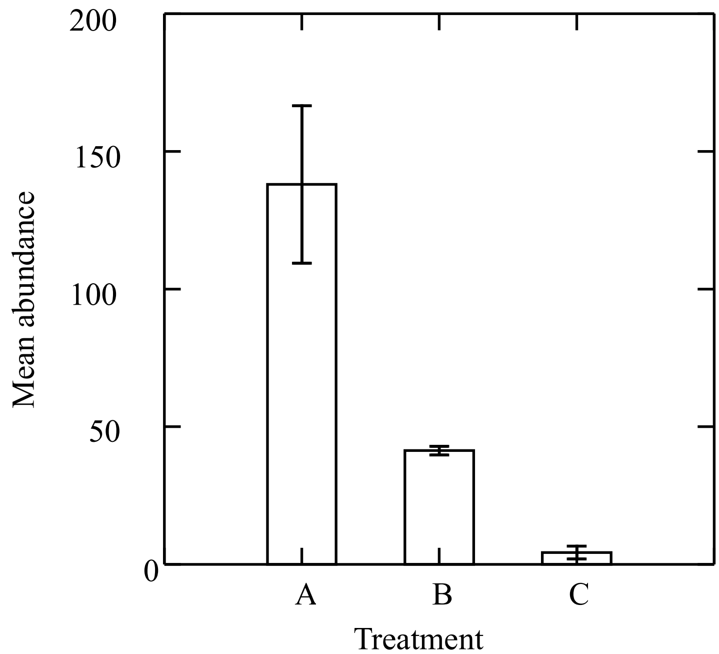

Figure 14. Comparison of bumble bee encounters across Native Meadow treatments. Kruskal-Wallis results are presented in Table IX. N = 551. Bars represent standard errors.

Table X. Kruskal-Wallis test statistics to accompany Figure 14. Kruskal-Wallis Test Statistic: 7.200. The p-value is 0.027 assuming chi-square distribution with 2 df.

Group	Count	Rank Sum
A	3	24.00
B	3	15.00
C	3	6.00

Honey bee encounters

I encountered 145 honey bees in the Native Meadow Trials across all surveys. I encountered a total of 66 honey bees in treatment A, 71 honey bees in treatment B and 8 honey bees in control plots. Observed abundance in the treatments were nearly significantly different (p = 0.059; Figure 15); pairwise comparison was not significant, but visual inspection shows greater abundance of honey bees on treatment A and B.

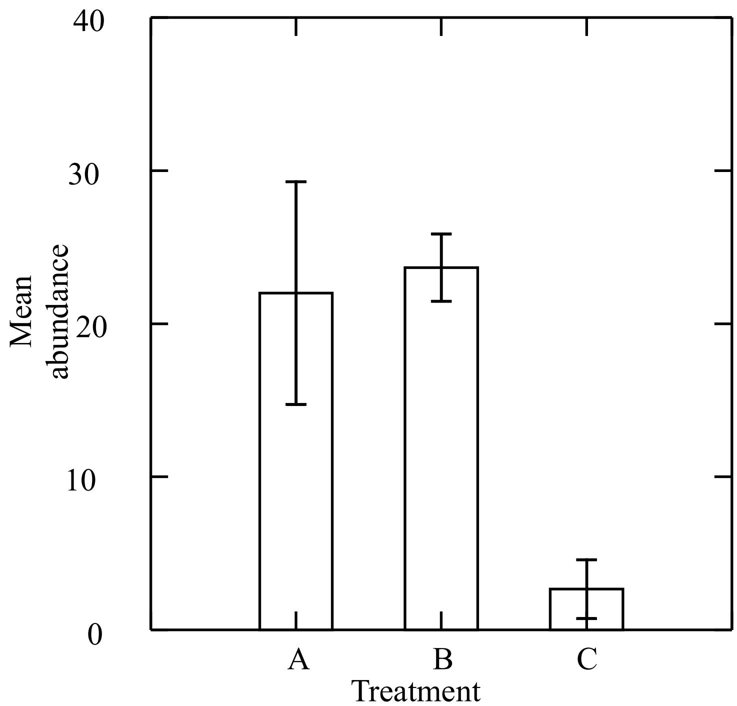

Figure 15. Comparison of honey bee encounters across Native Meadow treatments. Kruskal-Wallis results are presented in Table X. N = 145. Bars represent standard errors.

Table XI. Kruskal-Wallis test statistics to accompany Figure 15. Kruskal-Wallis Test Statistic: 5.647. The p-value is 0.059 assuming chi-square distribution with 2 df.

Group	Count	Rank Sum
A	3	18.00
B	3	21.00
C	3	6.00

Non-Apidae bee encounters

I encountered 672 wild non-Apidae bees in the Native Meadow Trials in all surveys. In treatment A trials, I encountered 288 non-Apidae bees. In treatment B trials, I encountered 287 non-Apidae bees. In control trials, I encountered 97 non-Apidae bees. The observed frequency of non-Apidae bees in both treatments was not significantly different from the observation frequency in control plots (p = 0.065; Figure 16).

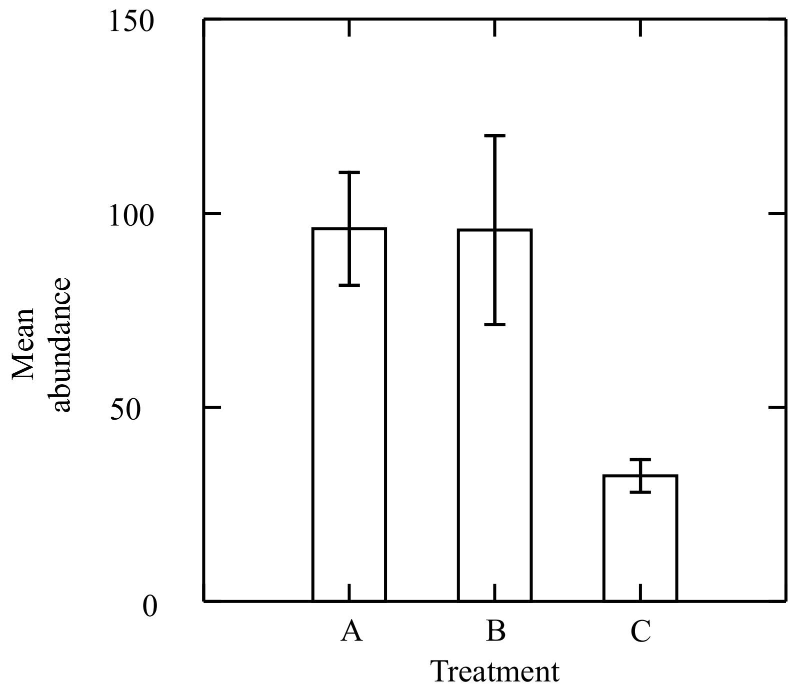

Figure 16. Comparison of non-Apidae bee encounters across Native Meadow treatments. Kruskal-Wallis results are presented in Table XI. N = 672. Bars represent standard errors.

Table XII. Kruskal-Wallis test statistics to accompany Figure 16. Kruskal-Wallis Test Statistic: 5.468. The p-value is 0.065 assuming chi-square distribution with 2 df.

Group	Count	Rank Sum
A	3	19.00
B	3	20.00
C	3	6.00

Hoverfly encounters

I encountered 546 hoverflies in the Native Meadow Trials. Of these, 246 were encountered in treatment A trials, 177 were encountered in treatment B trials and 123 were encountered in control trials. These differences in encounters across all three treatments were statistically significant ($p < 0.05$; Figure 17); pairwise analysis was not significant.

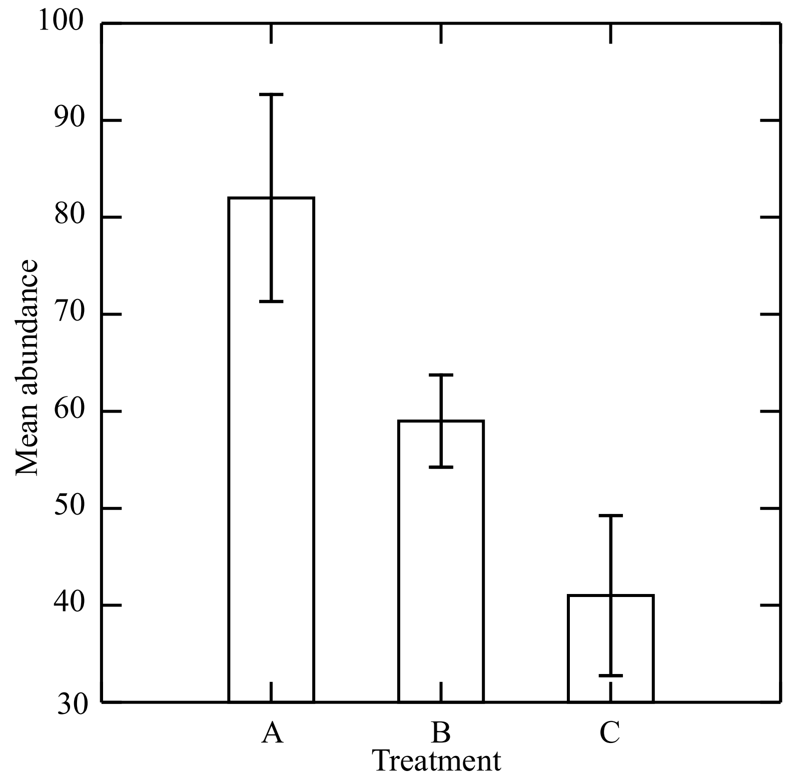

Figure 17. Comparison of hoverfly encounters across Native Meadow treatments. Kruskal-Wallis results are presented in Table XII. N = 546. Bars represent standard errors.

Table XIII. Kruskal-Wallis test statistics to accompany Figure 17. Kruskal-Wallis Test Statistic: 6.489. The p-value is 0.039 assuming chi-square distribution with 2 df.

Group	Count	Rank Sum
A	3	24.00
B	3	14.00
C	3	7.00

Encounters of other insect groups

A total of 215 wasps (75 in treatment A trials, 93 in treatment B trials, and 47 in control trials) were encountered. These encounters were not statistically significant across treatments (p-value = 0.285; Figure 18).

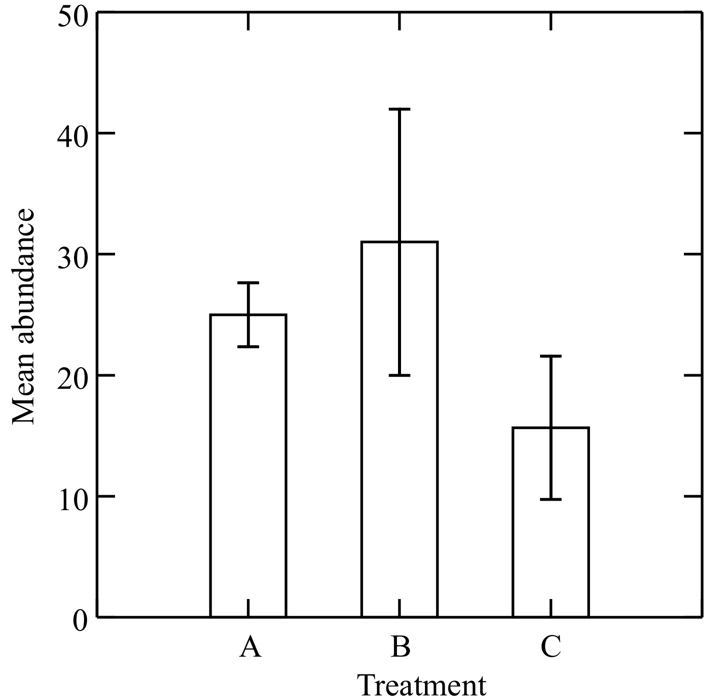

Figure 18. Comparison of wasp encounters across Native Meadow treatments. Kruskal-Wallis results are presented in Table XIII. N = 215. Bars represent standard errors.

Table XIV. Kruskal-Wallis test statistics to accompany Figure 18. Kruskal-Wallis Test Statistic: 2.510. The p-value is 0.285 assuming chi-square distribution with 2 df to accompany wasp analysis of variance.

Group	Count	Rank Sum
A	3	17.00
B	3	19.00
C	3	9.00

Lastly, 1,979 tarnished plant bugs were encountered (390 in treatment A trials, 673 in treatment B trials, and 916 in control trials). The differences in these encounters were not significant across treatments (p-value = 0.079; Figure 36-A and Table XLI-A in Appendix E). Similar trends occurred for lady beetles (see Figure 37-A and Table XLII-A in Appendix E).

Pollinator community response to native meadow treatments

Bray-Curtis similarity analysis was used to examine the differences in pollinator communities on each treatment based on taxonomic groups listed at the beginning of this section (Figure 19). Communities clustered into two groups around location, not treatment. In the first cluster (bottom branch), pollinator communities encountered in Trial 1 and Trial 2 had high self-similarity, regardless of treatment. In the second cluster (top branch), communities encountered in trial 3 and NMT2A had high self-similarity.

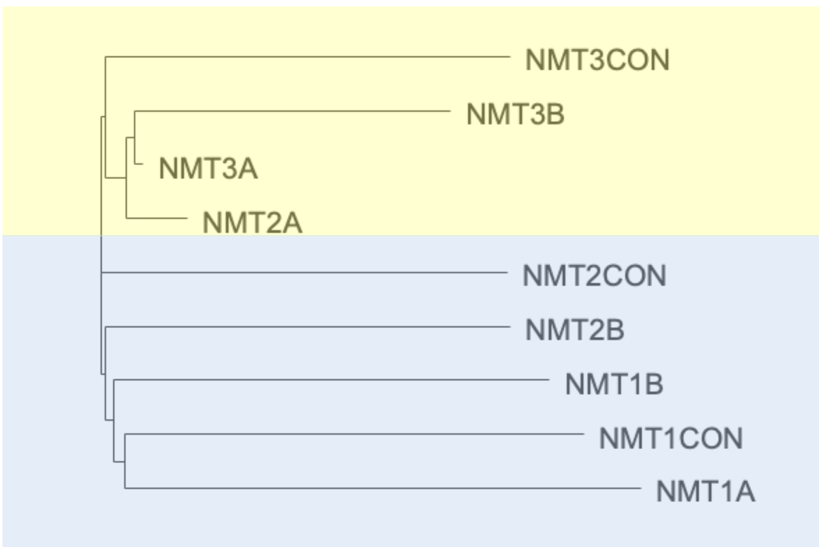

Figure 19. Additive tree dendrogram for Bray-Curtis similarity analysis of pollinator communities in Native Meadow Trials.

Discussion

For some groups of beneficial pollinators, such as bumble bees and hoverflies, the enriched seed mixes may attract significantly more individuals to the area. Although not measured in this study, other research on farms in New York State (Grab et al. 2018; Connelly et al. 2015) indicated that diverse landscapes can positively impact wild pollinator populations and subsequent fruit quality and quantity. Here, interpretation beyond test plot scale is limited.

The visual survey method indicated minimal or no difference in encounter rate across different treatments for the following groups: non-Apidae bees and wasps. Two groups of insects (lady beetles and tarnished plant bugs) were more abundant on plots established from the remnant agricultural seed bank (e.g. control plots; see Appendix E). Bray-Curtis similarity analysis failed to reveal any significant difference in community composition of observed pollinators across different treatments. Further study using GIS landscape analysis could elucidate variables other than floral abundance that are influencing pollinator communities at the farm scale.

Small sample sizes of certain groups of pollinators (e.g. wasps) may limit observation of any trends in occurrence different treatments. Pollinators are typically capable of long foraging distances and modifying foraging behavior based on resource availability (Spiesman and Gratton 2016). Given these variables, along with the proximity of the different Native Meadow trials to each other (< 2 km), the documented ambiguity of the observed communities across treatments and trials is not unexpected.

Here, the visual survey method also has some potential sources of error. Some taxonomic groups went unmeasured, or were poorly measured, due to limited capacity to identify to species in the field. For example, colleagues using sweep net sampling at the same site during the same field season noted an increased abundance of wasps in control plots. However, Horseweed was dense in these plots, and the height of Horseweed (> 6ft) limited observation of wasps and other pollinators foraging at the height of vegetation. Another limiting factor of wasp observation is their small size. Additionally, multiple flower visitations in rapid succession during periods of high flower density strained my capacity to record all flower visitation events.

This study was able to identify that high-forb density plots were able to attract significantly more hoverflies and bumbles to an on-farm habitat. Further study of increased pollinator diversity on farms has implications for ecological services to crops. The presence of physiologically similar pollinator species could provide redundancy in case of species loss, while the presence of many different species can add additional services and/or efficiency to the system (Cardinale et al. 2012). Recent evidence shows that agriculture is “pruning” certain taxonomic groups of pollinators from the field, contributing to potential loss in pollination services (Grab et al. 2019). Continued work should focus on the genetic study of physiologically or service-related clades captured in the field, supplemented with sweep and visual surveys, to seek to understand the phylogenetic structure of the pollinator communities attracted to the Native Meadow Trials. Such research would indicate whether specific taxonomic groups are present or absent, or vary in abundance, across different Native Meadow treatments.

Question 2: Can butterflies be surrogate measures of other flower visiting insects?

Analytical Methods

Based on ANOVA analyses and observations in the field of simultaneous butterfly–and bee–interactions with flowers, I conducted regression analyses using Excel 2013 and confirmed with SYSTAT 13 to identify whether Apidae and non-Apidae bee encounters could be estimated from butterfly encounters. Regression analyses were also conducted for the following insect groups: hoverflies, wasps, tarnished plant bugs and lady beetles. Observations were pooled for all treatments for May 2018 – September 2018.

Results

Regression analysis was conducted in order to see if a high abundance of butterflies could also be indicative of greater numbers of Apidae bees and non-Apidae bees in the Native Meadow Trials. Analysis revealed that a greater encounter frequency of butterflies was correlated with greater encounter rate of Apidae ($F = 30.579$, $r^2 = 0.814$, $p < 0.001$; Figure 20).

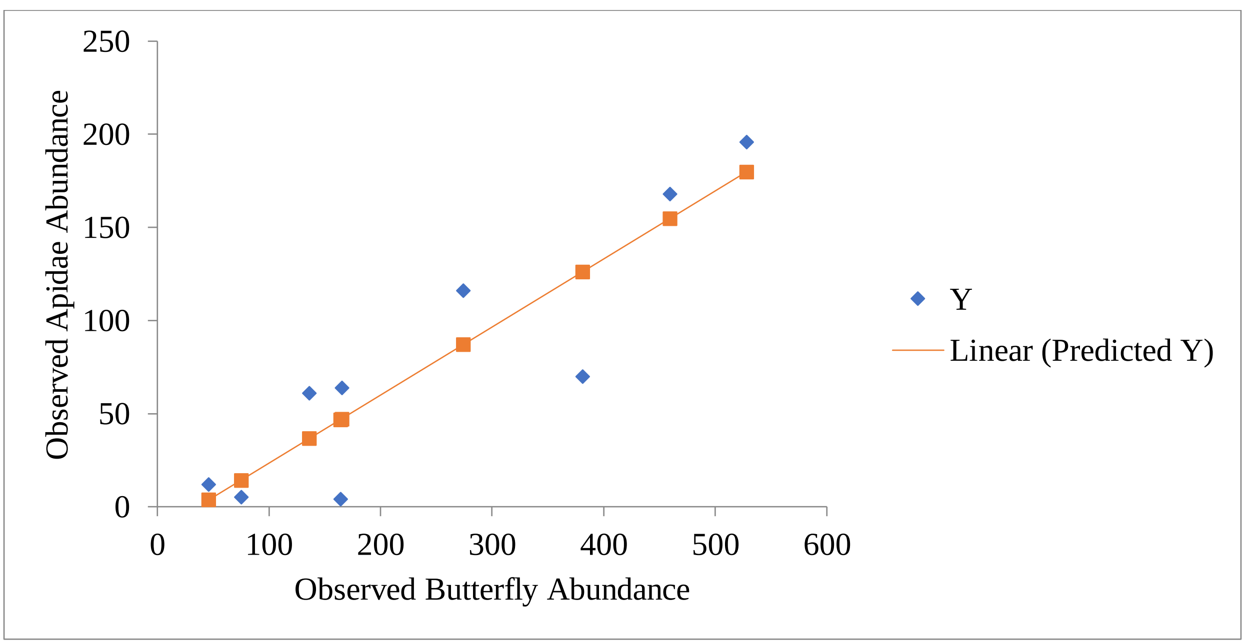

Figure 20. Regression analysis: butterfly and Apidae encounters in the Native Meadow Trials.

Table XV. Regression analysis statistics to accompany Figure 20.

	Coefficients	Standard Error	t Stat	P-value
Intercept	-13.169	19.588	-0.672	0.523
X Variable 1	0.366	0.066	5.530	0.001

Table XVI. Analysis of variance results to accompany Table XV.

	df	SS	MS	F	Significance F
Regression	1	31876.954	31876.954	30.579	0.001
Residual	7	7297.047	1042.435		
Total	8	39174			

Table XVII. Regression statistics to accompany Table XV and XVI.

Regression Statistics	
Multiple R	0.902
R Square	0.814
Adjusted R Square	0.787
Standard Error	32.287
Observations	9

Analysis also revealed a statistically significant correlation between butterflies and non-Apidae bees ($F = 10.687$, $r^2 = 0.604$, $p < 0.05$; Figure 21). Correlations between butterflies and hoverflies and between butterflies and wasps were not statistically significant (see Figures 22 – 23).

Regression analysis also revealed negative correlations between observed butterfly abundance and the abundance of each tarnished plant bugs and lady beetles. Both of these negative correlations were statistically significant (see Figures 24 – 25).

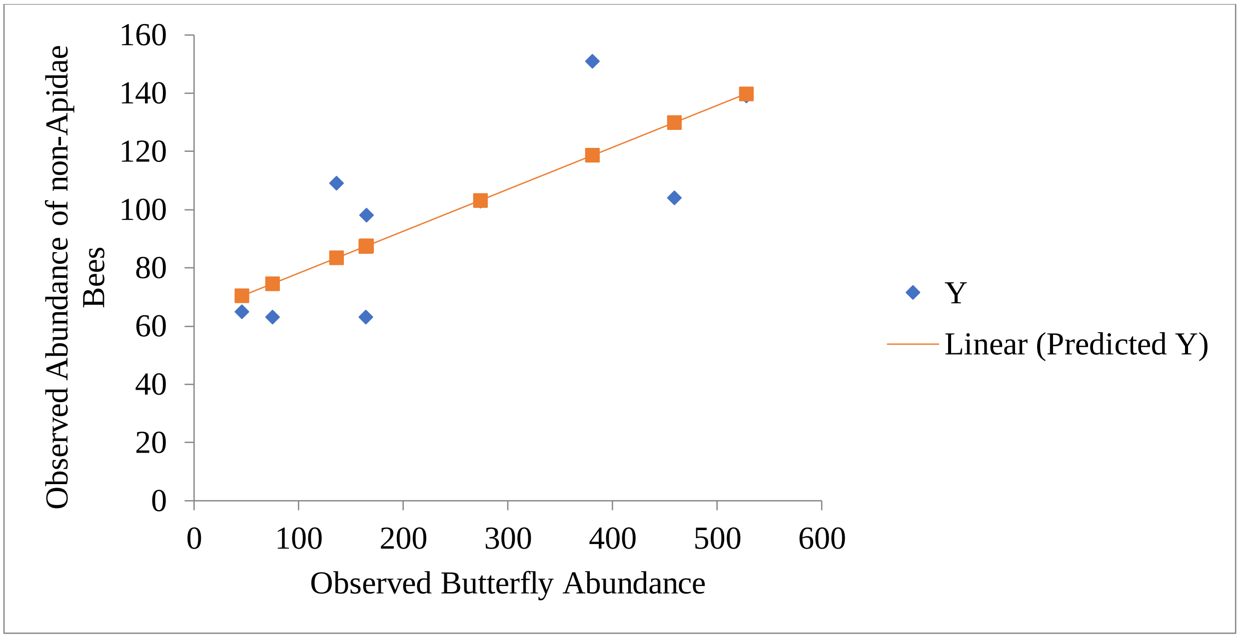

Figure 21. Regression analysis: butterfly and non-Apidae bee encounters in the Native Meadow Trials.

Table XVIII. Regression analysis statistics to accompany Figure 21.

	Coefficients	Standard Error	t Stat	P-value
Intercept	63.781	13.057	4.885	0.002
X Variable 1	0.144	0.044	3.270	0.014

Table XIX. Analysis of variance results to accompany Table XVIII.

	df	SS	MS	F	Significance F
Regression	1	4949.952	4949.952	10.687	0.014
Residual	7	3242.270	463.182		
Total	8	8192.22			

Table XX. Regression statistics to accompany Table XVII and XVIII.

Regression Statistics	
Multiple R	0.778
R Square	0.604
Adjusted R Square	0.548
Standard Error	21.522
Observations	9

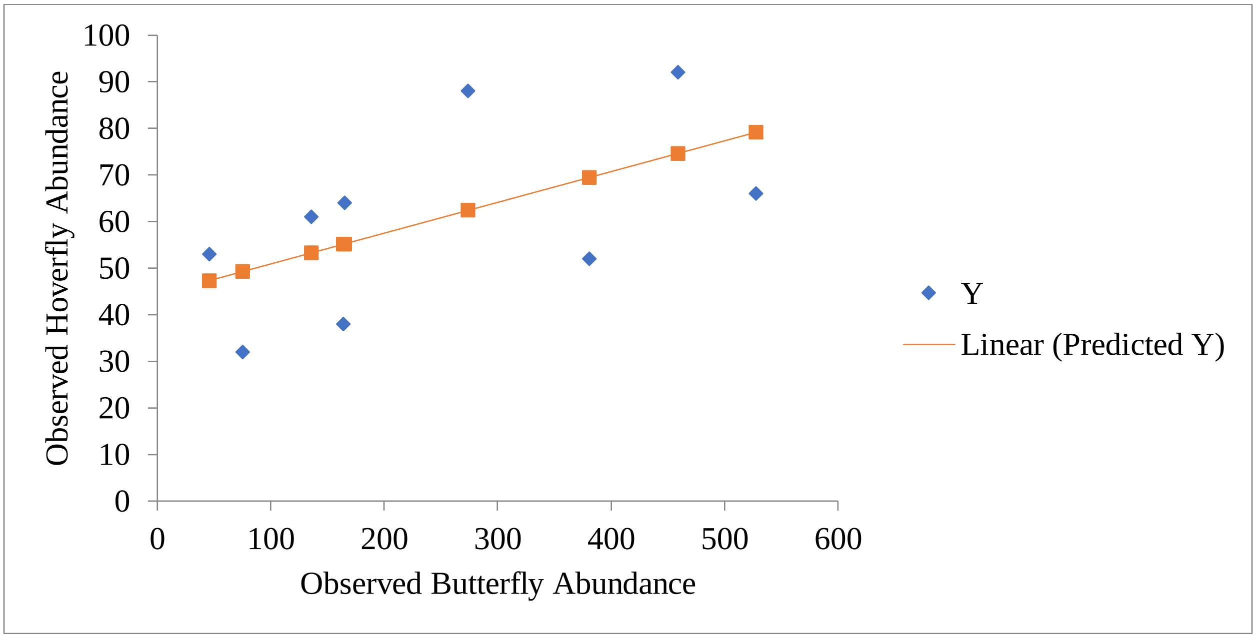

Figure 22. Regression analysis: butterfly and hoverfly encounters in the Native Meadow Trials.

Table XXI. Regression analysis statistics to accompany Figure 22.

	Coefficients	Standard Error	t Stat	P-value
Intercept	44.308	10.747	4.123	0.004
X Variable 1	0.066	0.036	1.822	0.111

Table XXII. Analysis of variance results to accompany Table XXI.

	df	SS	MS	F	Significance F
Regression	1	1041.477	1041.477	3.319	0.111
Residual	7	2196.524	313.789		
Total	8	3238			

Table XXIII. Regression analysis statistics to accompany Table XXI and XXII.

Regression Statistics	
Multiple R	0.567
R Square	0.322
Adjusted R Square	0.225
Standard Error	17.714
Observations	9

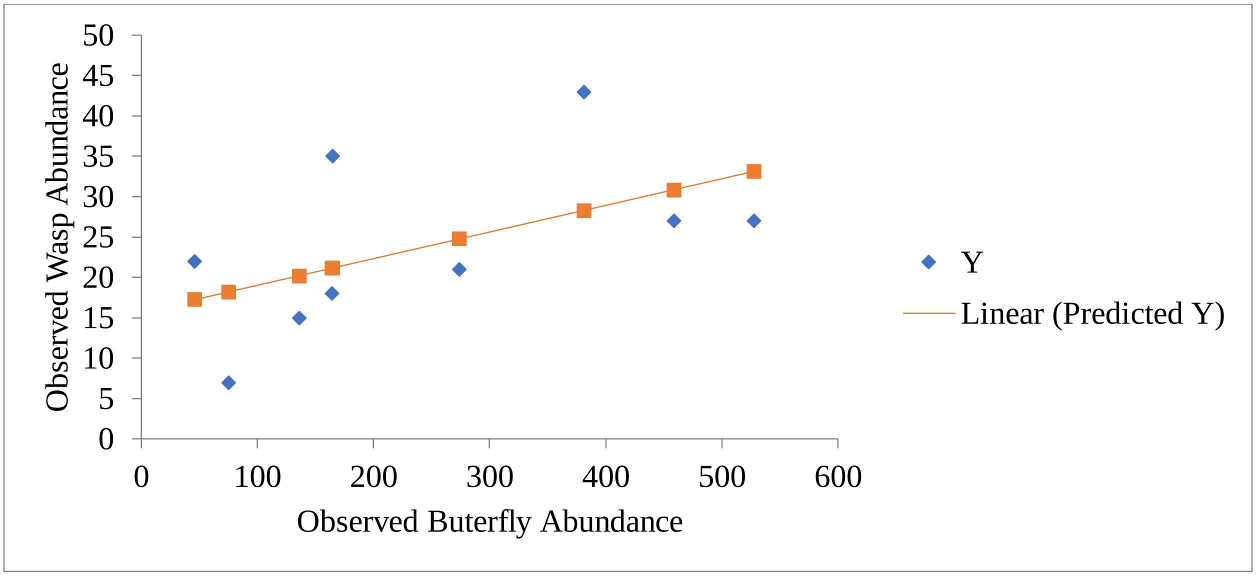

Figure 23. Regression analysis: butterfly and wasp encounters in the Native Meadow Trials.

Table XXIV. Regression analysis statistics to accompany Figure 23.

	Coefficients	Standard Error	t Stat	P-value
Intercept	15.725	5.889	2.670	0.032
X Variable 1	0.0331	0.020	1.659	0.141

Table XXV. Analysis of variance results to accompany Table XXIV.

	df	SS	MS	F	Significance F
Regression	1	259.393	259.393	2.753	0.141
Residual	7	659.495	94.214		
Total	8	918.889			

Table XXVI. Regression analysis statistics to accompany Table XXIV and XXV.

Regression Statistics	
Multiple R	0.531
R Square	0.282
Adjusted R Square	0.180
Standard Error	9.706
Observations	9

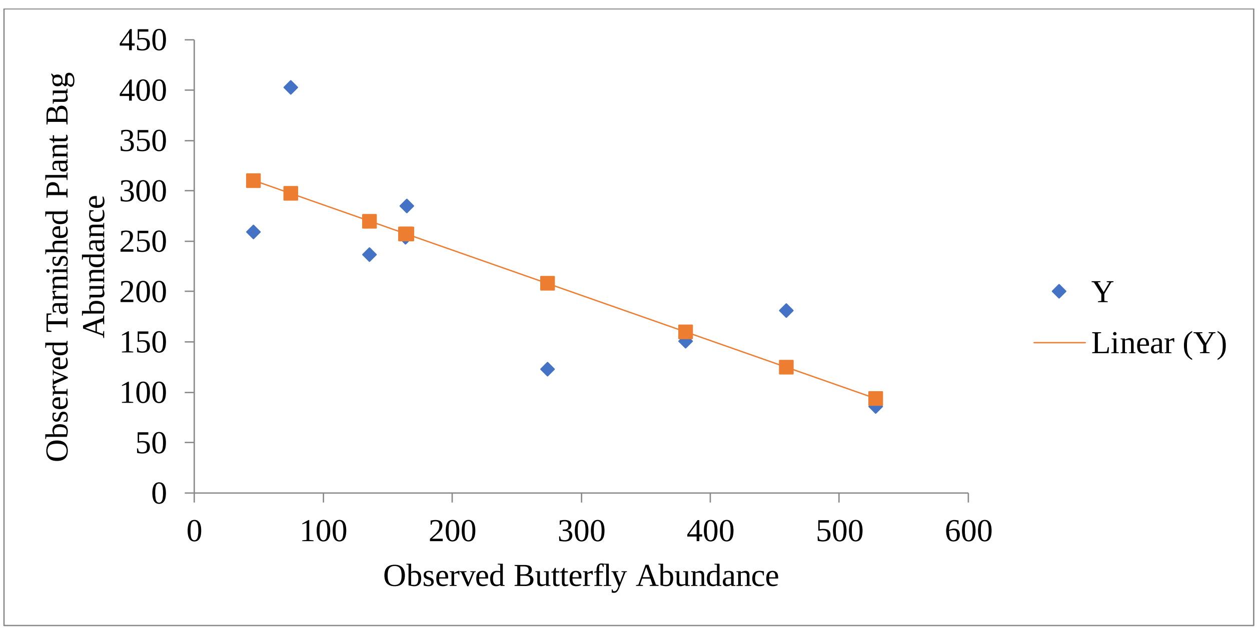

Figure 24. Regression analysis: butterfly and tarnished plant bug encounters in the Native Meadow Trials.

Table XXVII. Regression analysis statistics to accompany Figure 24.

	Coefficients	Standard Error	t Stat	P-value
Intercept	331.094	37.114	8.921	4.518E-05
X Variable 1	-0.449	0.125	-3.586	0.009

Table XXVIII. Analysis of variance results to accompany Table XXVII.

	df	SS	MS	F	Significance F
Regression	1	48129.037	48129.037	12.860	0.009
Residual	7	26197.852	3742.550		
Total	8	74326.889			

Table XXIX. Regression statistics to accompany Table XXVII and XXVIII.

Regression Statistics	
Multiple R	0.805
R Square	0.648
Adjusted R Square	0.597
Standard Error	61.176
Observations	9

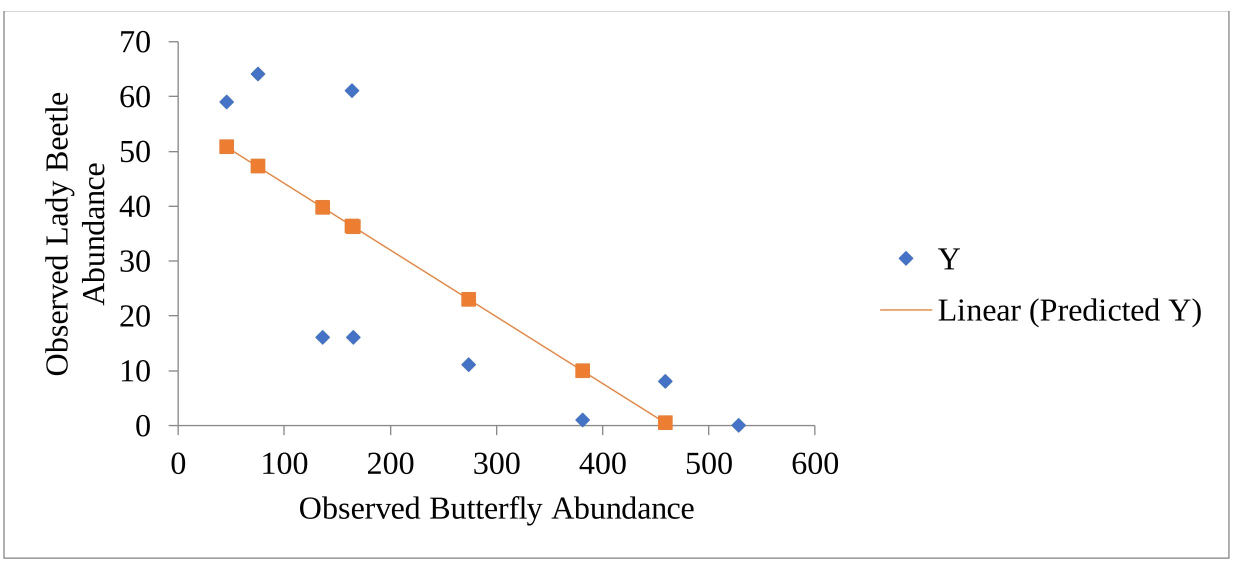

Figure 25. Regression analysis: butterfly and lady beetle encounters in the Native Meadow Trials.

Table XXX. Regression analysis statistics to accompany Figure 25.

	Coefficients	Standard Error	t Stat	P-value
Intercept	56.346	10.940	5.151	0.001
X Variable 1	-0.122	0.037	-3.296	0.013

Table XXXI. Analysis of variance results to accompany Table XXX.

	df	SS	MS	F	Significance F
Regression	1	3531.492	3531.492	10.861	0.013
Residual	7	2276.063	325.152		
Total	8	5807.556			

Table XXXII. Regression statistics to accompany Table XXX and XXXI.

Regression Statistics	
Multiple R	0.780
R Square	0.608
Adjusted R Square	0.552
Standard Error	18.032
Observations	9

<u>Discussion</u>

Regression analysis indicates that observed butterfly abundance positively correlates with the observed abundances of Apidae bees and non-Apidae bees more strongly than random chance. One can tentatively conclude that butterflies and bees can be indicators for each other. A butterfly survey could be used by interns, farmers, and/or land managers to gather an initial understanding of bee abundance on the farm. This result was expected because of the similar long-tongue foraging morphology of both butterflies and bumble bees and the presence of flowers with deep nectaries in treatment A.

Research conducted by Jones (2019) indicates that bumble bees are more likely to visit flowers that are being visited by conspecifics. Anecdotally, I observed bumble bees visiting flowers in quick succession after a butterfly landed on the flower. It is possible that bees are using visual cues from butterfly visitation regarding nectar availability. A future behavioral study in the lab could ask whether bees are likely to visit a flower equipped with a butterfly model.

If this positive correlation is replicable in other studies, there could be assessment implications for New York farm operations that rely on wild bumble bees for pollination ("buzz pollination"), specifically blueberries, tomatoes, peppers and eggplant. This positive correlation may not be replicated, however, due to the different emergence times of bumble bees and butterflies throughout the Northeast field season.

The correlation between butterflies and wasps was not statistically significant. Based on the comparison of abundances between treatments, one would expect there to be a negative correlation between wasps and butterflies (due to the higher abundances of wasps in control plots compared to treatment A documented via other sampling methods). Due to the height of vegetation in control plots, it is possible that the wasp abundances were under documented in visual surveys. Additionally, wasps may utilize different flowers due to their small foraging morphology (compared to long tongued butterflies and bees). Further study of wasp abundances would provide additional insight into whether wasps and butterflies are attracted to similar on-farm habitats and flowers.

Regression analysis indicates that observed butterfly abundance negatively correlates with the observed abundances of tarnished plant bugs and lady beetles. The negative correlation between butterflies and tarnished plant bugs is statistically significant, and one can conclude that high butterfly abundances may indicate lower abundances of these common pests outside of a random chance. This negative correlation could have occurred due to tarnished plant bug natural history (e.g. use of weedy areas with dense foliage at different life stages; Young 1986), or due to increased competition with larger flower visiting insects in on-farm habitats with greater flower density; however, both of these ideas must be explored with further study.

In practice, a negative correlation between butterflies and tarnished plant bugs could indicate that attracting butterflies to an on-farm habitat won't draw as many tarnished plant bugs (compared to fields undergoing un-mediated succession, as represented by the control plots), which are known to damage fruit crops such as strawberries. Future study could quantify the amount of crop damage to strawberry crops planted in proximity to habitat enrichment schemes similar to treatment A and compare crop damage due to tarnished plant bugs adjacent to control plots. Here, further study regarding wasps and other natural predator abundances in these plots would provide greater understanding of the mechanism(s) of biological control at play in habitat enrichment schemes.

The negative correlation between butterflies and lady beetles was not statistically significant. It is likely that the difference in observations between the number of butterflies and the number of lady beetles prevents full understanding of the relationship, if any, between lady beetle abundance and butterfly abundance.

Due to the diverse natural history and foraging behavior of different insect groups, any further interpretation of these initial correlations in observed abundances is limited. Deeper study of intra- and inter- specific competition and signaling may also be a promising avenue of study that may yield further understanding of positive and negative correlations among butterflies and other insect groups.

Question 3: Do different flower species present in on-farm habitats attract flower visiting insects equally?

Analytical Methods

Based on the diversity of on-farm habitats and the diversity of flowers available within both treatments, I wanted to better understand if pollinators were attracted to certain flowers more than would be expected, given the proportional abundance of those flowers. To account for the differential availability of the various flower species in on-farm habitats, insect visitation was compared to the relative proportion of each flower species available.

First, I calculated the total area that I sampled over each month based on the following:

$$= (\text{total visits})\left(\frac{\text{total points sampled}}{\text{visit}}\right)\left(\frac{\text{area sampled}}{\text{point}}\right)$$

For example, in September 2018, each habitat was visited twice, and 460 total points were sampled; 1.313 m^2 was sampled at each point, thus 603.98 m^2 was sampled in September. In all, 2,205.84 m^2 was sampled in the Native Meadow Trials between June and September 2018.

For every flower species present during the month, I converted the relative floral area rank to percent cover, using the values presented previously in Table IV. Given that a low number of encounters of a high-density flower could skew the average floral rank of the flower, all flower species with fewer than 10 encounters over the season were pooled into a category "other."

Then, I calculated the average percent cover of each flower species present throughout the time period of interest. Using these values, I determined the total area of each flower species present (area per point x total points sampled that month) and the total floral area of all flower species (sum of all floral area calculations) together.

These values were then used to calculate expected number of insect visits based on the overall availability of different flower species:

$$= (\%\ \text{of total available floral area represented by species})\ \text{x}\ (\text{total number of pollinator visits})$$

For example, if Lance Leaved Coreopsis represented 40 percent of the total available floral area on the farm in July, and there were 800 total pollinator visits, then 320 of those visits would be expected to be to Lance Leaved Coreopsis.

The calculated number of expected visits was then subtracted from the actual number of pollinator visits and divided by the number of expected visits to compare if the difference was greater or less than expected. These values per flower species were ranked from largest to smallest and graphed (Figure 26 - 29) to indicate which flower species attracted more than the anticipated number of visits based on floral area, and which of those attracted fewer than the anticipated number of visits based on floral area. A value of 1 indicates that a flower species received twice as many insect visitors as expected. On the other hand, a value of -0.5 indicates that a flower species received only half as many insect visitors as expected.

Given that the number of observations per taxonomic group were variable over the course of the season, often with fewer than 50 discrete observations on each flower species that attracted 10 or more visits than anticipated, the composition of these visiting groups is described in Figures 54-A – 76-A in the Appendix.

Results

Flower-visitation events

Nearly 70 percent of pollinator-flower interactions (in the Native Meadow Trials) occurred on five plant species. 34 percent of pollinator-flower interactions occurred on Black Eyed Susan, 15 percent on Horseweed, 8 percent on Lance Leaved Coreopsis, and 6 percent each on Wild Bergamot and New England Aster. Across all on-farm habitats sampled, 32.5 percent of visitations were to seeded, native flowers. 22.5 percent were to non-seeded, native flowers (55 percent of visitations to native flowers total), and 40 percent of visitations were to non-seeded, non-native flowers.

There were 78 observed flower-butterfly interactions: 32 percent on New England Aster, 27 percent on Wild Bergamot, 13 percent on Black Eyed Susan, 12 percent on Echinacea, 5 percent on Lance Leaved Coreopsis and 1 percent on each Wild Radish and Smooth Blue Aster. 86 percent of the butterfly-flower interactions involved visitation to seeded, native flowers.

Each dominant flower attracted a different number of pollinator groups. Black Eyed Susan attracted 14 taxa/groups. Horseweed attracted 9 taxa, Lance Leaved Coreopsis and Wild Bergamot: 9, each, and New England Aster: 5.

The following accounts present pollinator visitation to flowers while considering the varying dominance of the different flower species across the farm and season.

Expected vs. Actual Visitation to Flowers

In June, several early blooming flowers across the farm attracted more pollinator visits than would be expected. Among these flowers were Creeping Buttercup, Shepherds Purse, Hairy Vetch and Lance Leaved Coreopsis (Figure 26). Bees, both non-Apidae bees and Apidae, were the dominant visitors to these plant species in June (approximately 70 percent of visitors).

Hoverflies were also a notable visitor to Lance Leaved Coreopsis in June (39 percent of visitors). Other species that attracted more than the anticipated number of visits were Galinsoga, Philadelphia Fleabane, Red Clover and White Clover. See Figures 54-A – 56-A in Appendix G for the composition of pollinator visitors to some flowers with greater than expected visits for June.

Other flower species represented a significant proportion of the total floral area in the samples in June, but there were fewer than expected pollinator visits. Some flowers in this category were Prairie Coreopsis, White Plantain, Chicory and Round Headed Bush Clover.

In July, Black Eyed Susan, Queen Anne's Lace, Annual Fleabane and Spotted Knapweed all attracted more pollinator visits than expected. Among these, there were 423 more than the expected visits to Black Eyed Susan alone. Spotted Knapweed and Black-Eyed Susan attracted proportionally more bees (total bees: 87 percent and 74 percent of visits respectively), while Queen Anne's Lace and Annual Fleabane attracted mostly wasps and non-Apidae bees (approximately 30 percent of visits to both flowers in this month were wasps). In contrast, Chicory, Anise Hyssop, Spearmint, Spilanthes and many others all received fewer than the anticipated number of pollinator visits based on floral area. See Figures 57-A – 60-A in Appendix G for the composition of pollinator visitors to flowers with greater than expected visits for July.

Black Eyed Susan persists as a species that received greater than the expected number of visits given its floral abundance in August (53 more visits than expected). In addition, Horseweed (177 more visits), Chicory (124 more visits) and Wild Bergamot (64 more visits) also received a greater number of pollinator visitations based on their overall floral abundance. Visits to all of these flowers, except Horseweed, were dominated by bees. Together, wasps and hoverflies composed 70 percent of visits to Horseweed in August. See Figures 61-A – 68-A in Appendix G for the composition of pollinator visitors to flowers with greater than expected visits for August.

Cultivated flowers in the Herb Garden and the Cut Flower Garden represented a significant proportion of the total available floral area in August, however each received far fewer than the expected number of visits from pollinators. Some of the flower species that were cultivated but received fewer than anticipated visits were Zinnia, Celosia, Spilanthes and Anise Hyssop. This pattern of lower than expected visitation rates for these species persists through September.

New England Aster (98 more visits than expected), Horseweed (68 more visits than expected), Goldenrods (64 more visits than expected), White Clover (37 more visits than expected) and Lance Leaved Coreopsis (14 more visits than expected) are among the flowers with greater than expected visits in September. Lance Leaved Coreopsis and Horseweed attracted more wasps and hoverflies compared to other flowers that attracted many visitors, while the remainder attracted predominantly bees. See Figures 69-A – 75-A in Appendix G for the composition of pollinator visitors to flowers with greater than expected visits for September.

Notably, pollinator visits to White Clover were greater than the anticipated number of visits in three out of four months of the field season (in July, Enriched Hay fields, where White Clover was common, were mowed). For other flower species, such as Black Eyed Susan and Chicory, actual pollinator visits were greater than the number of expected visits for the part of the season, although this pattern shifts over time. In contrast, certain flowers that represented a greater proportion of total floral area during the season, such as Anise Hyssop, Zinnia and Celosia, consistently received fewer than expected pollinator visits.

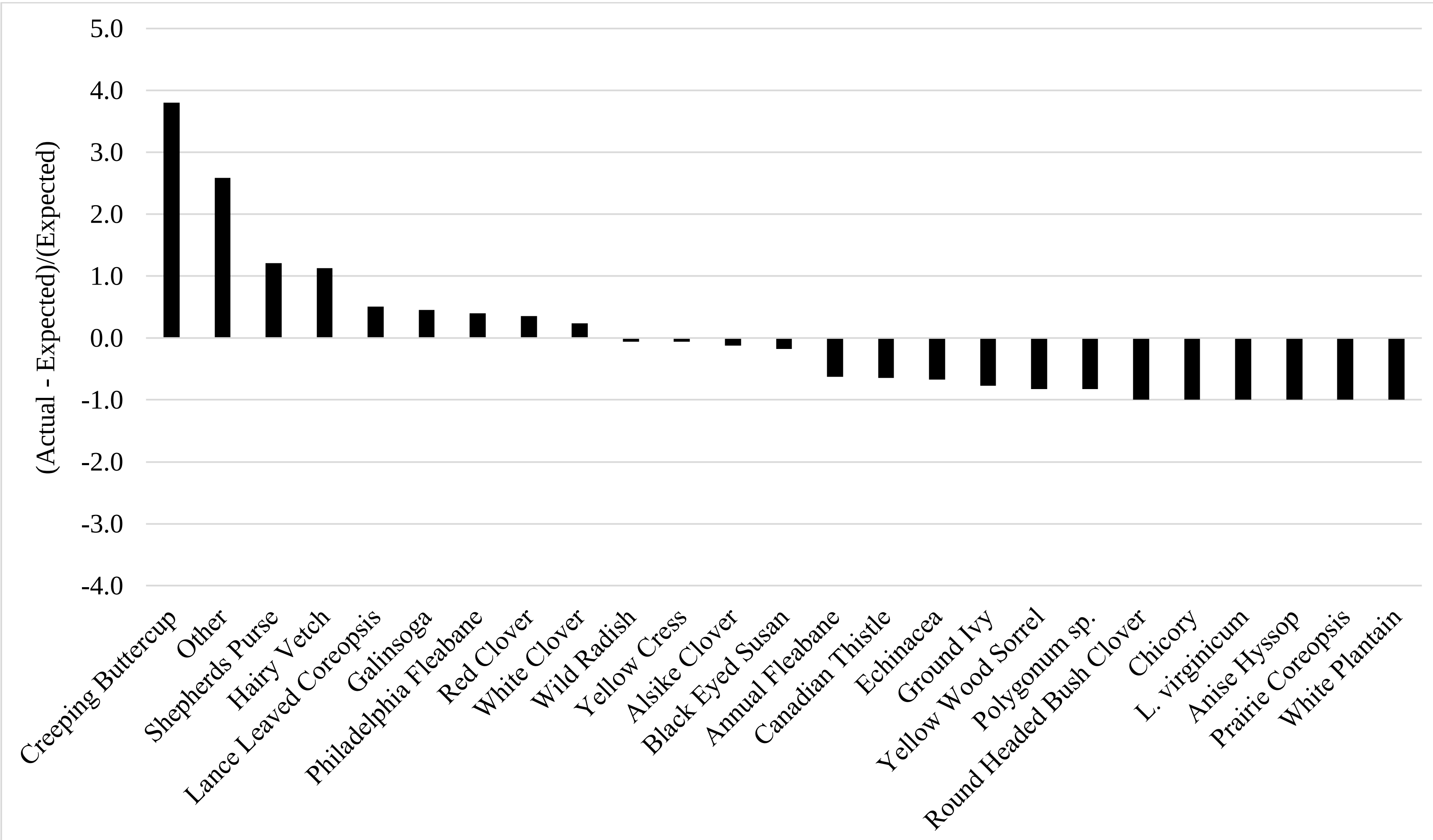

Figure 26. Difference in expected and actual number of pollinator visits to flowers in all on-farm habitats in June 2018. Total sample points = 400; total observations = 752.

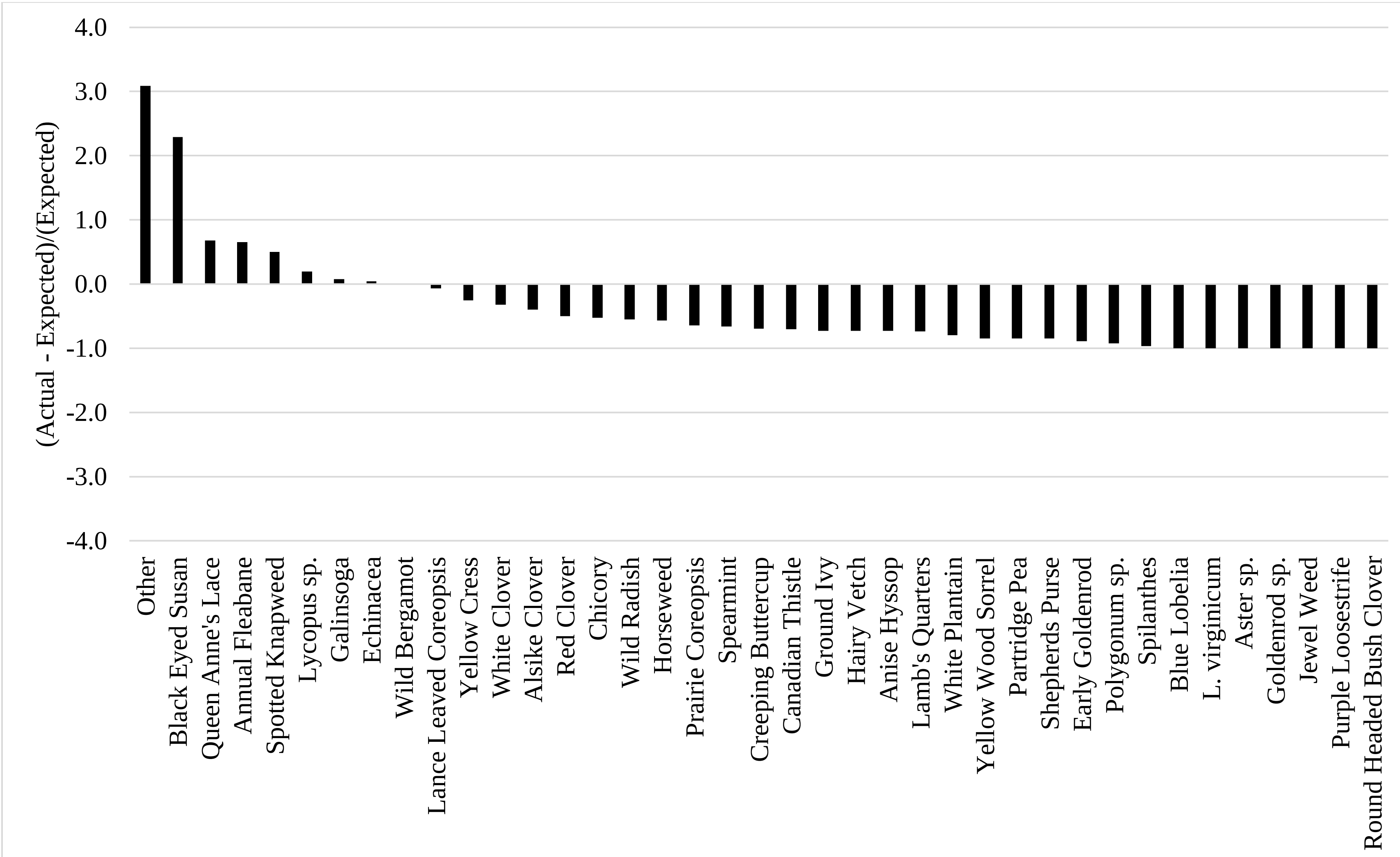

Figure 27. Difference in expected and actual number of pollinator visits to flowers in all on-farm habitats in July 2018. Total sample points = 460; total observations = 1,413.

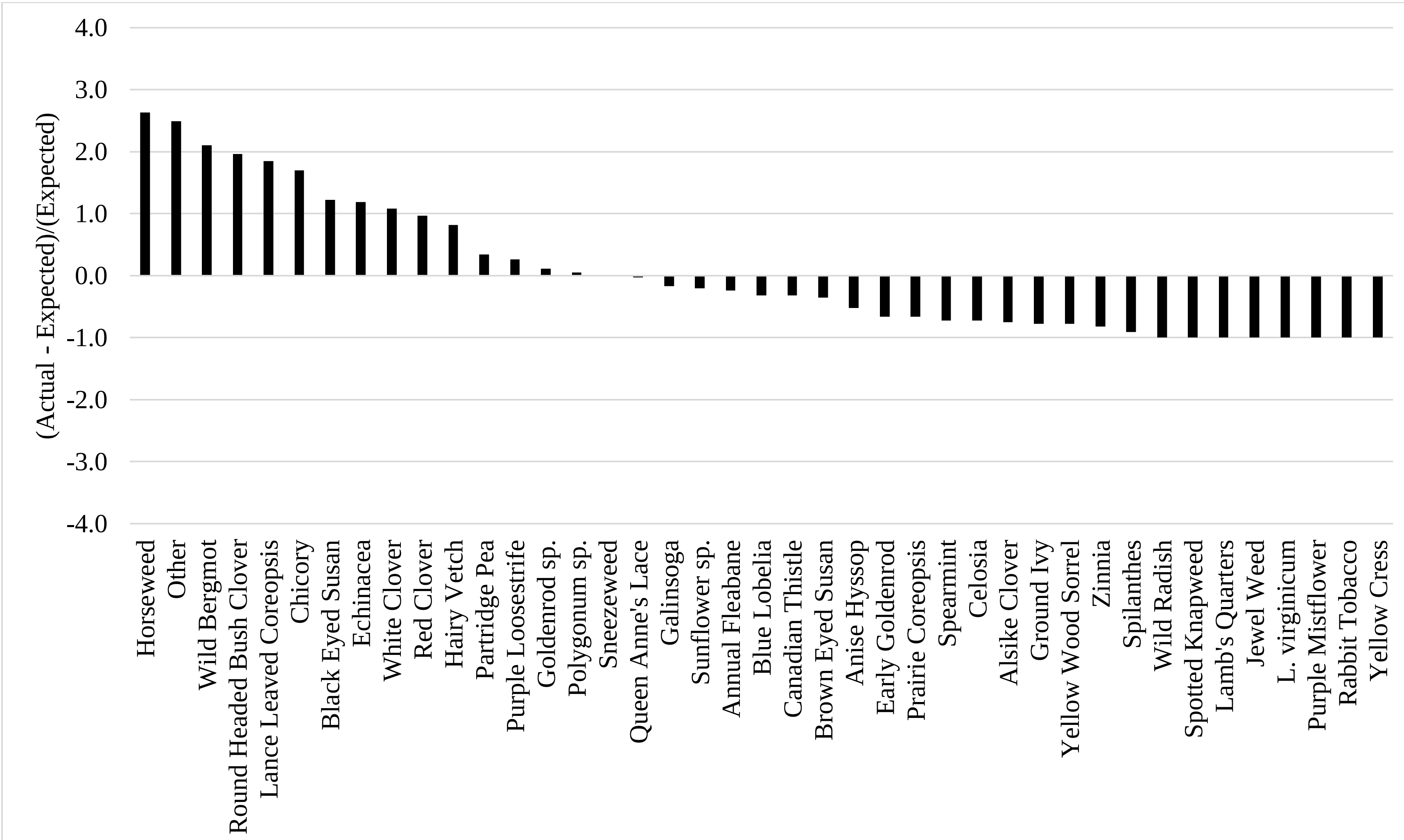

Figure 28. Difference in expected and actual number of pollinator visits to flowers in all on-farm habitats in August 2018. Total sample points = 360; total observations = 1,383.

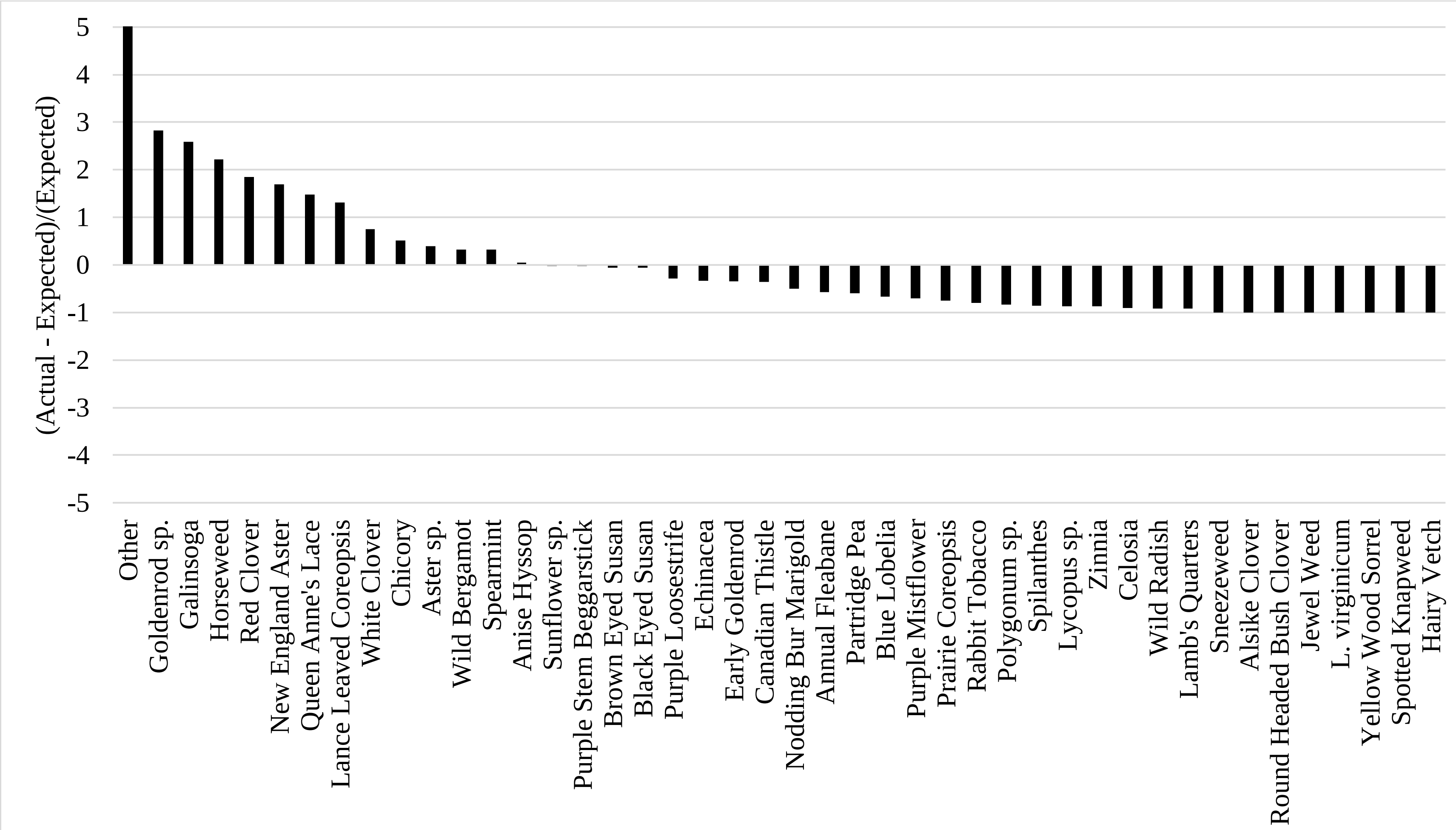

Figure 29. Difference in expected and actual number of pollinator visits to flowers in all on-farm habitats in September 2018. Total sample points = 460; total observations = 1,254.

Discussion

These results affirm trends from Research Questions 1 and 2, and reveal new understanding not provided by the analysis of treatment effect as a whole. Trends and new understanding are summarized here, followed by discussion of possible sources of incongruities and suggested future studies.

Results in Research Questions 1 and 2 revealed that many pollinator groups, such as bees and butterflies, were attracted to treatment A and treatment B of the Native Meadow Trials. Analysis here reinforces this trend, since comparison of expected and actual visits to flowers indicates that pollinators were drawn to Black Eyed Susan, planted in both treatment A and B, more often than would be anticipated based on the proportion of floral area it represented on the farm. Comparison of expected and actual visits also shows that other flowers in the Native Meadow Trials were visited more than would be anticipated in certain months: Lance Leaved Coreopsis, Wild Bergamot and Echinacea. Treatment level analysis revealed inconclusive information regarding wasp abundance. Here, flower-specific analysis reveals that Horseweed, the dominant flower in the control plots, was visited most often by hoverflies and wasps. This reinforces the high observed wasp abundance documented in the control plots with other sampling methods.

Given that cultivated areas attracted more pollinators compared to enriched and background habitats, it is interesting that some flower species planted in that area have fewer than anticipated visits based on floral area. For example, floral area ranks indicate that Zinnia and Celosia were dominant flowers in the Cut Flower Garden, but based on their proportion of total area sampled in July and August, they still attracted fewer than the expected number of pollinator visits.

Furthermore, it is interesting that the same flower species may attract different numbers of pollinators throughout the season (e.g. shifting number of actual visits to Black Eyed Susan and Lance Leaved Coreopsis June – September, even when considering the relative floral area each contributed to the landscape). For example, in June, Black Eyed Susan received fewer than expected number of visits from pollinators, but in July, it was by far the most visited flower species sampled on the farm. This is likely due to the peak availability of Black Eyed Susan nectar in July.

It is possible that certain flowers on the farm landscape are using other signals to attract pollinators, such as ultra-violet light patterns on flower petals, scent and varying quantity and nutritional quality of nectar. It is known that bees are capable of perceiving wavelengths of light outside the normal range of human vision. Flowers such as sunflowers, Black Eyed Susan and Coreopsis, have visible patterns that appear under different wavelengths of light. This signaling may account for some of the additional visits to these flower species compared to expected values.

Additionally, flower species in the Native Meadow Trials and in other dense on-farm habitats, may have benefited from a "cumulative attraction effect." Since there was a high number of diverse forbs in a small area, the flowers in that area benefited from the additional pollinator visits that occurred due to proximity to highly attractive flowers.

Likewise, there are some possible explanations for the lower than expected visitation rates to other flower species, or similar species at different times during the field season. Some flowers that were present in high densities, with high floral area ranks, may have received lower than anticipated pollinator visits because of their natural history. For example, Zinnia, Celosia, and Spilanthes are all cultivated flowers that are native to areas of Mexico and Central/South

America. While there is documentation of insects both visiting and relying on non-native plants for resources, there may be an adaptive delay for pollinators of a region to modify behavior to utilize these resources. Additionally, due to these flowers' native ranges, they bloom later in the season compared to native flowers such as Lance Leaved Coreopsis. As a result, their peak floral display (and/or peak nectar quality) may not match periods of peak pollinator abundance in New York's Southern Hudson Valley. Other flowers, through selective breeding and horticultural selection, may have lost the ability to produce pollen and nectar, and thus attract fewer pollinators.

This analysis also has limitations. First, there are inherent limitations in the sampling methodology. Even though floral area ranks were calibrated in the field, conversion to area based on the median range of each rank only provides coarse estimates of area. Additionally, for some species, these floral ranks could have overestimated (e.g. Horseweed) or underestimated (e.g. White Clover and Black-Eyed Susan) the relative availability of the flower across the farm during that time period. As mentioned previously, the visual sampling methods were also made at the height of the observer, thus likely underrepresenting the number of visitations (particularly those of wasps and other small insects) made to floral displays underneath other layers of vegetation or above the observer.

Second, the nature of the analysis presented here, though developed to address limitations of the data set, fails to address some ecological traits of both insects and flowers. For example, visitation to a flower does not necessarily indicate foraging behavior or successful pollination. It is known that some insects will "rob" nectar without depositing or picking up pollen, and others carry relatively little pollen. Here, visits to flowers may suggest successful provision of resources and pollination, but the data set does not measure either of these variables. The data analysis here also does not categorize flowers based on similar traits, such as color (which can provide reinforcing or contrasting signals), which may be influencing pollinator attraction to different species and treatments.

Moreover, insects emerge at different points in the season. Data here is pooled either for the entire season or for a single month of the season; some pollinator species may not live that long. For other species, such as the Monarch butterfly, there could be migratory patterns that are not captured at the month or season level scale. Even other species, such as the Cabbage White butterfly, have multiple broods per season.

While seven different on-farm habitats were sampled, they were all cultivated or early successional habitats. There are other habitats present at the Farm Hub and other farms of the Southern Hudson Valley, such as riparian corridors, secondary forest, primary forest and the built environment itself. In each of these, there are also floral resources available to pollinators. Furthermore, insects move among these different habitats and utilize different resources at different points of both the season and their life cycle. Analysis here focuses only on the use of floral resources in open, on-farm habitats by pollinators.

Additionally, for some flower species, a single encounter of the species at a high density skewed the calculation of total floral area it represented on the farm. To address this, only flowers with 10 or more encounters were considered for determination of proportion of total floral area available. The remainder of flowers, both wild and seeded in various on-farm habitats, were pooled into an "Other" category. Analysis reveals that this category of other flowers on the farm provides a consistent source of floral resources for different pollinators over the course of the season (as represented by the greater than expected number of visits to this category over the course of the entire season), even though the flowers in this group were not analyzed individually. This result is reinforced by previous analysis of average floral rank throughout the season; “all others” in the Native Meadow Trials maintained an average floral rank of 1.0 – 2.0 (approximately 0.5% - 10% cover) throughout the field season. Finally, while the flower preference calculations are based on the pooled visits of all insects, and the pie charts in the Appendix do represent the proportions of different insect groups seen on various flower species at different times throughout the summer (without consideration of the relative abundance of each flower or the number of insects in each group observed on all flowers during the respective period), the number of observations was not enough for a detailed analysis of flower preference within individual insect groups.

To address the limitations named here, future study could focus on the following questions: (1) How do these results compare to different sampling methods, such as timed flower watches at single individuals of a species? (2) How do pollinators and other flower-visiting insects move among and between different on-farm habitats, and what floral resources are available to pollinators within riparian corridors, forest habitats and the built environment? and (3) What signals (e.g. nectar quality) are the insects we hope to attract to the on-farm habitats positively responding to?

CONCLUSION

My study provides initial evidence that regionally specific, pesticide-free habitat enhancement strategies can attract pollinators and other beneficial insects to on-farm habitats. My results here indicate that observed butterfly abundance is greater in on-farm habitats with high-density floral resources, such as the native meadows established at the Hudson Valley Farm Hub. Greater butterfly abundance also positively correlates with the observed abundance of certain other pollinator groups: bumble bees and honey bees, non-Apidae bees and hoverflies. If these results can be consistently verified at other Hudson Valley farms, butterflies can be used by citizen scientists, interns, students and land managers when surveying the on-farm landscape as indicators of certain beneficial insects.

Moreover, results here validate the need for continued study of the capacity of certain flower species, both within habitat enhancement treatments and naturally occurring across the farm landscape, to attract different insect groups to the farm. Deeper understanding will empower farmers and land managers to make informed choices about how to naturally attract pollinators and control potential pest species. While there is always demand for ongoing research and understanding, this study affirms that native flower enhancement projects are a tool that ecologists can quickly and effectively improve on-farm habitat for butterflies and other pollinators in New York State’s Southern Hudson Valley region.

AFTERWORD: POLLINATOR POLICY OVERVIEW

Historically, agriculture in New York has been a leading cause of habitat destruction and fragmentation; while there are other dominant causes of habitat destruction in our modern world, agriculture remains both a source of natural habitat conversion and a contributor to regionally economic activity and food production. In order to preserve biodiversity and increase food resiliency, land managers, conservationists and farmers in New York are beginning to embrace methods that maintain crop quality and quantity *and* support ecosystem services provided by the plant and animal species in the farm's surroundings. My study contributes to the growing body of knowledge regarding how "whole landscape" management (e.g. production, land use and habitat enhancement decisions) can impact both production and insect communities on the farm. Here, I summarize (1) the current status of federal and state policy supporting pollinators and (2) management and policy implications of this work.

Federal Policy

For the purpose of this thesis, I considered legislative policy and federal agency guidance documents. Specifically, I consider the mention of pollinator communities in the 2018 Farm Bill, guidance documents from the U.S. Department of Agriculture and the Environmental Protection Agency, and recent agenda setting memos issued from the executive branch. Many of these policies and regulations were developed in the "Strategy to Promote the Health of Honey bees and Other Pollinators," the Pollinator Research Action Plan and/or the Pollinator Protection Task Force created by the executive offices of President Obama between 2014 and 2016 (Vilsack and McCarthy 2016; Office of the Press Secretary 2014).

In October 2018, the Farm Bill was reauthorized with bipartisan support. In the Habitat Protection Act (S. 1496), crop producers are provided financial incentives for utilizing conservation practices to benefit pollinators under the following programs: Conservation Reserve Program, Conservation Security Program, and the Environmental Quality Incentive Program. All three of these programs already exist, and financial investment in these programs remained constant; the definition of applicable activities that receive financial incentives was simply expanded to include pollinators (U.S. Congress 2018). Increased availability of grant funds can encourage farm owners and land managers to plan and implement management strategies that support pollinator health. This thesis aims to contribute to the growing body of knowledge that will inform farmers on (1) how to develop low-maintenance habitat for pollinators without the use of pesticides and (2) which management strategies can support specific taxa of pollinators, in a regionally appropriate manner.

The Saving America's Pollinators Act (introduced in 2017; HR 3040) tasked the Environmental Protection Agency and the Department of the Interior with (1) suspending the use of neonicotinoid pesticides until evaluation of their impact on pollinators is complete, (2) monitoring native bee populations and (3) identifying potential causes of mortality among native pollinator groups. This act would have had significant impact on pesticide use on farms and plant nurseries. The Act was neither voted upon nor passed at the time of its introduction. If passed, it would fund research evaluating the role of neonicotinoids and associated pesticides on pollinator communities. The negative impact of chemical inputs on our pollinator communities increases the need and value of studies such as this, that demonstrate how habitat enhancement can (1) be established without the use of herbicides, (2) contribute to pollinator health and (3) attract beneficial insects that may mitigate pest populations on crops (U.S. Congress 2017). Results indicating impact of pesticides and herbicides on our pollinator communities, and thus regional food resiliency, will greatly impact our contemporary food production and distribution.

Despite the failure of the Saving America's Pollinators Act to reach a vote in the House of Representatives, the U.S. Department of Agriculture and the U.S. Environmental Protection Agency each have internal policies and programs concerning pollinators, described below.

The Forestry Service, within the U.S. Department of Agriculture, issued the "Pollinator-Friendly Best Management Practices for Federal Lands" in 2015. This document provides farmers with resources and guidance on how to (1) mitigate stressors (e.g. pesticides and extreme weather events) on pollinators and (2) develop conservation and education partnerships to support pollinator health. The Department of Agriculture also released a series of "MAE" (Monitoring, Assessment and Evaluation) Pollinator Reports that elaborate on the current status of pollinators and suggested management alternatives. Likewise, the Natural Resource Conservation Service within the USDA distributes, with educational reports, "Conservation Innovation Grants" that fund ongoing research regarding alternative management strategies. Recent awardees have included research projects analyzing the impact of pollinator habitat provisioning in agricultural settings. If continued, such policies will provide the necessary financial capital to continue research of habitat enhancement strategies' impacts on pollinators and crop quality (USDA 2019; US Forestry Service 2015; Regents of the University of California 2014).

The Environmental Protection Agency also recently issued non-regulatory guidance regarding pollinator health. The EPA "Policy Mitigating Acute Risk to Bees from Pesticide Products" is the EPA policy regarding pollinator health. Specifically, it recommends that each state and Native American tribe write individual Pollinator Protection Plans and outlines steps required to protect managed pollinators during pesticide application. This EPA policy directly resulted in the development of State Pollinator Plans such as New York's Pollinator Protection Plan (EPA 2017).

The Endangered Species Protection Program (under the EPA) also issues regulatory bulletins required under the Federal Insecticide, Fungicide, and Rodenticide Act and the Endangered Species Act. These bulletins seek to limit the utilization of specific pesticides in regions with endangered species. Currently, there is limited focus on pollinator and beneficial insects under this program, and there is only one active pesticide limitation site in New York State. To the best of my knowledge, there is not work regarding the impact of these pesticide limitation areas on pollinator populations, nor included guidance for farmers on alternative methods to manage pest populations (EPA 2019).

Overall, these internal policies and federal grants indicate that, even in the absence of new pollinator-specific federal legislation, federal agencies are growing to understand the importance of supporting wild and native pollinators on agricultural habitats. These federal policies also have direct impact on the development of state policy and non-regulatory guidance.

New York State Policy

During the 2017 – 2018 legislative session, NYS passed Senate Bill S6339A, which amended NYS Department of Agriculture and Markets law to call for the development of management plans and research regarding pollinator health in collaboration with research universities. This legislation has led to financial support and organizational development of projects through Cornell University, and the New York Natural Heritage Program (New York State 2017).

Together with the New York State Department of Agriculture and Markets, the New York Department of Environmental Conservation wrote the Pollinator Protection Plan (2016) in response to federal policy and guidance described above. In New York, the Pollinator Protection Plan led to the development of the Empire State Native Pollinator Survey conducted by the New York State Natural Heritage Program concurrent with this study. The Empire State Native Pollinator Survey, together with results from this work and others, will contribute information about pollinator communities in on-farm habitats in the lower Hudson Valley region.

Pollinators may also indirectly benefit from the New York State Conservation Easement Tax Credit program. Through this program, farmers and land managers are provided with the financial incentive via tax credits when land is permanently placed into an easement program and managed by a conservation agency. Depending on the type of easement, goal of the easement and the managing conservation agency, easements could have direct or indirect benefits to pollinators. For example, an easement created to preserve an agricultural viewshed may have indirect benefits to pollinators by preventing development. However, an easement has better potential to provide direct benefits to pollinators if developed with requirements for an ongoing habitat management program. While outside the purview of this work, exploration of additional financial incentives to integrate pollinator conservation strategies into easements would provide insight into how to encourage private farm owners to implement conservation (New York State Statute 49-303, Title III).

Leveraging Regional Planning and Land Management

Regional planning and municipal codes can also encourage pollinator health on and around agricultural lands. By writing the comprehensive plan and implementing zoning laws, urban planners and community members can establish conservation and agricultural districts in the municipality. These can provide legally defensible restrictions on development, which in turn can preserve marginal habitats on and near farms that could benefit pollinator populations.

Furthermore, municipal governments can utilize the comprehensive plan to distribute grant money for pollinator conservation projects, in alignment with state and federal policy.

While not analyzed here, local land trusts and educational agencies, such as Cornell Cooperative Extension, can also support regional implementation of pollinator conservation strategies. Given the scale at which agricultural development and conservation management occur, municipal planners, in collaboration with land owners including farmers, can best conserve regional pollinator populations. Further analysis of land use regulations and incentives within the 10 counties of the Hudson Valley region, along with the Hudson Valley Regional Council, can shed light on current policies that support pollinator conservation.

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APPENDICES

Appendix A – Composition and Source of Native Seeds in Treatments

Table XXXIII-A. Composition and source of native seeds in treatment A. Adapted from Claudia Knab-Vispo.

Native Meadow Mix A (“Treatment A”)				
Common Name	**Scientific Name**	**% of mix by volume (seed/ft^2)**	**Final Mix Total lb/1.5 acres**	**Supplier**
Black Eyed Susan	*Rudbeckia hirta*	6.5%	0.19	Ernst Seeds
Brown Eyed Susan	*Rudbeckia trilobal*	2.2%	0.18	Ernst Seeds
Butterfly Milkweed	*Asclepias tuberosa*	1.1%	0.73	Ernst Seeds
Common Milkweed	*Asclepias syriaca*	1.1%	0.73	Ernst Seeds
Dense Blazingstar	*Liatris spicata*	1.1%	0.51	Ernst Seeds
Early Goldenrod	*Solidago juncea*	3.2%	0.06	Ernst Seeds
Joe Pye Weed	*Eupatorium purpureum*	1.0%	0.07	Prairie Moon
Lance Leaved Coreopsis	*Coreopsis lanceolate*	8.6%	1.84	Ernst Seeds
Lavender Hyssop	*Agastache foeniculum*	8.6%	0.27	Ernst Seeds
Little Bluestem	*Schizachyrium scoparium*	19.4%	4.59	Ernst Seeds
Mistflower	*Eupatorium coelestinum*	6.5%	0.20	Ernst Seeds
Narrowleaf Mountainmint	*Pycnanthemum tenulfolium*	3.8%	0.03	Ernst Seeds
New England Aster	*Aster novae-angliae*	2.1%	0.09	Prairie Nursery
Ohio Spiderwort	*Tradescantia ohiensis*	2.2%	0.81	Ernst Seeds
Partridge Pea	*Chamaecrista fasciculata*	2.2%	1.57	Ernst Seeds
Purple Coneflower	*Echinacea purpurea*	4.3%	1.76	Ernst Seeds
Purprle Prairie Clover	*Calea purpurea*	2.2%	1.27	Prairie Moon
Roundhead Lespedeza	*Lespedeza capitate*	1.1%	0.19	Ernst Seeds
Showy Goldenrod	*Solidago speciose*	2.3%	0.08	Ernst Seeds
Slender Lespedeza	*Lespedeza virginiana*	2.1%	1.27	Ernst Seeds
Smooth Blue Aster	*Aster laevis*	2.1%	0.10	Pinelands Nursery
Tall White Beardtongue	*Penstemon digitalis*	9.7%	0.25	Pinelands Nursery
Wild Bergamont	*Monarda fistulosa*	6.7%	0.25	
	Totals	**100.0%**	**17.04 lbs**	

Table XXXIV-A. Composition and source of native seeds in treatment B. Adapted from Claudia Knab-Vispo.

Native Meadow Mix B ("Treatment B")				
Common Name	**Scientific Name**	**% of mix by volume (seed/ft^2)**	**Final Mix Total lb/1.5 acres**	**Supplier**
Autumn Bentgrass	*Agrostis perennans*	15.0%	0.09	Ernst Seeds
Big Bluestem	*Andropogon geradii*	6.4%	2.12	Ernst Seeds
Black Eyed Susan	*Rudbeckia hirta*	6.3%	0.19	Ernst Seeds
Canada Wildrye	*Elymus canadensis*	10.7%	4.47	Ernst Seeds
Indiangrass	*Sorghastrum nutans*	6.7%	1.82	Ernst Seeds
Lance Leaved Coreopsis	*Coreopsis lanceolate*	3.2%	0.69	Ernst Seeds
Little Bluestem	*Schizachyrium scoparium*	16.0%	3.82	Ernst Seeds
Partridge Pea	*Chamaecrista fasciculata*	1.1%	0.78	Ernst Seeds
Purple Coneflower	*Echinacea purpurea*	5.3%	2.20	Ernst Seeds
Purple Lovegrass	*Eragrostis spectablis*	1.3%	0.06	Prairie Moon
Purple Prairie Clover	*Dalea purpurea*	2.1%	1.27	Ernst Seeds
Purpletop	*Tridens flavus*	16.4%	1.69	Ernst Seeds
Slender Lespedeza	*Lespedeza virginiana*	1.1%	0.65	Ernst Seeds
Switchgrass	*Panicum virgatum*	8.5%	1.57	Ernst Seeds
	Totals	**100.0%**	**21.42 lbs**	

Appendix B – Species of Butterflies Encountered in Other On Farm Habitats

Table XXXV-A. Butterfly species encountered in the Cut Flower Garden. Four surveys were conducted between 8/7/19 and 9/24/19.

Cut Flower Garden		
Species	**Common Name**	**Count**
Colias eurytheme	Orange Sulphur	8
Colias philodice	Clouded Sulphur	12
Danaus plexippus	Monarch	5
Epargyreus clarus	Silver Spotted Skipper	1
Papilio polyxenes	Black Swallowtail	3
Papilio troilus	Spicebush Swallowtail	4
Phyciodes tharos	Pearl Crescent	1
Pieris rapae	Cabbage White	17
Thymelicus lineola	European Skipper	3

Table XXXVI-A. Butterfly species encountered in the Herb Garden. Seven surveys were conducted between 6/22/19 and 9/27/19. ** indicates a species not encountered in the Native Meadow Trials.

Herb Garden		
Species	**Common Name**	**Count**
Colias eurytheme	Orange Sulphur	242
Colias philodice	Clouded Sulphur	316
Cupido comyntas	Eastern Tailed Blue	5
Danaus plexippus	Monarch	33
Epargyreus clarus	Silver Spotted Skipper	36
Euphyes vestris	Dun Skipper	3
*Panoquina ocola***	Ocola Skipper	1
Papilio glaucus	Eastern Tiger Wwallowtail	8
Papilio polyxenes	Black Swallowtail	8
Pholisora catullus	Common Sooty Wing	3
Phyciodes tharos	Pearl Crescent	3
Pieris rapae	Cabbage White	241
Pyrgus communis	Common Checkered-skipper	1
Speyeria cybele	Great Spangled Fritillary	9
Thymelicus lineola	European Skipper	3
*Vanessa atalanta***	Red Admiral	3

Table XXXVII-A. Butterfly species encountered in the abandoned Gravel Extraction pit. Seven surveys were conducted between 6/22/19 and 9/27/19.

Dry Gravel Pit		
Species	**Common Name**	**Count**
Colias eurytheme	Orange Sulphur	23
Colias philodice	Clouded Sulphur	42
Cupido comyntas	Eastern Tailed Blue	16
Danaus plexippus	Monarch	4
Epargyreus clarus	Silver Spotted Skipper	12
Lycaena hyllus	Bronze Copper	1
Pholisora catullus	Common Sooty Wing	1
Phyciodes tharos	Pearl Crescent	5
Pieris rapae	Cabbage White	55

Table XXXVIII-A. Butterfly species encountered in the Wet Meadow trials. Seven surveys were conducted between 6/24/19 and 9/27/19. ** indicates a species not encountered in the Native Meadow Trials. Wet Meadow Trial 3 was not surveyed after July 2018 due to mowing to control Canada thistle (*Cirsium arvense*).

Wet Meadow Trials		
Species	**Common Name**	**Count**
Colias eurytheme	Orange Sulphur	24
Colias philodice	Clouded Sulphur	105
Cupido comyntas	Eastern Tailed Blue	10
Danaus plexippus	Monarch	11
Epargyreus clarus	Silver Spotted Skipper	6
Erynnis baptisiae	Wild Indigo Dusky Wing	1
Limenitis archippus	Viceroy	2
Papilio glaucus	Eastern Tiger Swallowtail	2
Papilio troilus	Spicebush Swallowtail	3
Pholisora catullus	Common Sooty Wing	7
Phyciodes tharos	Pearl Crescent	86
Pieris rapae	Cabbage White	101
*Polites peckius***	Peck's Skipper	3
Speyeria cybele	Great Spangled Fritillary	19
Thymelicus lineola	European Skipper	85

Table XXXIX-A. Butterfly species encountered in the active Gravel Extraction pit . Seven surveys were conducted between 6/14/19 and 9/20/19. ** indicates a species not encountered in the Native Meadow Trials.

Wet Gravel Pit		
Species	**Common Name**	**Count**
Colias eurytheme	Orange Sulphur	6
Colias philodice	Clouded Sulphur	67
Danaus plexippus	Monarch	1
Epargyreus clarus	Silver Spotted Skipper	2
*Polygonia interrogationis***	Question-mark	2
Papilio glaucus	Eastern Tiger Swallowtail	1
Phyciodes tharos	Pearl Crescent	8
Pieris rapae	Cabbage White	27

Table XL-A. Butterfly species encountered in Enriched Hay fields. Ten surveys were conducted between 5/25/19 and 9/20/19. Fields were enriched with: chicory, prairie coreopsis and black-eyed Susan. ** indicates a species not encountered in the Native Meadow Trials.

Enriched Hay		
Species	**Common Name**	**Count**
Belloria bellona	Meadow Fritillary	1
Coenonympha tullia	Common Ringlet	1
Colias eurytheme	Orange Sulphur	95
Colias philodice	Clouded Sulphur	210
Cupido comyntas	Eastern Tailed Blue	1
Danaus plexippus	Monarch	2
Epargyreus clarus	Silver Spotted Skipper	2
Pholisora catullus	Pearl Crescent	5
Pieris rapae	Cabbage White	94
Speyeria cybele	Great Spangled Fritillary	1
*Vanessa virginiensis***	American Lady	1

Appendix C – Expected and Observed Pollinator Abundance by Habitat Type Calculation

Analytical Methods

In order to identify whether pollinators were attracted to specific on-farm habitats, the number of expected visits per habitat type were calculated based on the proportion of the total area sampled each habitat type represented.

Four general categories of habitat type were established: "treatment," "enriched," "cultivated" and "background" areas. The treatment category contained sample points from Native Meadow Trial treatments A and B. Enriched habitats were the Wet Meadow plots enriched with seed mix and Enriched Hay fields. The Herb Garden and Cut Flower Garden, both planted to yield marketable products, together made the cultivated category. All other areas, control plots and the abandoned Gravel Extraction pit, became the "background" category.

For June – September 2018, the total number of sample points per survey and the total number of surveys were determined for each habitat type (summed for habitat category). The total area per point (118.23m^2) was used to determine the total area sampled per habitat type over the season. This can be summarized by the following

$$= (\text{total points sampled})(\text{total number of surveys})(118.23\text{m}^2)$$

The sum of the total area sampled from June – September 2018 was determined by adding area for each habitat sampled. Then, the proportion of total area sampled was determined by the following

$$= \frac{\text{area of habitat sampled}}{\text{total area sampled}}\ x\ 100\ \%$$

Using the total number of documented pollinator visits to flowers in all habitats from June – September 2018, the above proportion was utilized to calculate the expected number of pollinator visits each habitat would attract if pollinators were drawn based on total available area alone

$$= (\%\ \text{of total floral area the habitat category represents})(\text{total number of visits})$$

This number was compared with the actual observed visits for each habitat category. Statistical difference in proportion of expected and actual pollinator visits was tested using Chi Square Test in Excel 2013 and confirmed with SYSTAT 13.

Appendix D – Documented Insect Community in Other On-farm Habitats

Analytical Methods

Documented visitations were pooled for June 2018 – September 2018 for each of the following habitat types: Wet Meadows (WMT1 Central and South; WMT2 Central and South), Cut Flower Garden, Medicinal Herb Garden, Abandoned Gravel Extraction Pit, Enriched Hay and Native Meadow Trials. Insect visitations were categorized into the following taxonomic groups: butterflies, Apidae (bumble bees and honey bees), non-Apidae bees, hoverflies (Syrphidae), Wasps (Apocrita and Chrysididae), tarnished plant bugs and lady beetles. Figures 32 - 37 show the proportional abundances of each taxonomic group compared to total observations for each habitat type.

Results

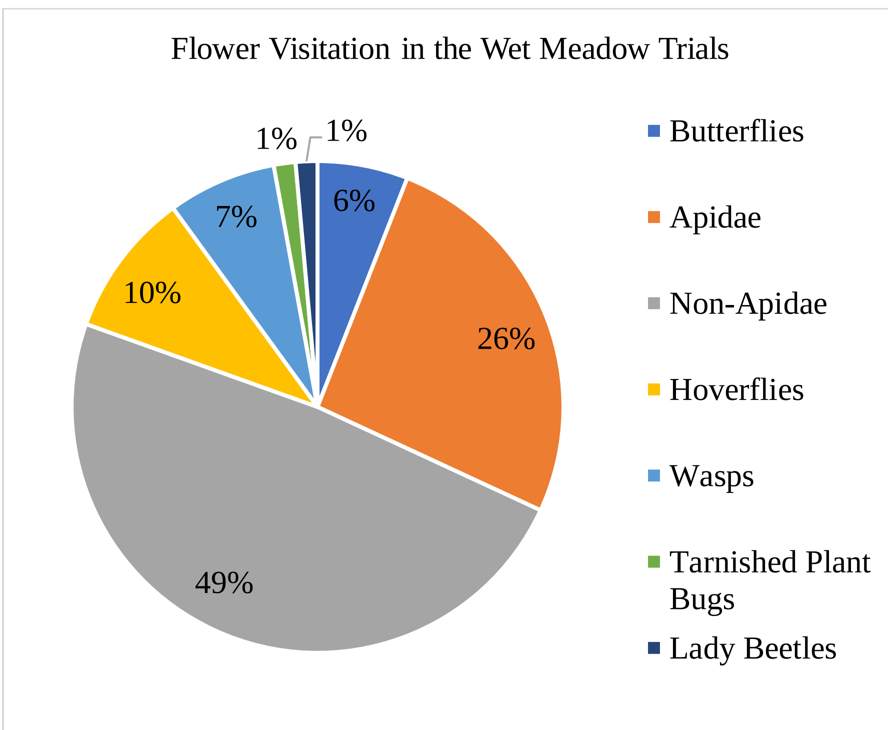

Figure 30-A. Proportion of insect visitations by taxonomic group in the Wet Meadow trials. N = 420.

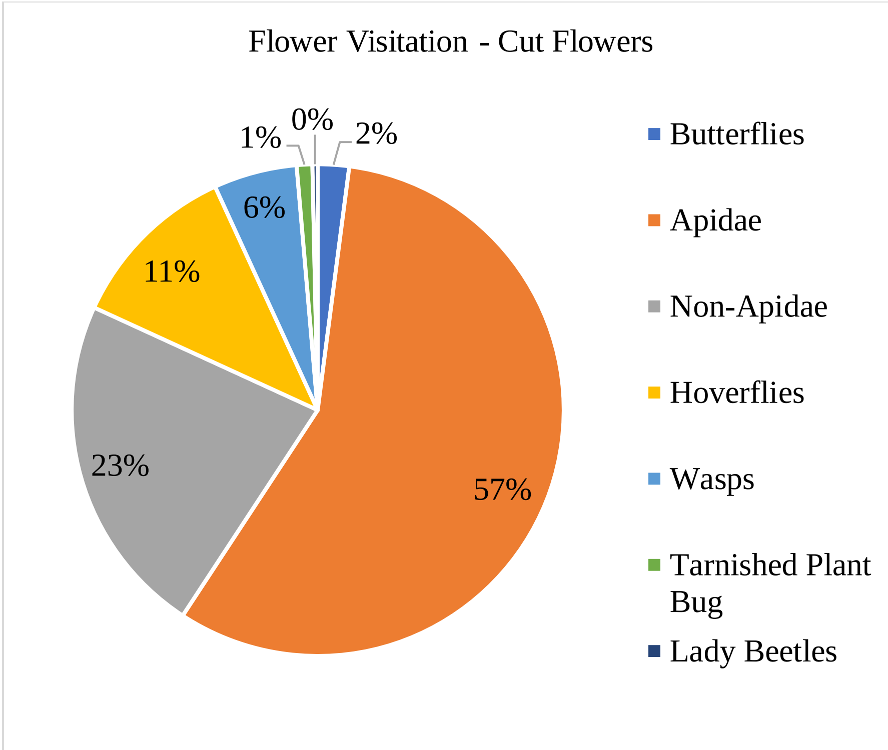

Figure 31-A. Proportion of insect visitations by taxonomic group in the Cut Flower Garden. N = 292.

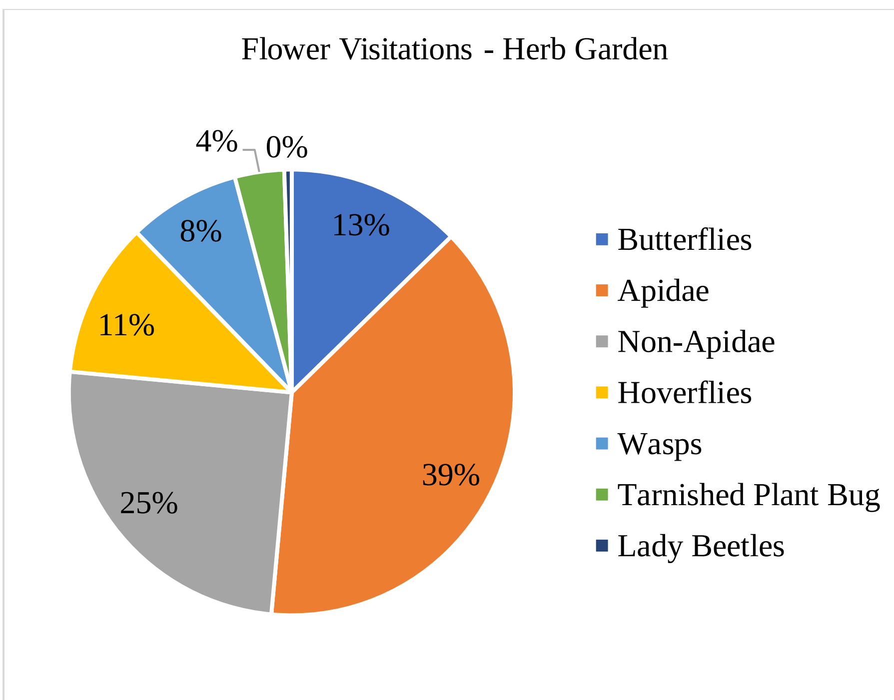

Figure 32-A. Proportion of insect visitations by taxonomic group in the Herb Garden. N = 923.

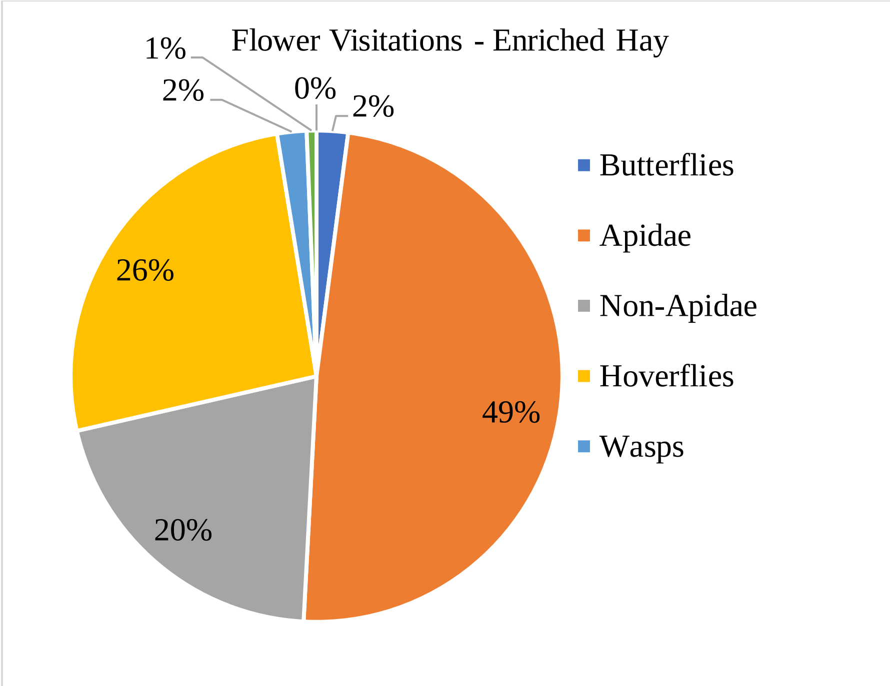

Figure 33-A. Proportion of insect visitations by taxonomic group in Enriched Hay fields. N = 777.

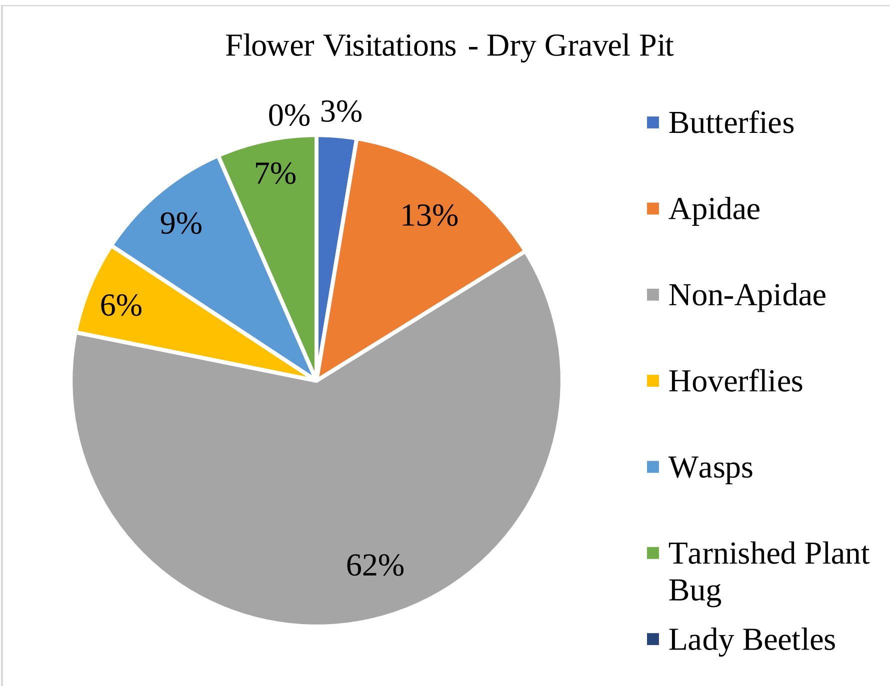

Figure 34-A. Proportion of insect visitations by taxonomic group in the abandoned Gravel Extraction pit. N = 229.

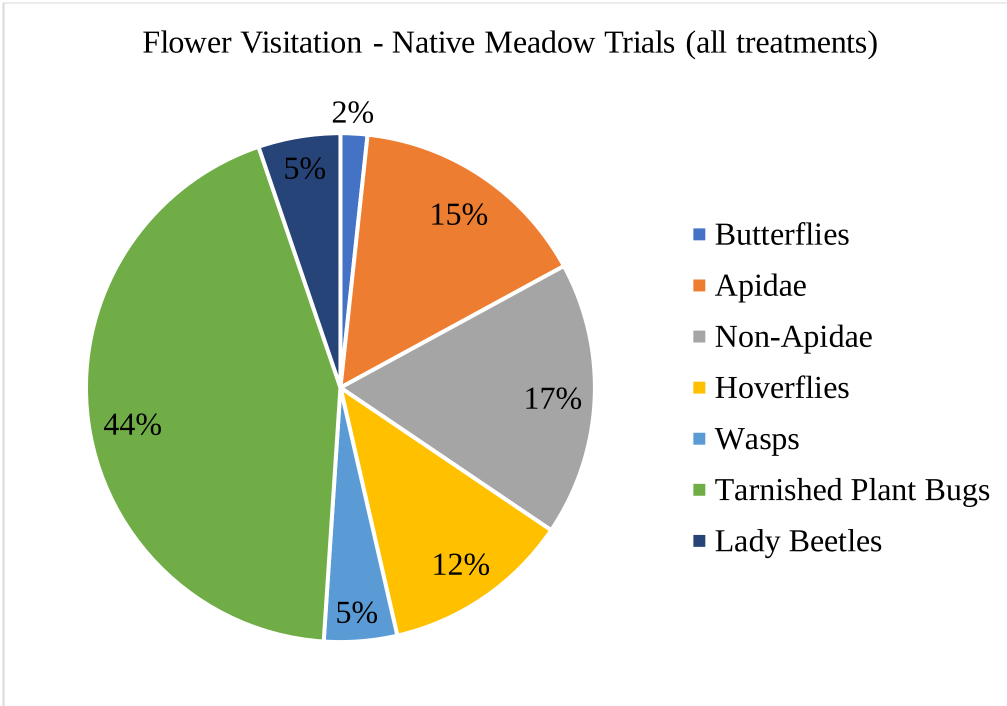

Figure 35-A. Proportion of insect visitations by taxonomic group in the Native Meadow Trials. N = 4,523.

Appendix E – ANOVA Results for Tarnished Plant Bugs and Lady Beetles

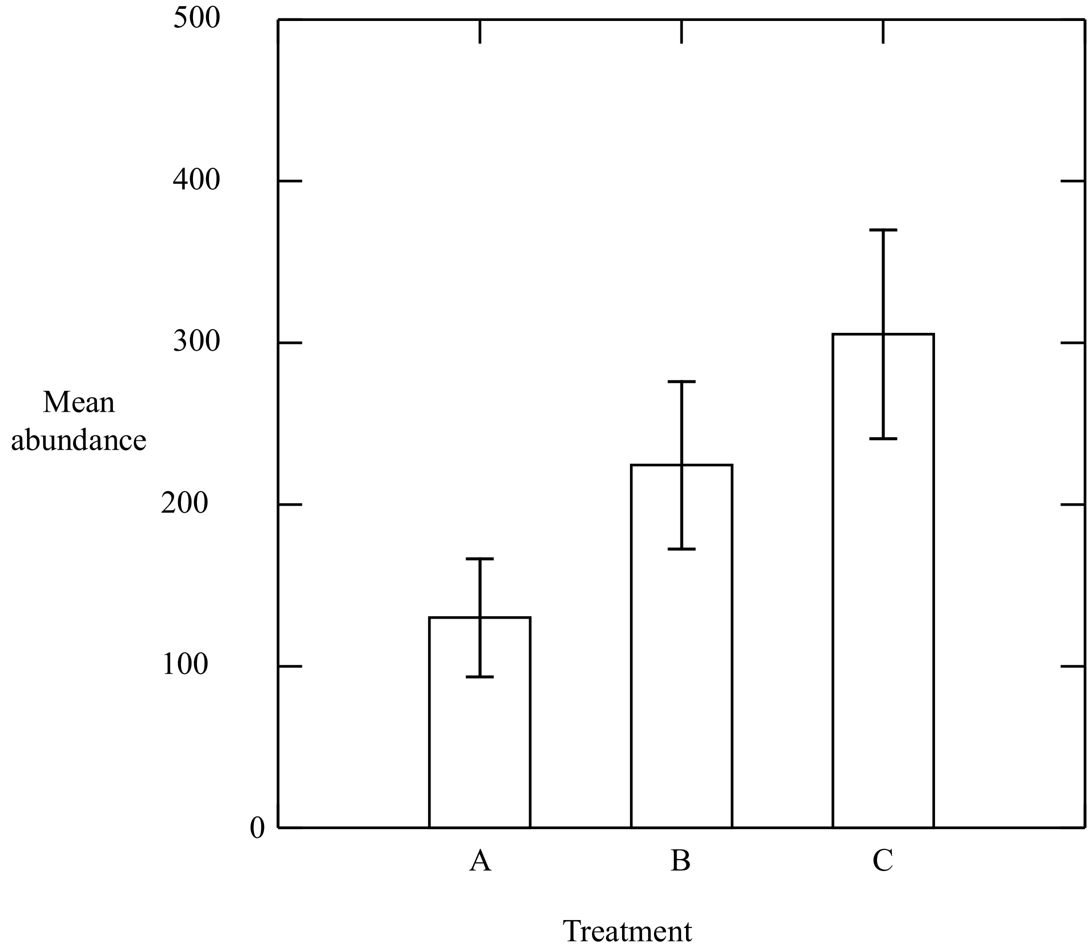

Figure 36-A. Comparison of tarnished plant bug encounters across native meadow treatments. ANOVA results are presented in Table XLIII. N = 1,984.

Table XLI-A. Analysis of variance statistics to accompany Figure 36-A.

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Treatment	46,201.556	2	23,100.778	4.928	0.054
Error	28,125.333	6	4,687.556		

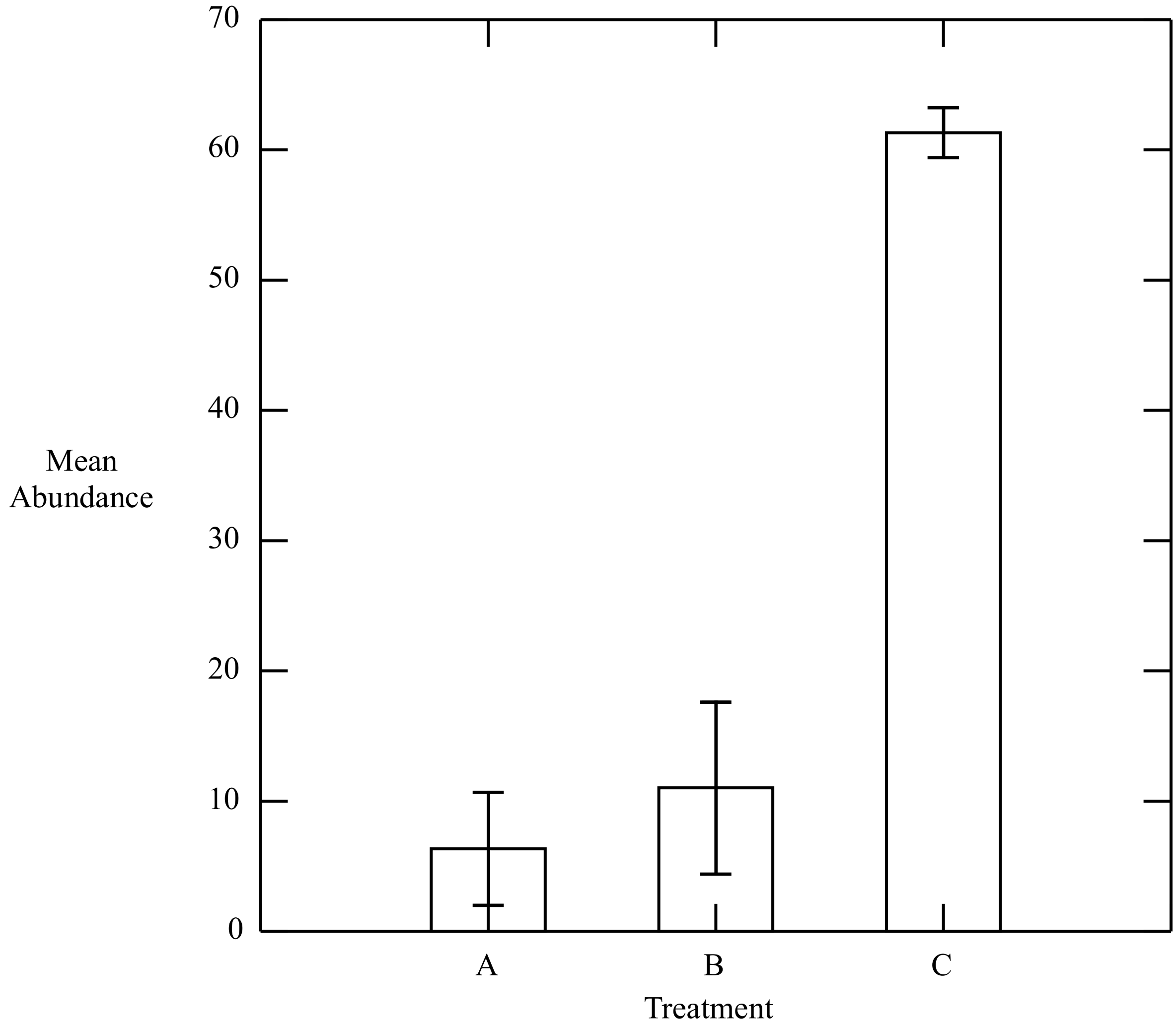

Figure 37-A. Comparison of lady beetle encounters across native meadow treatments. ANOVA results are presented in Table XLIV. N = 236.

Table XLII-A. Analysis of variance test statistics to accompany Figure 37-A.

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Treatment	5,580.222	2	2,790.111	73.639	0.000
Error	227.333	6	37.889		

Appendix F – Visitation Response to Cumulative Floral Rank

Analytical Methods

To determine how floral abundance rank impacted flower visitation rates, I found the cumulative floral abundance rank for each survey visit. Then, I determined the total number of flower-pollinator interactions observed during each survey visit. For all the native meadow treatments combined, and for each treatment separately, I plotted the log transformed cumulative floral abundance rank (x-value) by the log transformed sum of pollinator-flower interactions (y-value). I assessed each plot to identify whether there is a positive correlation between cumulative floral abundance rank and number of observed pollinator interactions. I repeated this process for each of the following groups: butterflies, bumble bees and honey bees (Apidae), hoverflies (Syrphidae*)*, wasps (Apocrita and Chrysididae), and sweat bees (Halicitidae).

Results - Pollinator response to cumulative floral abundance rank

All isolated groups (listed above) exhibited a positive response to increasing cumulative floral abundance rank (Figure 40). This indicates that encounters of pollinators will increase as the relative cover of open flowers increases.

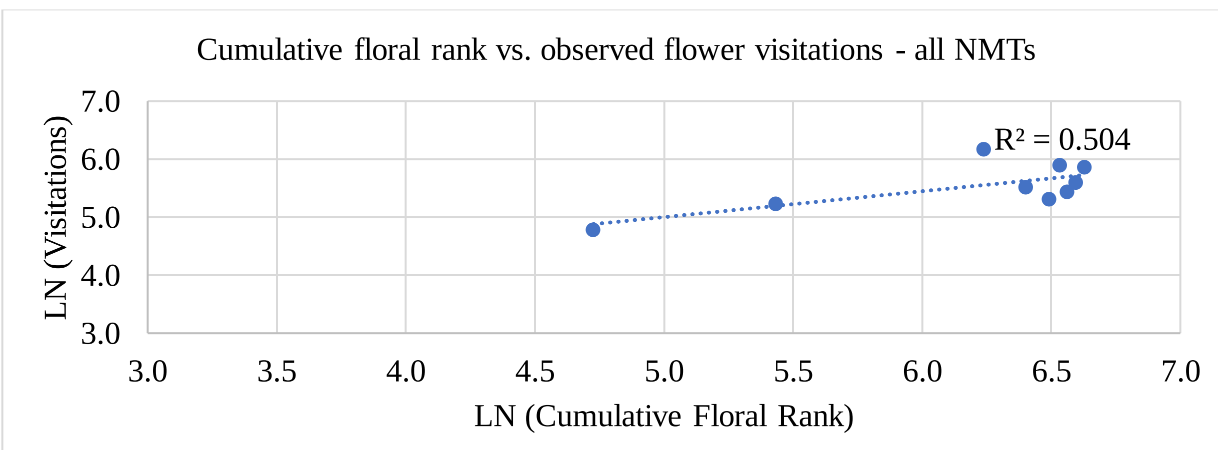

Figure 38-A. Observed response in insect visitation to cumulative floral rank – all Native Meadow treatments.

The positive correlation between cumulative floral rank and observed pollinator visitations holds up for most groups separately: butterflies ($r^2 = 0.44$), bumble bees and honey bees ($r^2 = 0.70$), wasps ($r^2 = 0.46$), and hoverflies ($r^2 = 0.51$). Halicitidae sweat bees demonstrate a slightly positive correlation with cumulative floral rank ($r^2 = 0.06$) and the category of other native bees, (including sweat bees), demonstrated a negative correlation with cumulative floral rank ($r^2 = 0.04$).

The relationship between cumulative floral rank and observed pollinator-flower interactions was particularly strong across treatment A plots (Figure 41). Here, the cumulative floral rank explained a greater proportion of the encounters of particular pollinator groups: bumble bees and honey bees ($r^2 = 0.87$), wasps ($r^2 = 0.67$) and hoverflies ($r^2 = 0.63$) all responded positively to cumulative floral rank. Again, encounters of other native bees was slightly negative related to cumulative floral rank ($r^2 = 0.02$) and Halicitidae sweat bee encounters (alone) were slightly positively correlated ($r^2 = 0.06$).

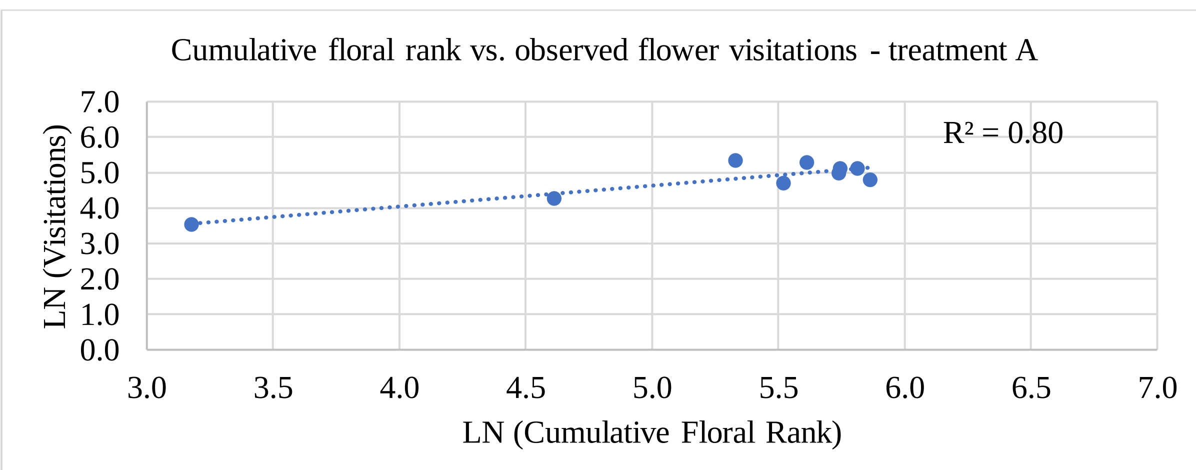

Figure 39-A. Observed response in insect visitation to cumulative floral rank – treatment A.

Similar trends emerge for treatment B. Positive correlations were calculated for the following: butterflies (r^2 = 0.26), bumble bees and honey bees (r^2 = 0.35), wasps (r^2 = 0.20), hoverflies (r^2 = 0.73) and Halicitidae sweat bees (alone) (r^2 = 0.31). Other native bees also had a slightly positive correlation to cumulative floral rank in treatment B (r^2 = 0.05).

Correlations between observed flower-pollinator interactions and cumulative flower rank in control plots were more variable. Observation of butterflies (r^2 = 0.25), bumble bees and honey bees (r^2 = 0.17) and other native bees (r^2= 0.53) was negatively correlated with cumulative floral rank. Wasp (r^2 = 0.18), hoverfly (r^2 = 0.46) and Halicitidae sweat bee observation (r^2 = 0.01) was positively correlated with cumulative floral rank. Overall, however, there was still a positive correlation between cumulative flower rank and observed flower visitations of all pollinators in the control plots (r^2 = 0.47).

Supporting Graphs - Pollinator response to cumulative floral abundance rank

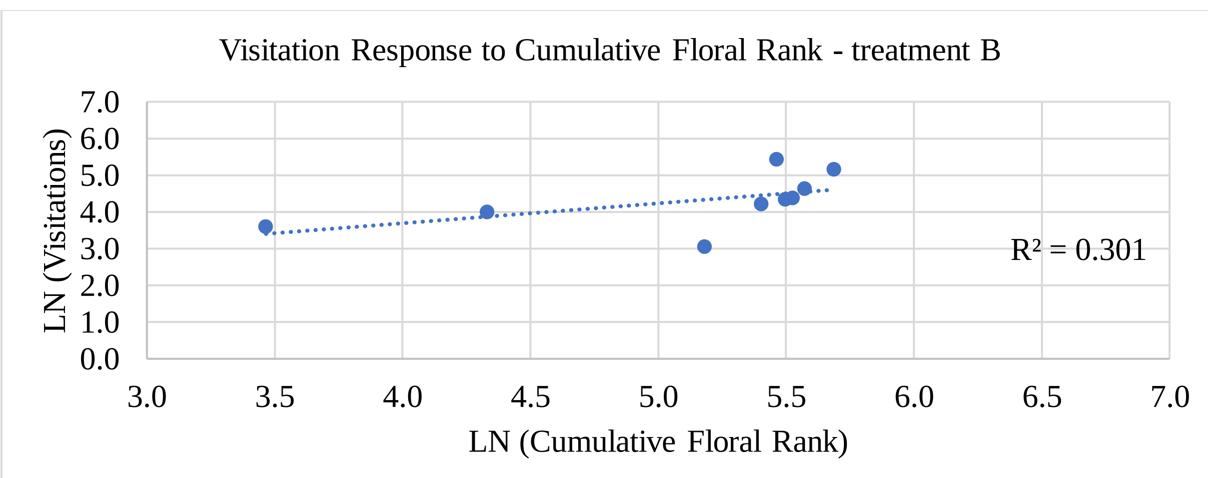

Figure 40-A. Observed response in insect visitation to cumulative floral rank - treatment B.

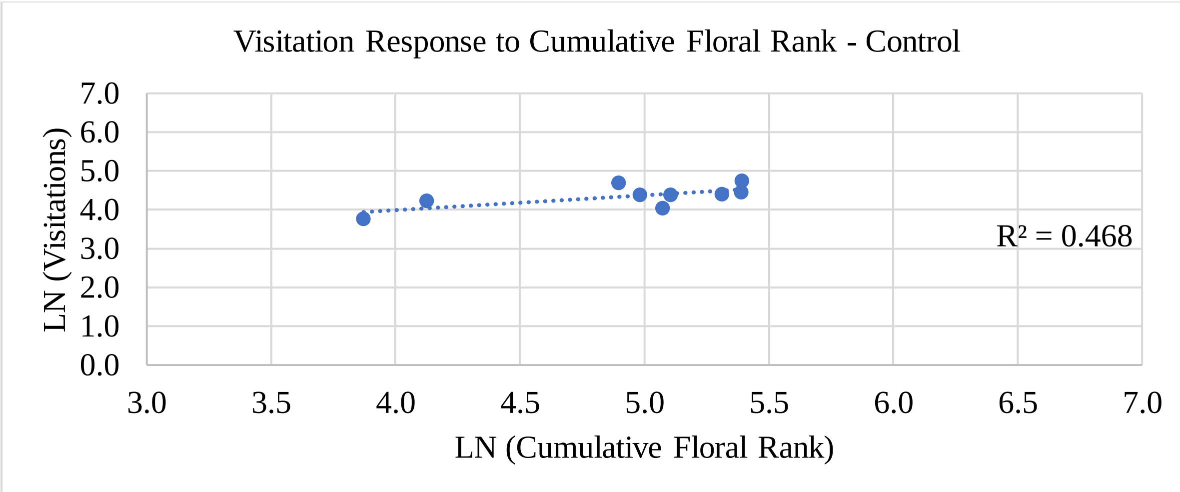

Figure 41-A. Observed response in insect visitation to cumulative floral rank in control plots.

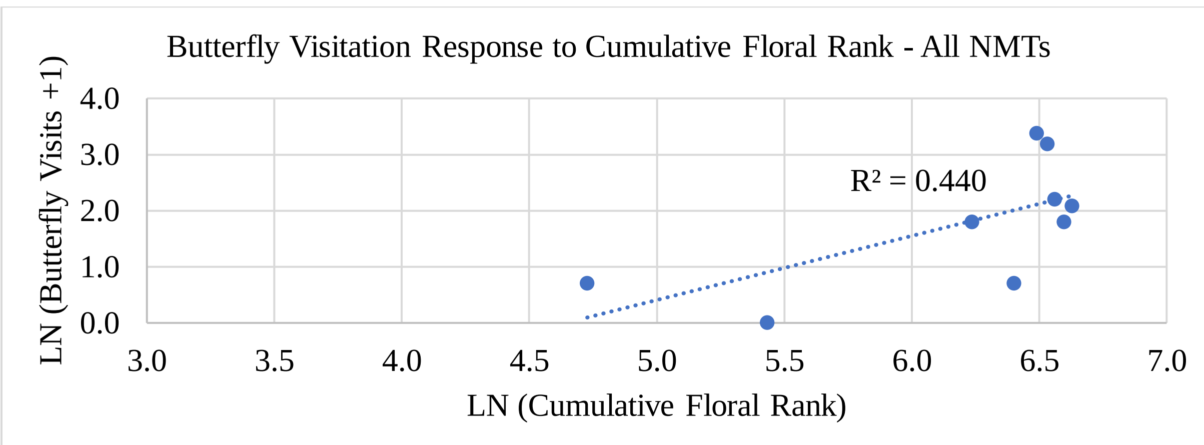

Figure 42-A. Butterfly response to cumulative floral rank in all Native Meadow plots.

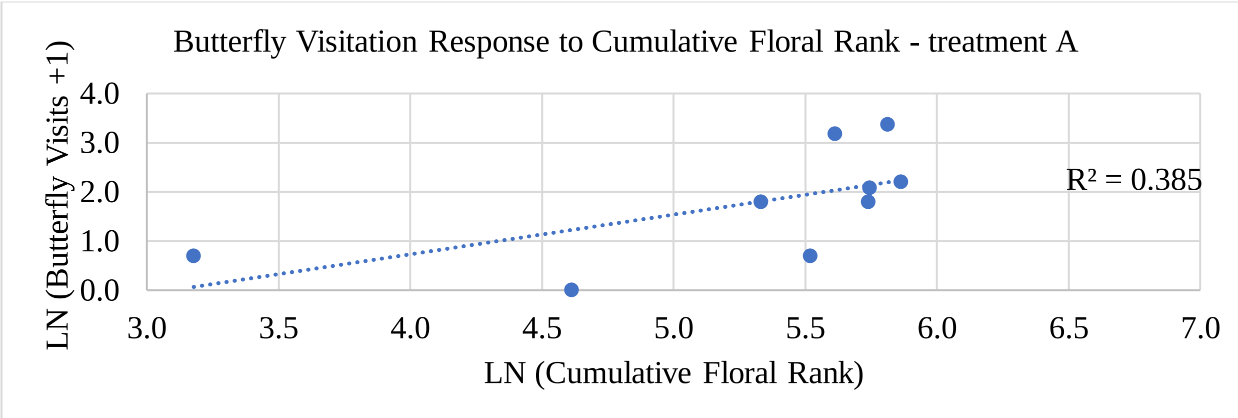

Figure 43-A. Butterfly response to cumulative floral rank in treatment A.

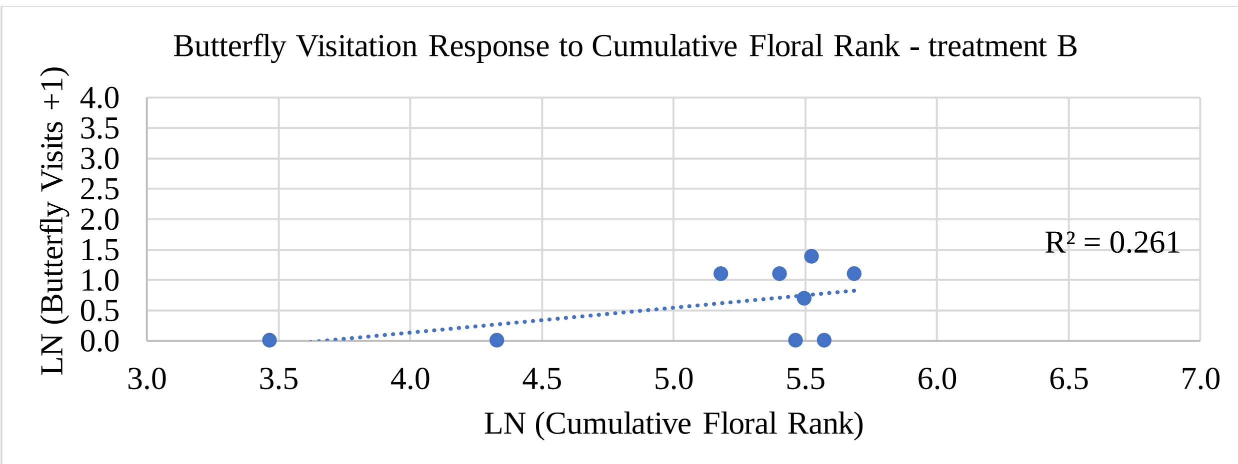

Figure 44-A. Butterfly response to cumulative floral rank in treatment B.

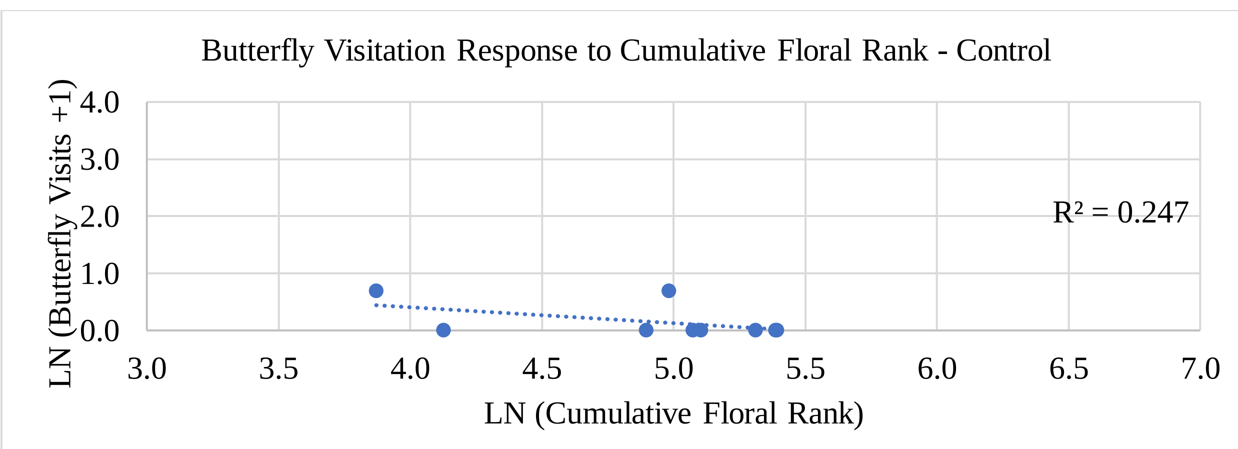

Figure 45-A. Butterfly response to cumulative floral rank in control plots.

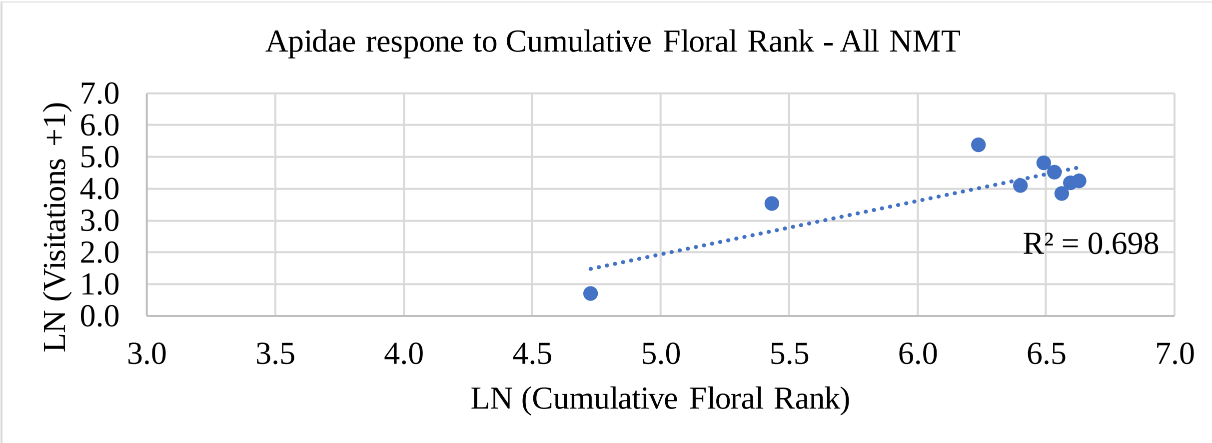

Figure 46-A. Apidae response to cumulative floral rank in all Native Meadow plots.

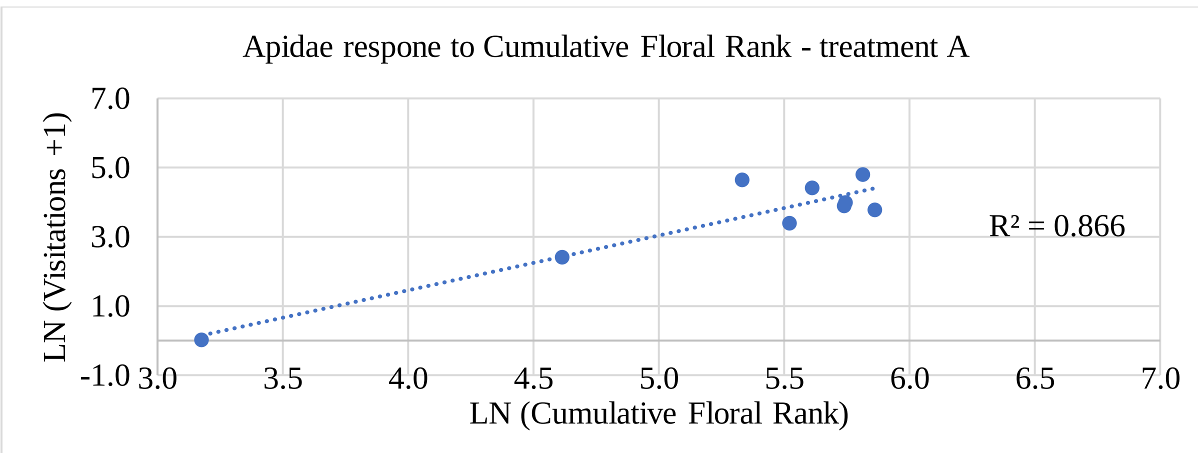

Figure 47-A. Apidae response to cumulative floral rank in treatment A.

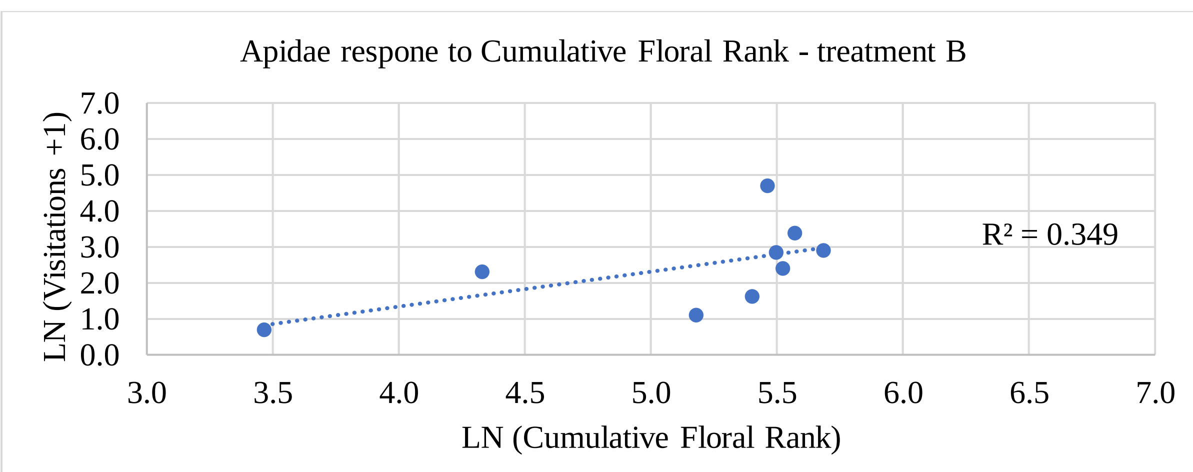

Figure 48-A. Apidae response to cumulative floral rank in treatment B.

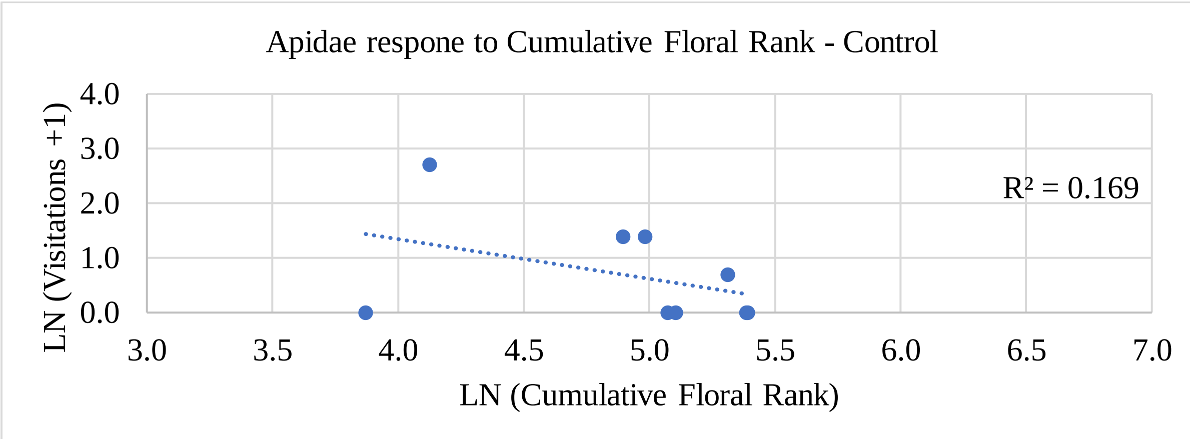

Figure 49-A. Apidae response to cumulative floral rank in control plots.

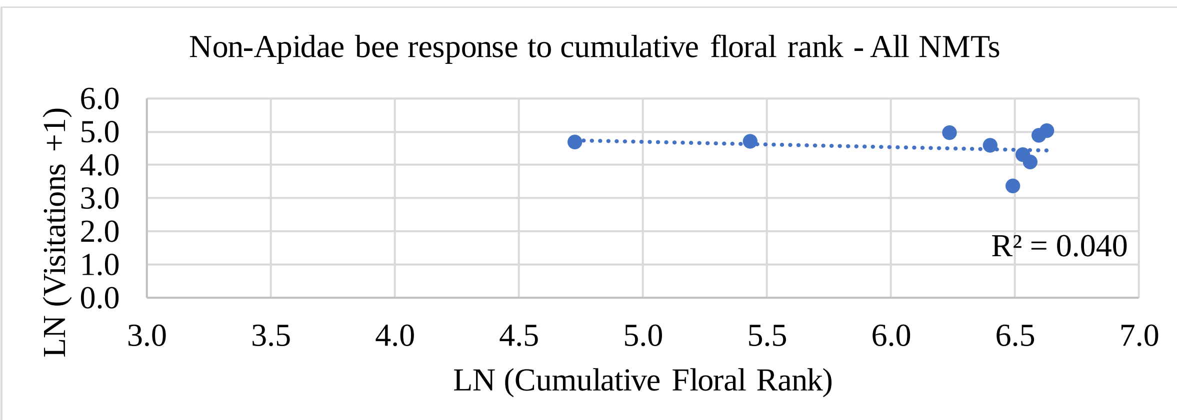

Figure 50-A. Non-Apidae bee response to cumulative floral rank in all Native Meadow plots.

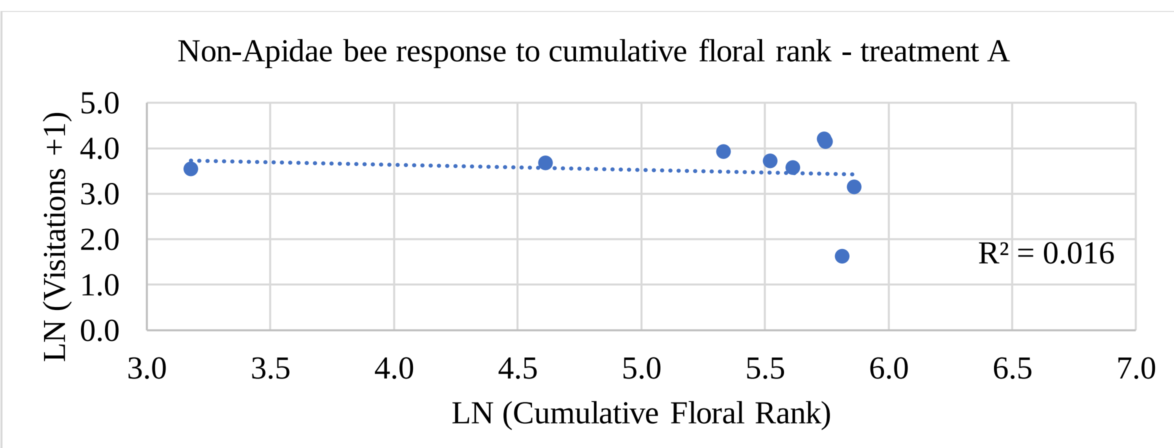

Figure 51-A. Non-Apidae bee response to cumulative floral rank in treatment A.

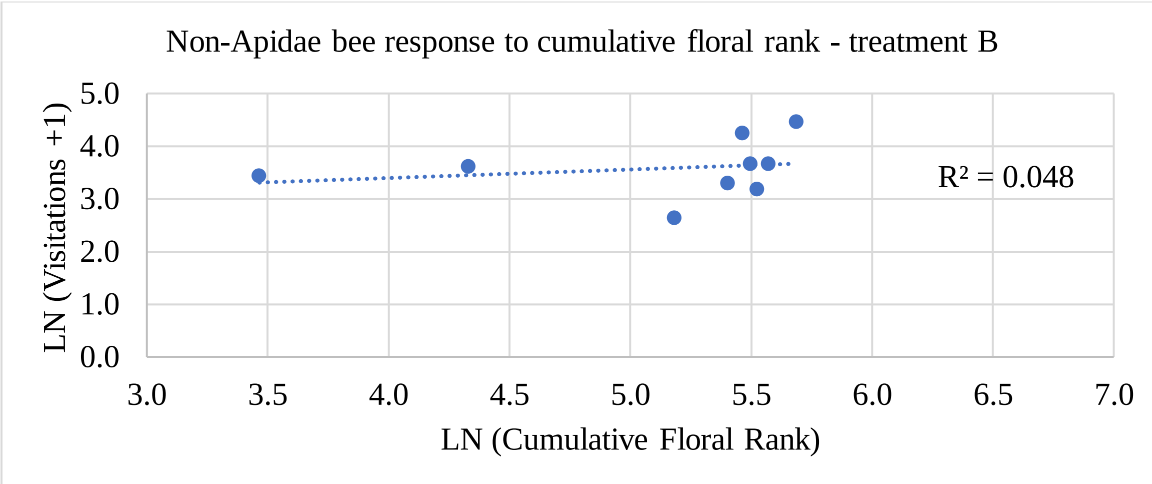

Figure 52-A. Non-Apidae bee response to cumulative floral rank in treatment B.

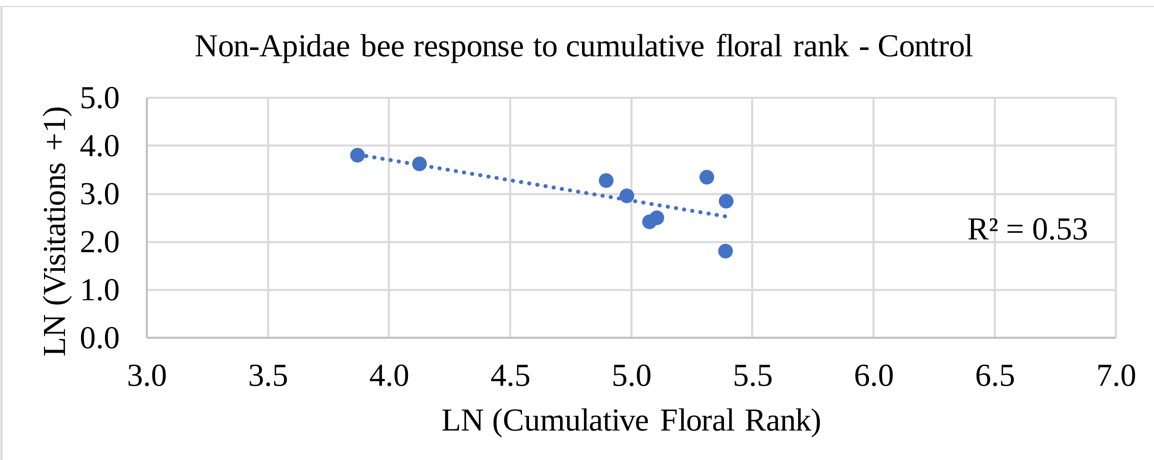

Figure 53-A. Non-Apidae bee response to cumulative floral rank in control plots.

Discussion

Pollinator-flower visitation by treatment

Treatments A and B both increased the chances of encountering butterflies, bumble bees, honey bees, wasps, hoverflies and sweat bees. It was surprising that the chances of encountering other native bees on treatment A was negatively correlated with cumulative floral rank due to research indicating that wild bees respond to floral nectar density (Mallinger et al. 2016; Davis et al. 2007). This negative correlation could have occurred due to non-Apidae bees foraging at Horseweed in the control plots that went undocumented due to vegetation height, or a seasonal decline in the abundance of one or more taxa that composed this group.

Butterflies, bumble bees and honey bees were encountered less frequently on control plots even when increasing cumulative floral rank was documented. This suggests that there is a floral nectar source in the treatment A and treatment B seed mixes that attracted these pollinators. In contrast, observations of wasps and sweat bees showed little difference across the treatments. This suggests that these pollinator groups may be responding to a different environmental variable (e.g. inter-species competition, floral cues, dispersal behavior). This observation is supported by (1) greater proportion of these insects documented in other sampling methods by the Farmscape Ecology Team, (Hawthorne Valley Farm Farmscape Ecology Program, unpublished data), (2) the smaller foraging/nectar morphology of these insects and the flower species present on the plots and (3) possible competition from larger flower visiting insects (re: butterflies and bumble bees).

These results reinforce that farmers and land managers should carefully consider the pollinator groups they hope to attract and support by enhanced habitat management plans. A high-forb native seed mix, such as treatment A, will likely attract increased numbers of butterflies and bumble bees. However, if one desires to attract wasps and/or hoverflies, the financial investment of high-forb seed mixes may not be justified, and will require further planning and study.

This study only broadly considers the impact of flower-density, as defined in treatment A and treatment B, on the chance of encountering insects from different pollinator groups. Some unexpected results (e.g. negative correlation between treatment and observed abundance non-

Apidae bees) reinforce the fact that insects are responding to other cues in the environment, or specific floral cues such as color and/or scent. For example, insects are capable of sensing ultraviolet cues, colors and scents associated with flowers. In these treatments alone, there are orange, white, purple, yellow blue and red flowers. Future study should seek to categorize these flowers into different categories based on traits (e.g. nectar quality, scent, flower color and/or ultraviolet petal patterns) and identify the relationship between cumulative floral rank of these flowers and the total observed pollinator visitations.

Appendix G – Proportion of Insect Visitations to Flowers with Greater than Expected Visits

Documented visitations were pooled for each month June 2018 – September 2018 for each of the following taxonomic groups: butterflies, Apidae (bumble bees and honey bees), non-Apidae bees, hoverflies (Syrphidae), Wasps (Apocrita and Chrysididae), tarnished plant bugs and lady beetles. For flower species on which we documented more than 10 visits (actual – expected visits), the composition of the insect community visiting these species is represented in Figures 54-A – 76-A.

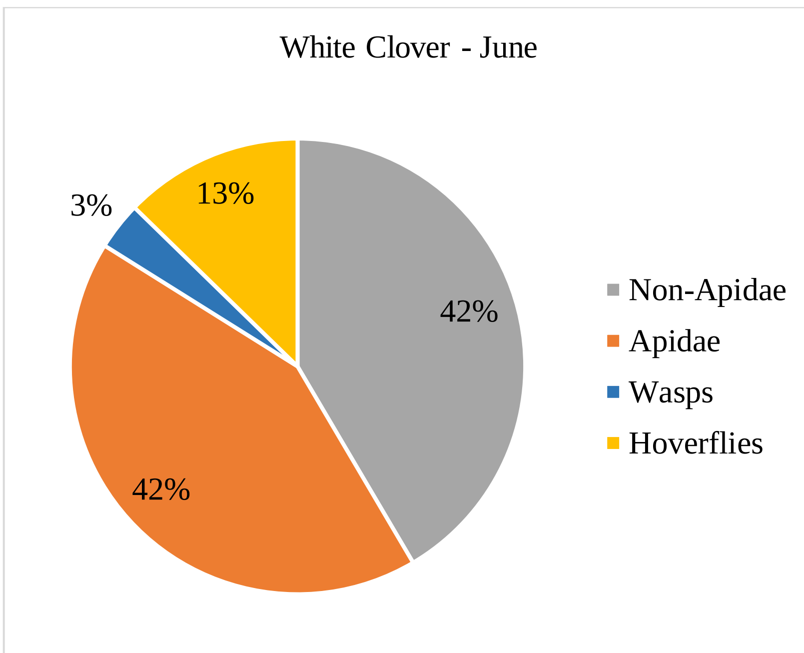

Figure 54-A. Proportion of observed insect visitations to White Clover in June 2018. N = 118.

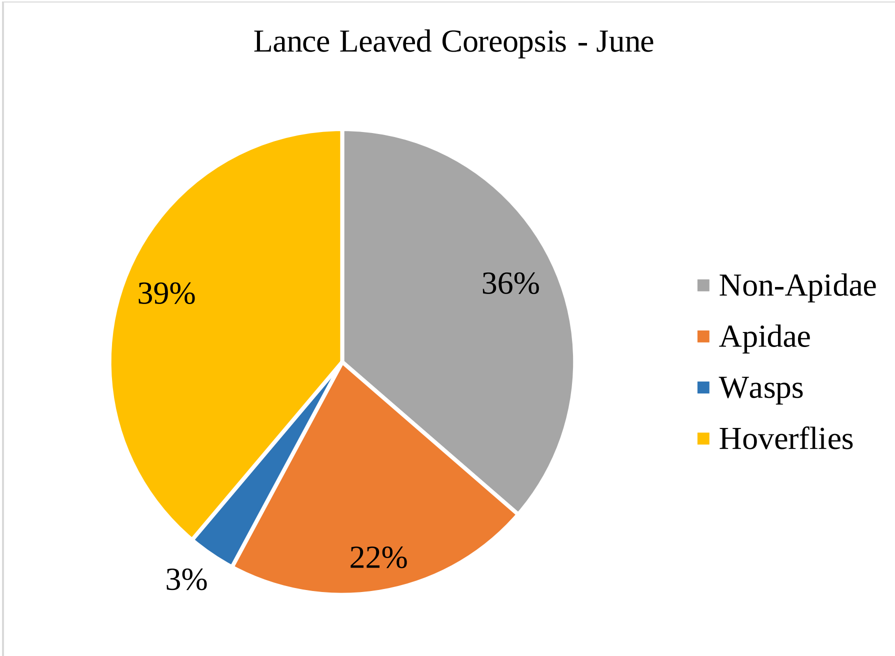

Figure 55-A. Proportion of observed insect visitations to Lance Leaved Coreopsis in June 2018. N = 121.

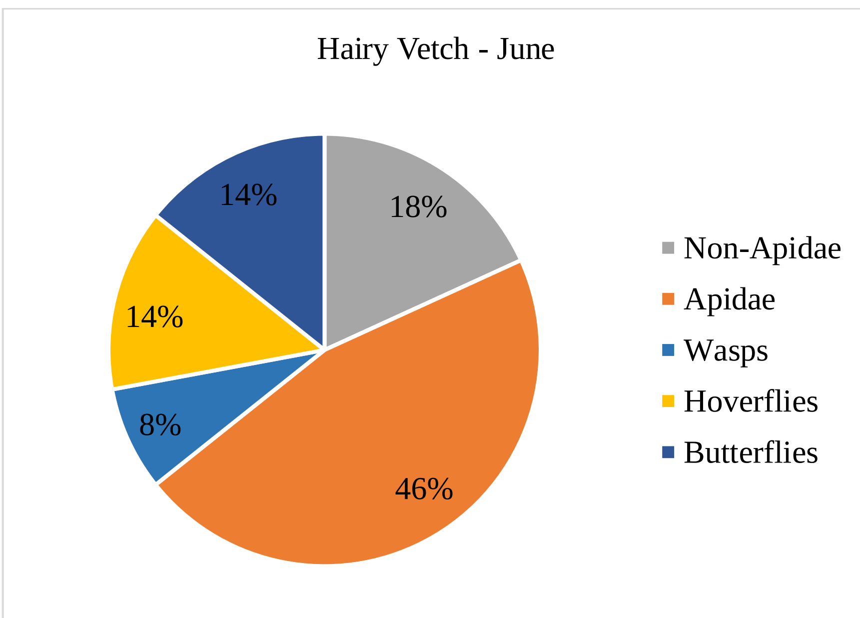

Figure 56-A. Proportion of observed insect visitations to Hairy Vetch in June 2018. N = 154.

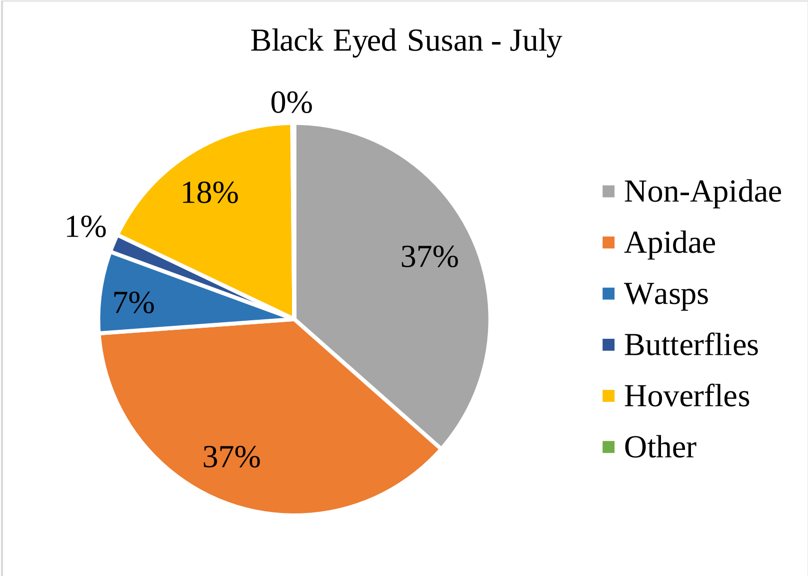

Figure 57-A. Proportion of observed insect visitations to Black Eyed Susan in July 2018. N = 608.

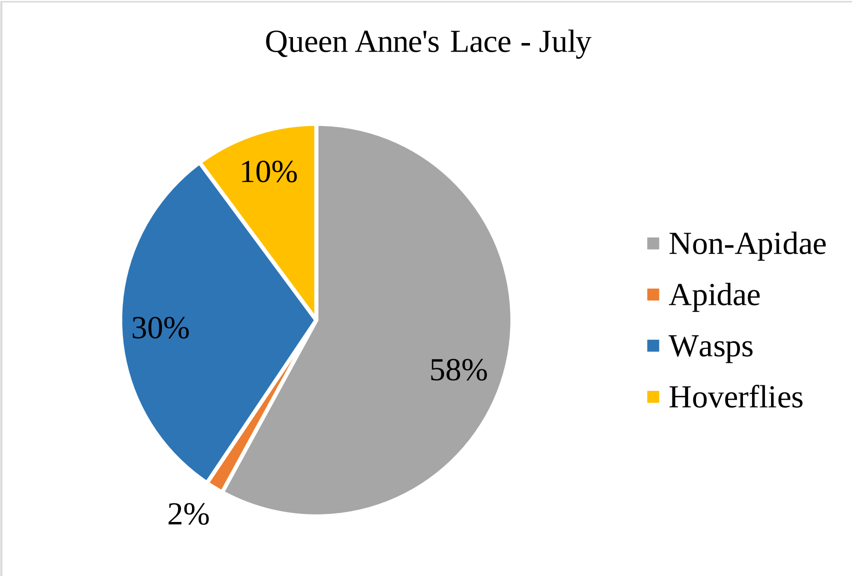

Figure 58-A. Proportion of observed insect visitations to Queen Anne’s Lace in July 2018. N = 69.

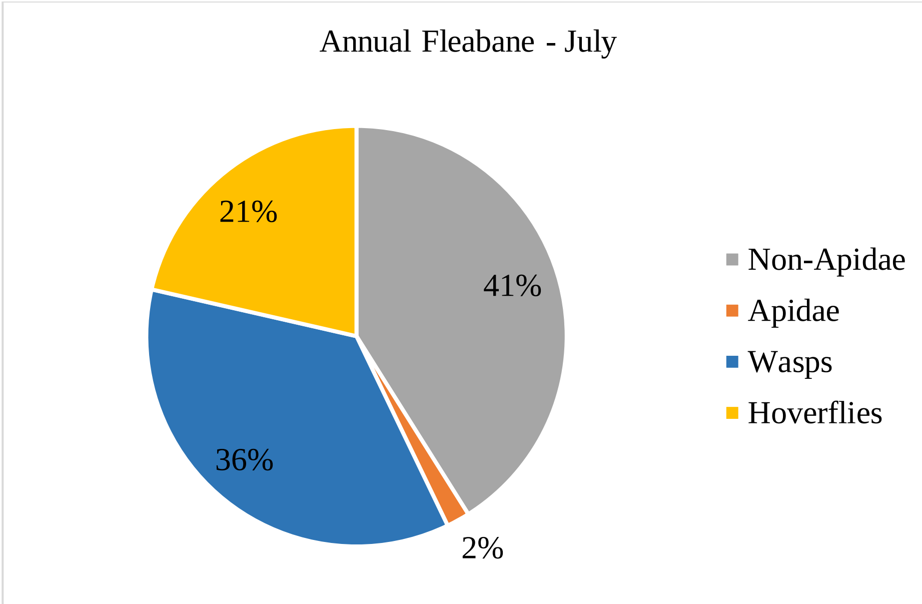

Figure 59-A. Proportion of observed insect visitations to Annual Fleabane in July 2018. N = 56.

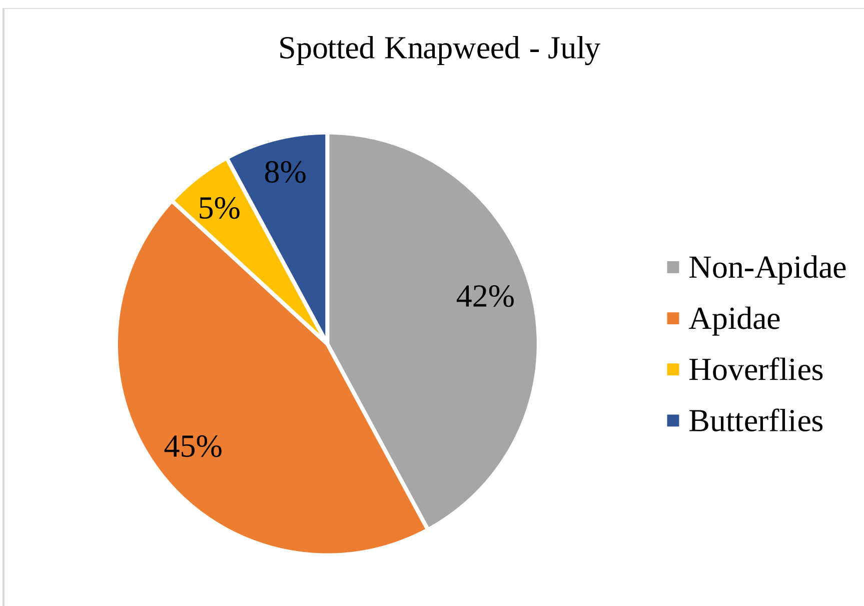

Figure 60-A. Proportion of observed insect visitations to Spotted Knapweed in July 2018. N = 38.

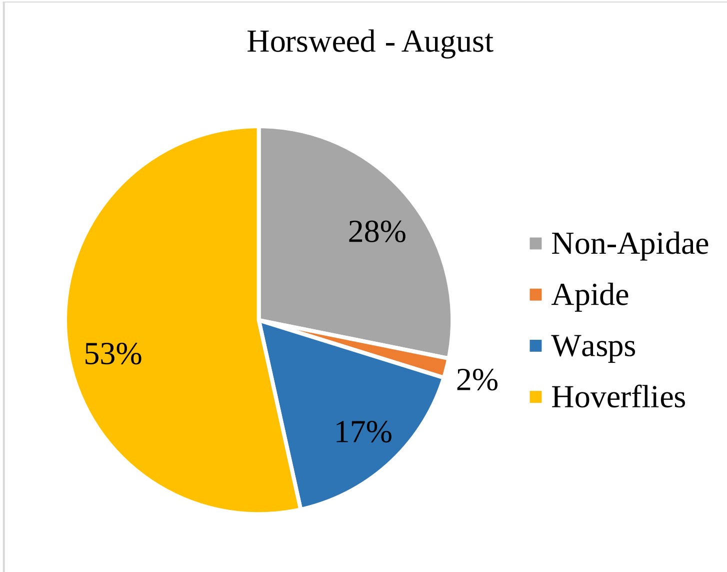

Figure 61-A. Proportion of observed insect visitations to Horseweed in August 2018. N = 245.

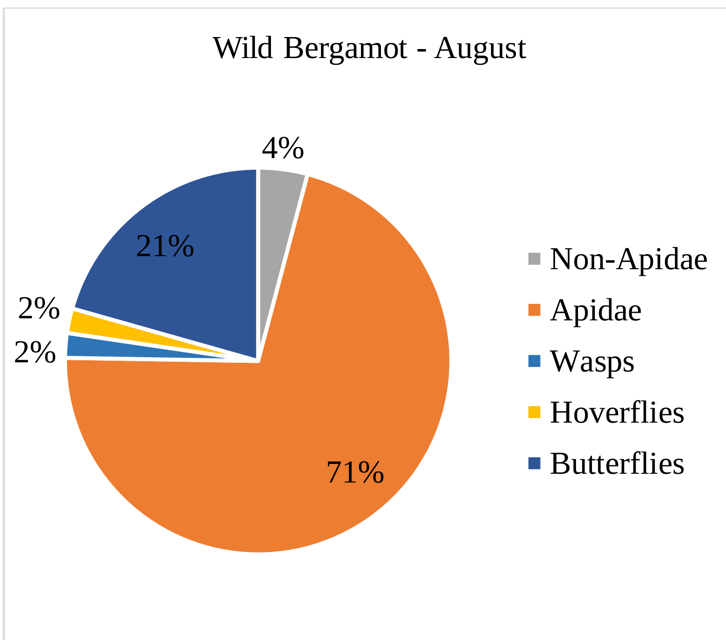

Figure 62-A. Proportion of observed insect visitations to Wild Bergamot in August 2018. N = 97.

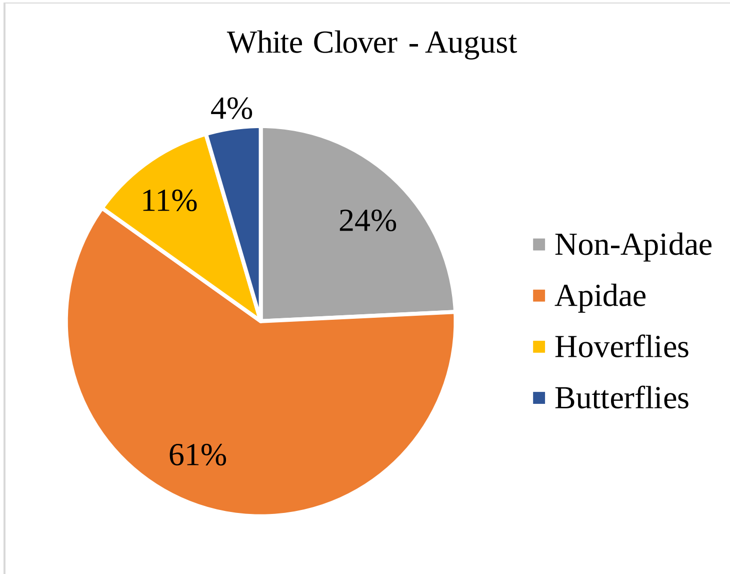

Figure 63-A. Proportion of observed insect visitations to White Clover in August 2018. N = 66.

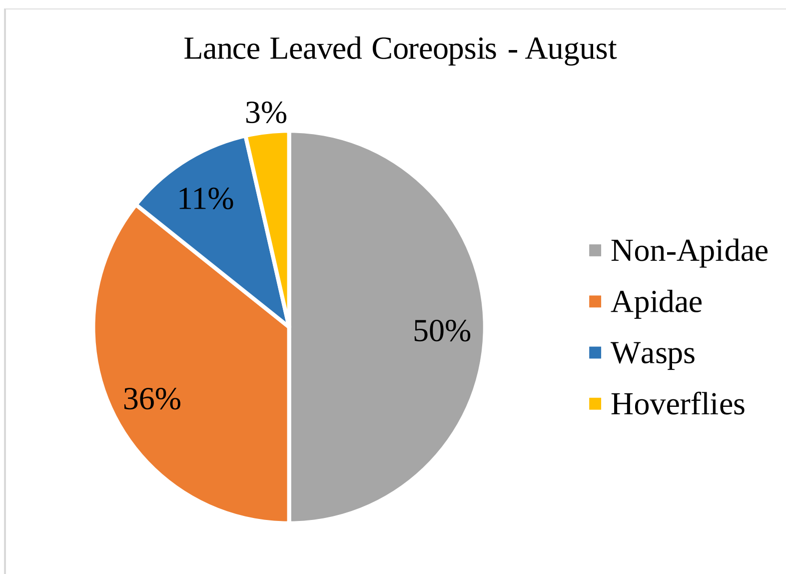

Figure 64-A. Proportion of observed insect visitations to Lance Leaved Coreopsis in August 2018. N = 28.

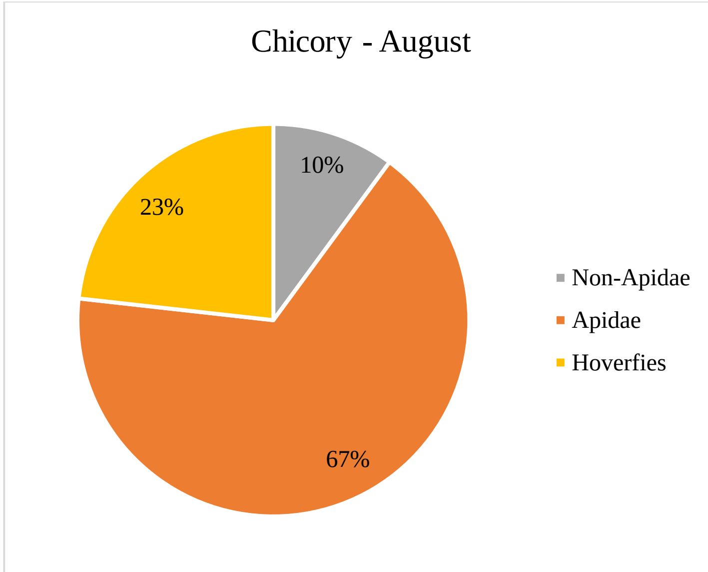

Figure 65-A. Proportion of observed insect visitations to Chicory in August 2018. N = 198.

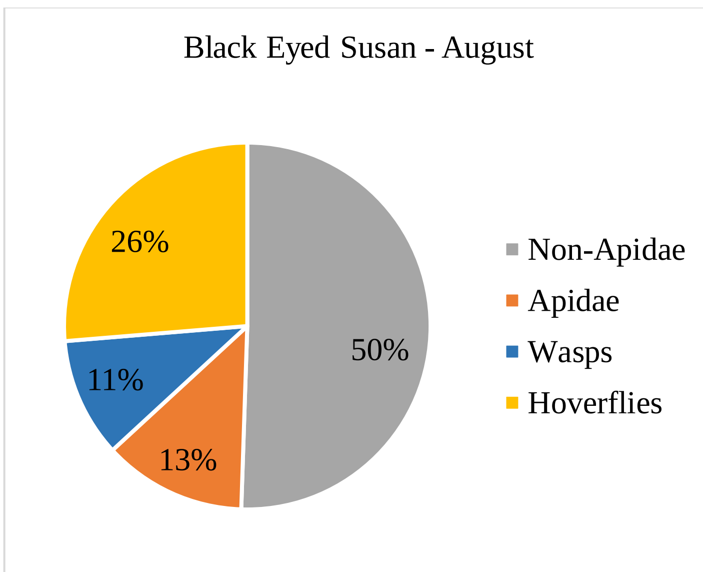

Figure 66-A. Proportion of observed insect visitations to Black Eyed Susan in August 2018. N = 97.

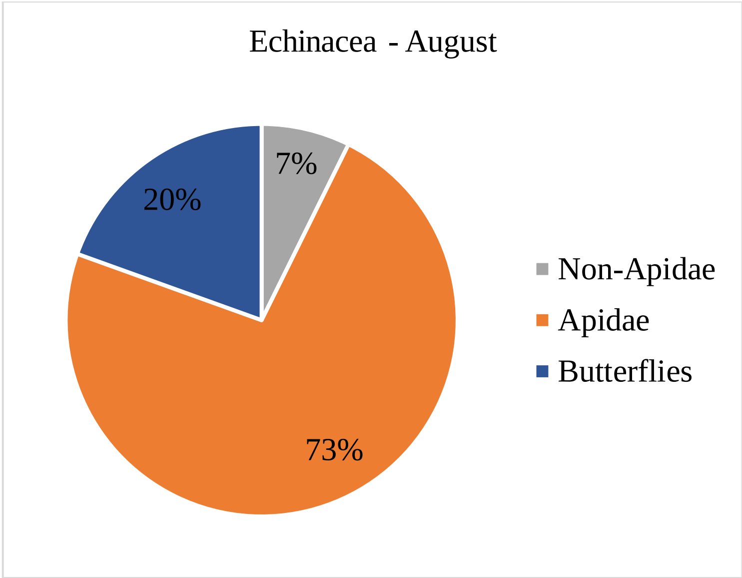

Figure 67-A. Proportion of observed insect visitations to Echinacea in August 2018. N = 41.

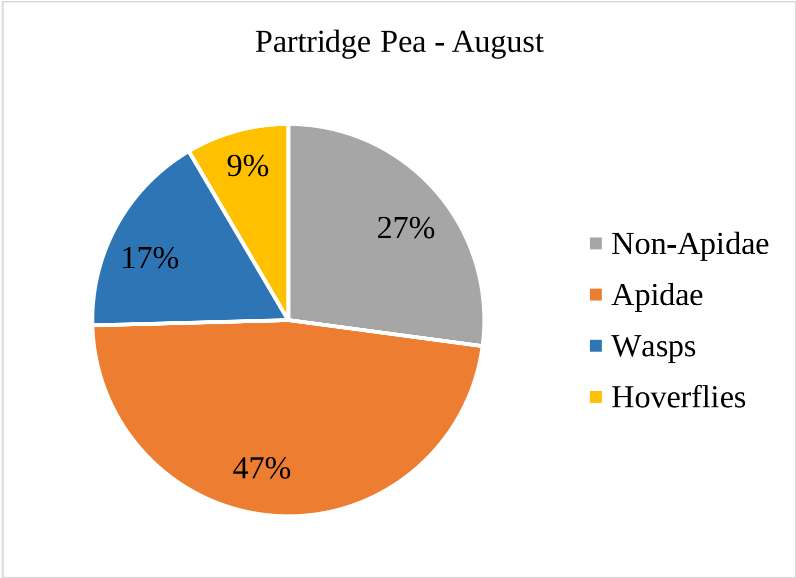

Figure 68-A. Proportion of observed insect visitations to Partridge Pea in August 2018. N = 59.

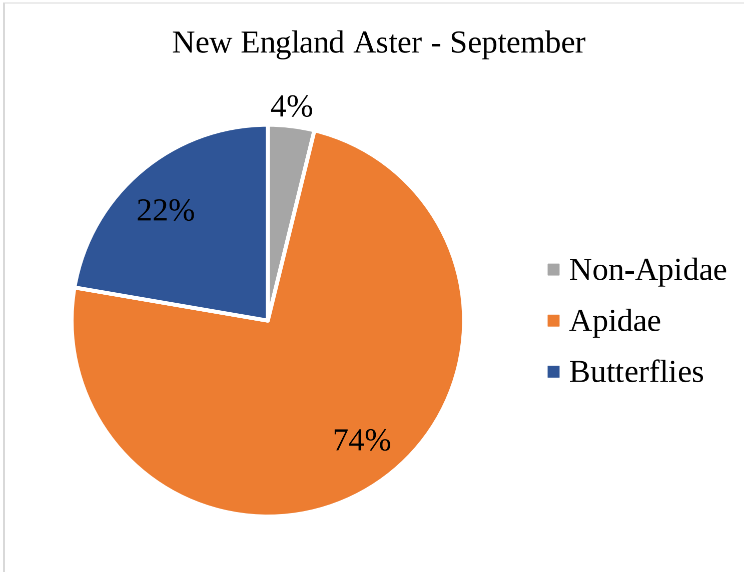

Figure 69-A. Proportion of observed insect visitations to New England Aster in September 2018. N = 157.

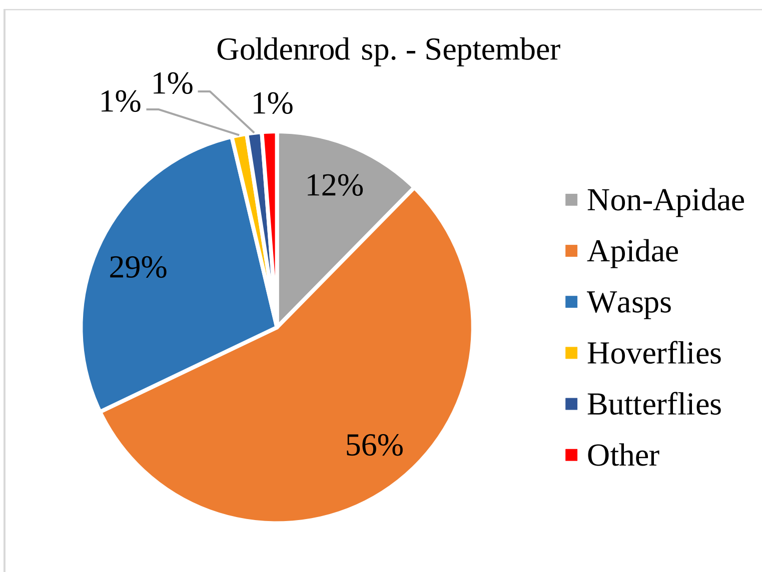

Figure 70-A. Proportion of observed insect visitations to Goldenrods in September 2018. Here, “other” visitors are moths. N = 81.

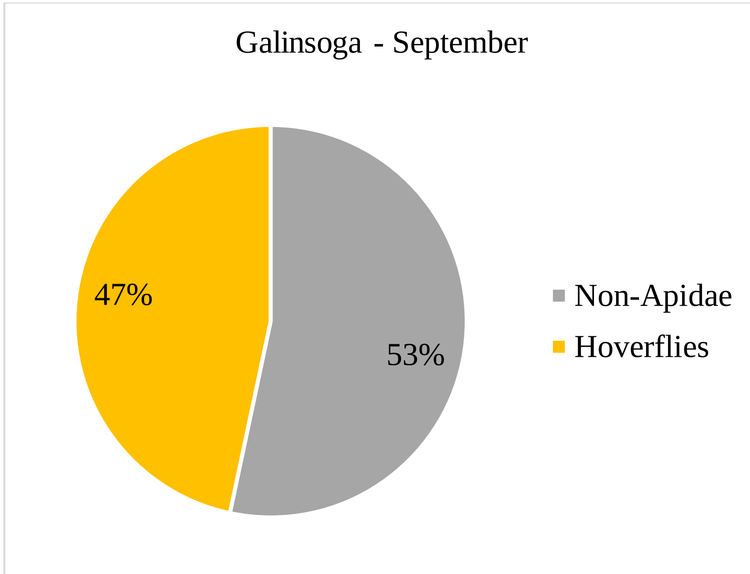

Figure 71-A. Proportion of observed insect visitations to Galinsoga in September 2018. N = 45.

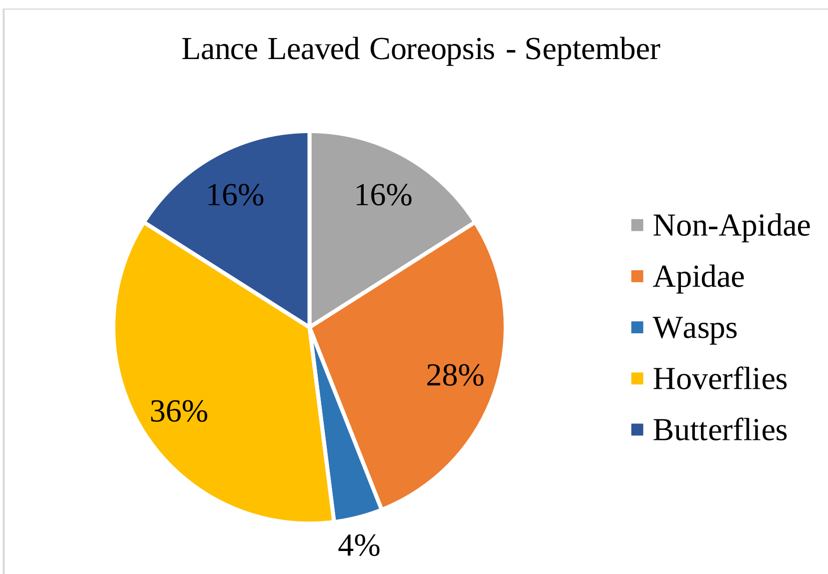

Figure 72-A. Proportion of observed insect visitations to Lance Leaved Coreopsis in September 2018. N = 25.

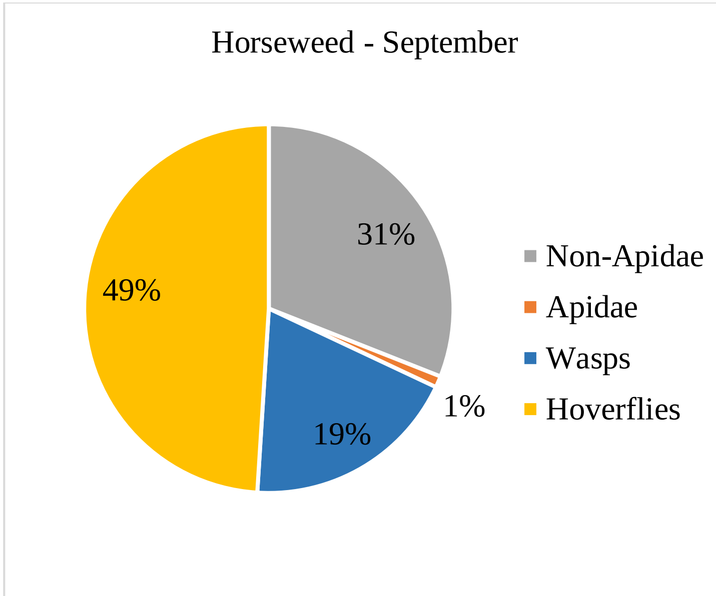

Figure 73-A. Proportion of observed insect visitations to Horseweed in September 2018. N = 100.

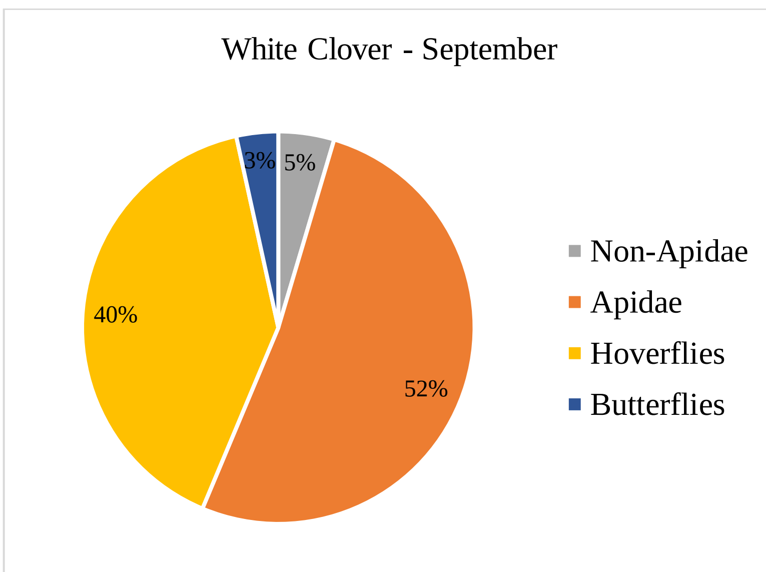

Figure 74-A. Proportion of observed insect visitations to White Clover in September 2018. N = 87.

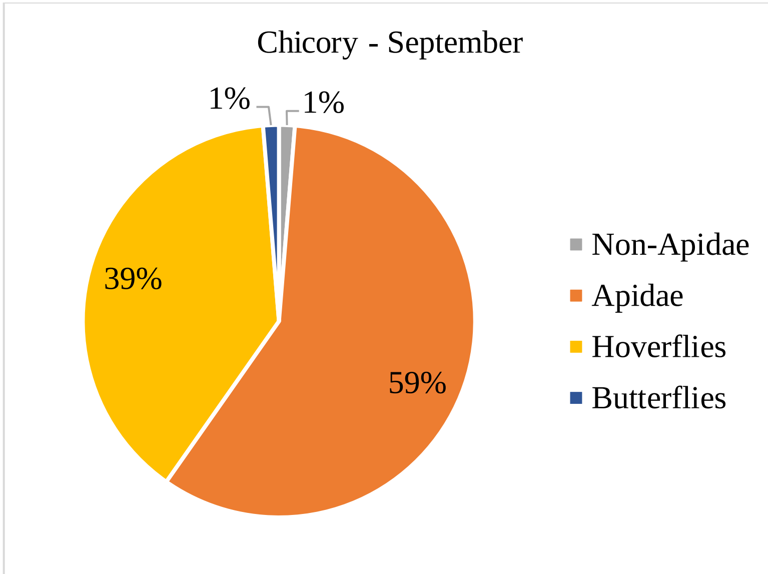

Figure 75-A. Proportion of observed insect visitations to Chicory in September 2018. N =77.

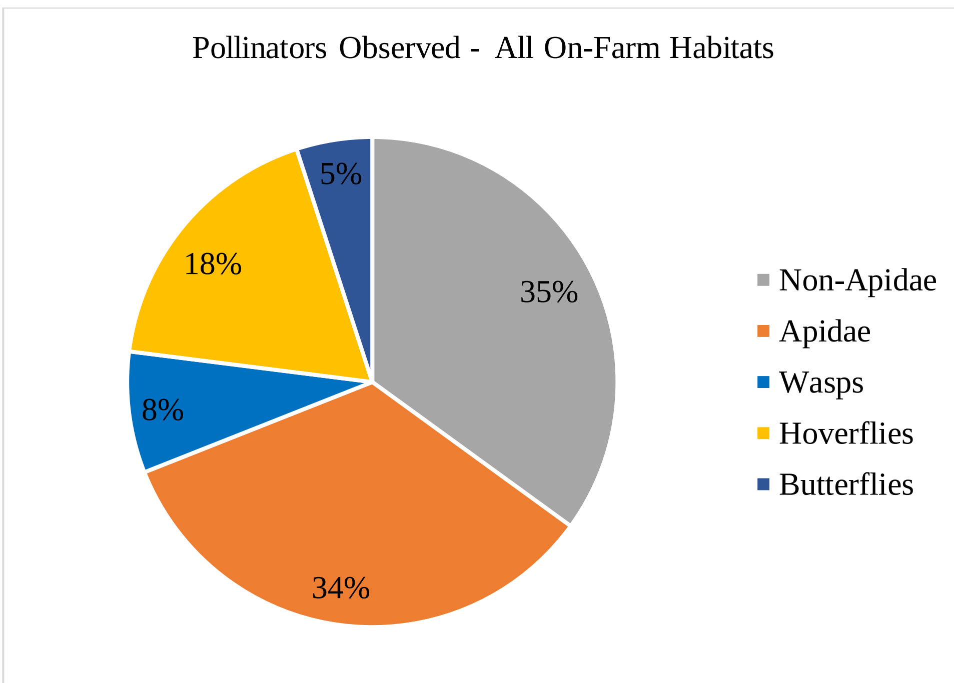

Figure 76 – A. Proportion of observed insect visitations to flowers on all on-farm habitats. N = 8,989.