

11-5-2019

Evaluation of Drought-Resistant Plants for Beneficial Insect Attraction

Benjamin Gluck
benjaminlgluck@protonmail.com

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Evaluation of Drought-Resistant Plants for Beneficial Insect Attraction

Benjamin Levi Gluck

B.A., University of Connecticut, 2010

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

At the University of Connecticut

2019

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APPROVAL PAGE

Masters of Science Thesis

Evaluation of Drought-Resistant Plants for Beneficial Insect Attraction

Presented by

Benjamin Levi Gluck, B.A.

Major Advisor _____

Dr. Ana Legrand

Associate Advisor _____

Dr. Kim Stoner

Associate Advisor _____

Julia Cartabiano

University of Connecticut

2019

Acknowledgements

I would first like to thank my thesis advisor, Dr. Ana Legrand. She provided invaluable advice on how to develop my research project, and also demonstrated endless patience during the editing process. I would also like to thank the members of my thesis committee, Dr. Kim Stoner and Julia Cartabiano, who helped me refine my study and provided valuable feedback.

Additionally, my research project was made possible by the UConn floriculture staff, and the UConn Plant Science research facility crew. Nick Pettit, Shelley Durocher, and Ron Brine, provided greenhouse space, growing expertise and help watering my plants. Steve Olson provided a field plot for me to conduct the experiment on, and advice on how to do so. Scott Vose, Mark Oliver and Gregg Tormey helped set up and maintain my field plot and plants. Without their contributions, this research would not have been possible.

Many of my fellow graduate students from the Department of Plant Science and Landscape Architecture, and from the Department of Statistics provided helpful advice. Kevin Shen, Marlesse Lessing and Jim Harrington helped with field work.

The Department of Plant Science and Landscape Architecture provided a graduate assistantship, which allowed me time to focus on my studies and research.

Finally, I must express my profound gratitude to my parents for providing me with continuous encouragement and support throughout my entire academic career. Without their support I would never have made it this far.

Thank you,

Benjamin Gluck

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Abstract

Beneficial insects, such as natural enemies and pollinators, provide billions of dollars of ecological services to agricultural operations. However, as the climate changes, Connecticut is projected to have longer periods of drought. This could negatively impact the availability of flowering plants, and the beneficial insects who rely on their floral resources.

This research focuses on the diversity of insect visitors to five species of drought-resistant plants at the Plant Science Research and Educational facility. Over the two-year study the visitation frequency of pollinators and beneficial insects on the plants was observed, insect samples were collected for further identification. *Agastache foeniculum* and *Gaillardia pulchella* had the most visitors, and the majority of the visiting pollinators were from the families Apidae and Halictidae. *Cota tinctoria* had the most visitors from natural enemies.

Additionally, the length of time insects visited the plants was compared against a water-stressed experimental group. There was no significant difference between the total length of insect visitation to the water-stressed experimental group and control groups of *Agastache foeniculum*. However, there was significant differences between the total length of bee visitation to the experimental and control groups of *Fagopyrum esculentum*.

Chapter 1: Literature Review

While all insects are intrinsically valuable, there are many that provide ecological services that can be quantified. These “beneficial insects” provide an estimated \$60 billion per year in ecosystem services (Losey and Vaughan 2006). Two of the most economically important insect groups are pollinating insects and natural enemies of agricultural pests. Globally, up to 75% of agricultural crops rely on bee pollinators to improve or stabilize yields (Klein et al. 2007). These bee-pollinated crops account for up to 35% of global food production (Klein et al. 2007). Clearly, insect pollinators are vital to our food production systems. While managed pollinators, mainly the honey bee *Apis mellifera*, are responsible for the bulk of agricultural pollination, wild bees also play a role on our farmlands to an estimated \$3 billion/year (Losey and Vaughan 2006). Even on farms with honey bee hives, flowers were visited by *Bombus impatiens* more times than *A. mellifera* overall (Stoner 2013). Additionally, for some specialty crops most of the pollination is done by wild bees. Many of these solitary bees are adapted to pollinate only a few species of plants, but these specialized bees are often more effective and efficient than *A. mellifera* at pollinating these plants. (Westerkamp and Gottsberger 2000).

Many other beneficial insects can have positive impacts on agriculture. The natural enemies of arthropod pest species can help reduce pest populations, which could potentially reduce the necessity of pesticide application. For example, ladybird beetles eat aphids, assassin bugs eat larger pests, and some parasitoid wasps’ larval stages use herbivorous caterpillars as a food source. Losey and Vaughan (Losey and

Vaughan 2006) estimated that there was a \$4.5 billion per year biological control ecosystem service provided by natural enemies.

Unfortunately, beneficial insects are in decline across the world. Reductions in beneficial insects' populations have resulted in loss of pollination and natural control ecosystem services. It is often agricultural practices that are harming these insect species the most. Land use changes from wild habitat to agricultural and residential interests often increase the distance between floral resources and crops. Isolation from existing natural habitats diminishes the amount and diversity of bees present (Steffan-Dewenter and Tschamntke 1999). Fortunately planting flowers nearby crops can help provide pollen and nectar, the main sugar and protein sources for bees, in otherwise generally flowerless monocultures. For example, data suggest that agricultural fields within 1 km of gardens have larger bumble bee population sizes than those farther from gardens (Goulson et al. 2010).

In addition to nutritional resources, pollinators also require nesting sites. Similar to how *A. mellifera* need a suitable location to build their colony, native bees have specific nesting requirements. *Bombus* species need bare soil or hollow logs to build their nests, and many solitary bee species require hollow grasses or reeds to provision nests. Even when they have nutritional resources, without appropriate nesting sites nearby only the farthest-flying beneficial insects will be able to reach the crops. This is evidenced by the differences in nesting requirements by different species of *Bombus*. For example, *B. lapidarius* needs gardens within a 750 m and 1000 m radius to help nest survival numbers, while *B. pascuorum* needed flowers within a 500 to 750 m radius (Goulson et al. 2010).

This reduction in the bee population and diversity is likely a factor in the loss of pollination services (Kremen et al. 2002). For example, a 2001 study found that organic farms within 1km of natural habitat could have their watermelon pollination needs met by the native bee population alone, but agricultural intensification greatly diminished these pollination services (Kremen et al. 2002). Studies show that agricultural intensification can reduce the diversity and abundance of native bees such that there may be insufficient pollination to produce marketable products (Westerkamp and Gottsberger 2000).

While there are fewer floral resources available in farmland, there is also a lack of floral resources throughout the human-impacted landscape. One meta-analysis in England found that of the 97 bumble bee forage plants they studied, 71% had a negative change index, meaning almost three-quarters of known pollinator plants were declining (Carvell et al. 2006). In terms of magnitude of change for individual plant species, this means 24 of the 68 species tested showed significant negative changes in frequency (Carvell et al. 2006).

Additionally, loss of natural enemy populations due to landscape simplification correlated with an increase in Midwestern US pesticide use of \$69 million per year (Meehan et al. 2011). Increased pesticide use causes millions of dollars' worth of damage in pesticide resistance, possible groundwater contamination and pesticide drift, pollinator losses and damages to human health (Khan et al. 2002). Therefore, using lesser amounts of pesticides may result in less environmental and economic costs.

Climate Change

In addition to the declining availability of floral resources, anthropogenic climate change is altering the landscape. Throughout New England, the average winter-spring air temperature has risen roughly 1.5°C between the years 1850 and 2000 (Hodgkins et al. 2002). These changes are altering the interactions between insects and plants. For example, a study in northeastern North America shows that the ten generalist bee species studied emerged an average of 10 days earlier (Bartomeus et al. 2011). In this study, the bees and plants both shifted their emergence times earlier at relatively similar rates. This suggests that, for now, there may not be any phenological mismatch between plants and bees, but specialist bees may eventually become more out of synchronization with the few plant species which they adapted to forage—the bees are emerging either too early or late to have a food source. Similarly, the plants will not have pollinators available when they are in flower and need to be pollinated. This could lead to declines in abundance of that particular plant species, which could harm any pollinators relying on said plant as a food source.

Even when flowering plants remain synchronized with their pollinators, they might not be able to provide the same level of floral resources they had in pre-industrial times. While nectar does increase with temperature, one study found this correlation only holds until around 40°C and with adequate watering (Petanidou and Smets 1996). Above that range, or with insufficient watering, the *Thymus capitatus* and *Ballota acetabulosa* in that study produced less nectar. So, climate change may raise summer temperatures to new highs that could reduce nectar production. Not only may this

reduce the availability of food resources, but it may damage plant-pollinator relationships. Pollinators are very risk-averse and will quickly stop visiting flowers if the nectar variability is too high (Kearse et al. 2008). Even if pollinators continue to visit the drought-stressed plants, the pollen from these plants may not be as likely to develop into viable seeds (Turner 1993). This means the plants may be less likely to successfully reproduce, leading to losses for both plant and pollinators.

Another potential effect of climate change is the alteration of spatial distributions of pollinators and plants. When long-term climate changes occur, species tend to move towards the poles and to higher elevation during warming events and towards the equator and lower elevations during cooling events (Taberlet et al. 1998). Theoretically, one species of the plant-insect mutualism might disperse more slowly than the other, or be unable to extend its range northward, leading to a geographic mismatch between the two species. One modeling study showed plant-pollinator populations declining at a linear, rather than a catastrophic rate (Devoto 2007). While immediate collapse of plant-pollinator systems is therefore unlikely, a more gradual decline may still happen as many key species are lost.

Additionally, regions such as New England are predicted to have longer intervals without rainfall during the summer months. More specifically, the future climate of the Northeast's summers is predicted to be hotter and experience droughts more frequently (Dupigny-Giroux et al. 2018). These droughts could lead to water-stress in the plants which might impact their nectar production. Decreased nectar production could make otherwise ideal pollinator plants less useful to pollinators. Incorporating

drought-resistant plants into pollinator mixes may help increase the resilience of pollinator plantings to climate change.

Floral Characteristics and Pollinators

While many species of natural enemies and pollinators may be in decline, planting additional floral resources may help mitigate losses. Community gardens in California were able to gain a six-fold increase in pollinator species over two years, simply by adding well-known pollinator plants (Pawelek et al. 2009). Flowering plants have been recommended as beneficial food sources to any biocontrol programs using Hymenopteran parasitoids (Jervis et al. 1993), primarily because nectar can increase parasitoid parasitism rates and longevity (Powell 1986).

However, many agricultural areas do not have the nutritional resources necessary to sustain a healthy population of beneficial insects. Since pollinators require a diverse selection of flowering plants, many entomological or conservation organizations compile lists of “pollinator-friendly” plants for the public. These lists help farms, gardeners and concerned citizens provide floral resources for pollinators. However, lists of plant suggestions for pollinators and natural enemies are occasionally based more on anecdote than science. While many plant species have been tested, testing in different locations with different pollinator or natural enemy communities may yield different results (Isaacs et al. 2009). This may help fine-tune plant lists to make them better suited for the pollinators in specific regions. Furthermore, with our changing climate these plants may have to endure drought stresses more frequently. Therefore, it

could be helpful to study the pollinator attractiveness of many different flowering plants and how this is affected by water-stress.

There is relatively little information about which species of flowering plants provide the floral resources, or the landscape context in which they should be distributed (Isaacs et al. 2009). However, some plant characteristics have been shown to correlate with attracting a greater abundance of beneficial insects. For example, total floral area of the plant was found to attract more natural enemies than any other characteristic studied (Fiedler and Landis 2007a). Similarly, pollinators such as *Syrphid* flies and *Bombus* were most attracted to plants with numerous, large flowers which result in a large floral area (Conner and Rush 1996; Hegland and Totland 2005).

Pollinator attraction is driven by many factors including the physical and chemical properties of the plants. For example, the color of the flower is very important, and pollinators have been found to have preferences for certain colors (Reverté et al. 2016). This however does not mean a species of pollinator will only visit one color of flower. Larger flowers are easier for *Bombus* to detect, especially those with a color that contrasts with the surrounding landscape (Spaethe et al. 2001). Smaller flowers took longer for the *Bombus* to find. The shape and quality of the petals also determines the brightness of the petal pigmentation visible to insects (Glover and Martin 1998). Pollinators can also use patterns of colors on the flower petals to determine which have the most floral resources (Hempel de Ibarra et al. 2015). They can associate different qualities of floral resources with different patterns on the petals and choose accordingly.

Chemical signals such as floral odors also play a role in attracting pollinators. These signals are dispersed in the form of volatile organic compounds. Like visual cues,

pollinators associate certain of these chemical signals with floral resources (Raguso 2008). However, some plants with low rewards do disperse organic compounds that falsely claim they have higher quality resources available (Haber et al. 2019). Other plants with irregular blooms or sporadic distribution rely on scents to attract pollinators from a great distance to find their blooms (Grison-Pigé et al. 2002). At longer distances, floral scent was a greater determinate of pollinator preference, but at closer ranges the visual cues were more important (Glover 2011; Klahre et al. 2011).

Another factor to consider is whether the plant is an annual, a perennial, or native to the area. First, if the plant is not native to the area, it may not be adapted to the soil type and may not grow to the robustness or density needed to provide for pollinators. Annuals need to regenerate from seed each year so are not as permanent. Exotic plants can be unfamiliar to beneficial insects and underutilized. Native perennials in their second year attracted more natural enemies than the most commonly recommended exotic annuals (Fiedler and Landis 2007b). While this is beneficial, it comes at the cost of slower growth in the plant's first season. However, once the perennials were established they provided these floral resources for a greater portion of the growing season than the exotic annuals (Fiedler and Landis 2007b). These native perennials also attracted different species of natural enemies than the exotic annuals, making them more complimentary than redundant to each other. The authors stressed the importance of screening the plants for potential arthropod herbivores, as attracting new pests would be counterproductive.

Objectives

The purpose of this study is to ensure more reliable and consistent access to floral resources for pollinators during droughts. The first objective of this study was to determine the attractiveness of five different species of drought tolerant flowering plants to beneficial insects. This also provided data on which genera and species of beneficial insects in Connecticut visit these plants.

The drought-tolerance of these plants is important as flowers more tolerant of dry conditions will require less watering, making them more of a “low-maintenance” option for pollinator resources. Landowners will be more likely to plant flowers that do not require much irrigation.

A second objective was to determine the influence of water stress on how many pollinators visit these plant species. To account for this potential change in precipitation, an additional test was conducted to determine how well some of the test species attract pollinators while under water-stress. The insect’s behavior and visitation frequency to the water-stressed plant and to the control plant was monitored. If the plants are still able to support beneficial insects under these conditions, then they might be of use in pollinator plantings in drought-prone areas or where irrigation would be impractical.

Chapter 2: Survey of Beneficial Insects on five species of Drought-Resistant Plants

Introduction

Pollinators are declining all over the world, partially due to habitat loss and lack of floral resources (Kluser and Peduzzi 2007). Pollinator plantings can help mitigate the loss of these floral resources, but we must consider both the location they are planted in, and the future climate conditions that these plantings will face. While some of these plants have been tested for pollinator attraction in other parts of the country, it is important to determine if they would make a suitable pollinator plant in eastern Connecticut. Additionally, Connecticut is projected to experience longer periods of drought for the rest of the century, so it is imperative to understand what drought tolerant plants can be suggested for pollinators (Frumhoff et al. 2007). The objective of this study is to determine how attractive certain drought-resistant plants are to beneficial insects. This provides valuable information as it helps determine which plants may be useful in pollinator plantings for drier climates.

The research plan involved testing five species for attractiveness of floral resources for beneficial insects. The plants chosen for this study are three members of the Asteraceae family (*Echinops ritro* L., *Gaillardia pulchella* Foug., and *Cota* [=Anthemis] *tinctoria* Kelwayi), a species from the Lamiaceae family (*Agastache foeniculum* Kuntze) and a species from the Boraginaceae family (*Phacelia tanacetifolia* Benth.). These were selected because of their alleged attractiveness to pollinators or their tolerance of hot and dry conditions. These plants were also selected based on their

growing condition requirements, temperature requirements, how aggressively the plant reseeds, and phenology. Additionally, the USDA NRCS plant database was consulted to determine if the plants would be invasive in Connecticut.

Binomial	<i>Agastache foeniculum</i>	<i>Cota tinctoria</i>	<i>Echinops ritro</i>	<i>Gaillardia pulchella</i>	<i>Phacelia tanacetifolia</i>
Common Name	Annise Hyssop	Dyers' Chamomile	Globe Thistle	Firewheel, Indian blanket	Lacy Phacelia
Family	Lamiaceae	Asteraceae	Asteraceae	Asteraceae	Boraginaceae
Drought Tolerance	Dry to medium	Thrives in dry conditions	High	High	High
Pollinator Attraction	High	Unknown	Mentioned in one study	Tested, but only in seed mixes	High
Blooming Time	June to September	Summer	June to September	June to frost	Spring to summer
Distribution	Northern U.S.A.	Northern U.S.A.	Northwest U.S.A.	Eastern U.S.A.	Southwest U.S.A.
Hardiness Zones	4 - 8	3 - 7	3 - 9	2 - 11	7 - 10
Invasive status	Not invasive, CT Native	Not invasive	Not invasive	Not invasive, CT Native	Not invasive

Table 1. Characteristics of drought-tolerant plants selected for this study

Agastache foeniculum is the only Lamiaceae, or mint, in the study. It is often recommended as a pollinator plant, but no studies were found on its effectiveness in the northeastern United States. It has a deep taproot, making it quite drought resistant (Saeedfar et al. 2015). It is used as a decorative flower, and occasionally as a tea or

medicinal herb (Duda et al. 2014). *Cota [=Anthemis] tinctoria* is often referred to as Golden Chamomile or Dyers Chamomile. It is a drought-resistant naturalized perennial native to Europe (Cornell University 2006a). *Echinops ritro* is quite drought tolerant and has nectar attractive to pollinators in Poland (Jablonski and Koltowski 2001). It is a perennial aster thistle with spikey leaves that can reach a height of one meter and produces blue globe shaped flowers. While not native to the United States, they are non-invasive and have been naturalized in the Pacific Northwest (Cornell University 2006b).

Gaillardia pulchella is listed in several pollinator plant lists, but no primary research could be found on its effectiveness as a pollinator and insectary plant outside of seed mixes. As a Connecticut native, it was selected to be a part of the study, because native plants were recommended as superior sources of floral resources as they attracted more natural enemies (Isaacs et al. 2009).

P. tanacetifolia (Boraginaceae) is a plant most commonly used in agricultural systems as a cover crop to prevent nitrate leaching. While it is well documented as an abundant source of pollinator floral resources in its native range of northern Mexico and the American southwest (Pawelek et al. 2009), there is little to no documentation of how it will fare as a floral resource in the northeastern United States. Another Borage, *Borago officinalis*, was tested in Belgium for bee attractiveness under different temperature and water conditions. The treatments that received less water and the treatments that had increased temperature both had decreased nectar production (Descamps et al. 2018).

Methods

Field Planting for Surveys

The field selected for the study was previously a turf research field at the UConn Plant Science Research Farm in Mansfield, CT. A turf cutter was used to remove the top few inches of vegetation so flowers could be planted directly into the soil. Starting in April 2017, seedlings were started in a greenhouse and were transplanted into the field in May and June 2017. Other plants were directly sown into the fields. Seeds and transplants were watered when placed in the fields but all other watering came from rainfall. The plants were covered with hay mulch to suppress weeds, but significant hand weeding was also necessary. No pesticides or herbicides were used on the plants in this study.

The *A. foeniculum* used in this study was the 'OG' cultivar from Johnny's Selected Seeds from Winslow, ME. The *C. tinctoria* was the 'Kelwayi' cultivar from Outside Pride from Independence, OR. The *E. ritro* was also from Outside Pride, but no cultivar was listed. The *G. pulchella* was from Native American Seed from Junction, TX. The *P. tanacetifolia* was from the Vermont Wildflower Farm in Hinesburg, VT.

The experiment was laid out in a randomized complete block design (hereafter "RCBD"). The experimental field was divided into six longitudinal blocks. This is to control for changes in sunlight levels caused by shade from trees on the western border of the field, which could otherwise alter the amount of sunlight the plants receive and potentially affect the data. Additionally, the blocking pattern addresses any disturbances

caused by the dirt road along the eastern border of the field. The treatments were the five species of flowering plants listed previously. Plant species tested were planted in 1.5m² plots with one of each species in each block 6.7 m (22 feet) apart. The field was 50m x 54m (170 feet x 180 feet) and the blocks were an average of 8.5 m (28 feet) apart.

In the second year an additional plot of *P. tanacetifolia* was planted in each block. The second *P. tanacetifolia* plot was not planted until the first plot was starting to bloom, to ensure that there would always be one plot blooming in each block.

Observational Survey

Data collection took place weekly from June until October in 2017 and 2018. Data were collected by first observing and recording number of bees from each family collecting nectar or pollen from one plant plot. The starting block was randomly selected to reduce bias. Observations were performed between 9am and 4pm. Observations and netting were performed on separate days to limit number of bees scared away by presence of the observer. Observations and netting were postponed one day if weather conditions are rainy, below 15°C, above 38°C, heavily overcast, or overly windy (>4 meters per second). The number of flowers and inflorescences that were in bloom and likely were producing nectar were counted in each plot.

Observations categorized the bees into visual categories (*Figure 1*) based on the Xerces Society Pennsylvania Native Bee Survey Citizen Science Monitoring Guide

(Donovall and vanEngelsdorp 2008). The categories include honey bee, bumble bee, large carpenter bees, hairy leg bees, large dark bees, small dark bees, green sweat bees, and hairy belly bees. Hairy leg bees are defined as small striped Apidae with long scopa on their hindlegs. Large dark bees were medium sized Andrenid bees. Small dark bees are small Halictids such as *Lasioglossum* or *Halictus*. Green Sweat bees are the small metallic green Halictids such as *Agapostemon*, *Augochlora* or *Augochloropsis*. Dark hairy belly bees are the non-metallic Megachilids, who get their name from their scopa on the underside of their abdomens.

Beneficial insects landing on the flower corolla were recorded on data sheets. Observations were timed for one minute per plot with a handheld stopwatch, which was paused to give time to write out data.

Honey Bees



Size and Shape: Medium to large, moderately robust.



Color: Orange-brown to nearly black.

Hair: Fuzzy thorax and head, legs and abdomen less hairy.

Stripes: Abdomen tri-toned, with black, pale and orange-brown stripes of hair and body coloration.

Scopa: Enlarged, flattened hind legs; hairless in the center.

Antennal Length: Short.

Notes: Makes a buzzing sound when flying; the only bee with "hairy eyes".

3

Large Carpenter Bees



Size and Shape: Very large and robust.



Color and Hair: Shiny, nearly hairless black abdomen; thorax covered in yellow/light hair; males with a yellow spot on face.

Stripes: None.

Scopa: Hind leg enlarged, completely covered in scopal hairs.

Antennal Length: Short.

Notes: Will only see one or a few at a time; only species in PA: *Xylocopa virginica*.

5

Bumble Bees

Size and Shape: Medium to very large, robust.



Color, Hair and Stripes: Body black, with yellow, black, and, sometimes, orange hair stripes on thorax and abdomen.

Scopa: Hind legs enlarged and flattened; hairless in center.

Antennal Length: Short for females (for most bumble bees encountered), long for males.

Notes: Make a low buzzing sound when flying; painful sting that does not linger.



4

Hairy Leg Bees

Size and Shape: Small/medium to medium/large and robust.



Color and Hair: Dark, with white to yellowish/orange hairs.

Stripes: Abdomen often with pale stripes.

Scopa: On hind legs; appear as dense stands of long hair (like pipe-cleaners).

Antennal Length: Generally longer than most bees, especially males, who have very long antennae.

Notes: Very quick; difficult to collect.



Large Dark Bees



Size and Shape: Small to Medium/large, relatively narrow to moderately robust.



Color and Hair: Body dark, thorax covered in short, white to yellowish hairs; females with facial foveae; males with beard or mustache or yellow facial markings.

Stripes: If present, made up of pale hairs.

Scopa: On hind legs, often pale and short.

Antennal Length: Short in females, longer in males.

Notes: Can be numerous in Spring and Fall; one rare species, *Nomia nortoni*, with iridescent abdominal stripes.

7

Small Dark Bees

Size and Shape: Tiny to small/medium, moderately narrow.



Color, Hair and Stripes: Dark, often metallic; sometimes with yellow marks on face, thorax and/or legs; abdomen can be yellowish or reddish; body often dulled by short pale hairs, that can be in stripes or patches on abdomen.

Scopa: On hind legs, but can be difficult to see without pollen load.

Antennal Length: Short in females, longer in males.

Notes: Often most abundant group in the garden throughout the season.



8

Green Sweat Bees



Size and Shape: Small to Medium, relatively narrow.



Color, Hair and Stripes: Metallic green; abdomen can be dark and striped with yellow body markings or pale hairs.

Scopa: On hind legs; less noticeable than other bees, unless covered in pollen.

Antennal Length: Short in females, longer in males.

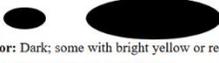
Notes: Relatively fast flying and numerous; most are ground nesters, but one especially numerous species nests in rotting wood, and, so, may be found in areas with a lot of woody debris.

9

Dark Hairy Belly Bees



Size and Shape: Small to very large, usually robust, can be relatively narrow.



Color: Dark; some with bright yellow or red markings on thorax and abdomen.

Hair and Stripes: Thorax and head thickly covered in white/pale to orange-colored hairs; abdomen with pale to white stripes or not striped.

Scopa: On underside of abdomen, can be dark or pale to orange (look for pollen).

Antennal Length: Short.

Notes: Abdomen often flexed upward (or "elevated") when feeding.

11

Figure 1. Visual categories from the Pennsylvania Xerces Society Native Bee Survey Citizens Science Monitoring Guide utilized in this study.

Net Collections

Insects were collected in an insect net and then transferred to glass or plastic vials labeled for each individual plant plot. Sweep netting consisted of two sweeps over the entire flower plot with a 15-inch diameter mesh net from Bioquip (Rancho Domingo, CA). Then collected insects were transferred into glass ethyl acetate kill jars for twenty minutes. The second year of the study kill jars were no longer used, and the insects were instead frozen. Bees and natural enemies were then identified to family level using dichotomous keys and the DiscoverLife.org website.

Statistical Analysis

Data were analyzed using R statistical software package (R version 3.5.1 - "Feather Spray") and were tested with a Kruskal-Wallis test, due to the non-normal distribution of the data. The data were tested to determine if there were significant differences between any plant species on the number of insect taxa visiting. Then if there were differences, each year's data were tested with a pairwise-Wilcox test to determine which flowers had a different distribution of that particular insect. A Bonferroni multiple comparisons p-adjustment was utilized to reduce the chances of Type 1 error (or a "false positive") from occurring.

The null hypothesis is that each flower species attracted a statistically similar number of beneficial insects. The alternative hypothesis is that at least one flower species received a number of beneficial insects not statistically similar to the other

flower species. There needed to be 6 treatment replications in the experiment for 85% chance of correctly rejecting a false null hypothesis.

Results

Over the course of the two-year project, 2,152 specimens were caught and identified. This included 646 bees, 440 natural enemies, and 1,066 “other” insects. The bees (Clade: Anthophila) were from the families Apidae, Halictidae, Megachilidae, Andrenidae, and Colletidae. The natural enemies’ category was made up primarily of hover flies (Diptera: Syrphidae), Spiders (Araneae), and parasitic and predatory Hymenoptera (colloquially “Wasps”). There were also a small number of robber flies (Diptera: Asilidae) and assassin bugs (Hemiptera: Reduviidae). The “other” category included insects that were neither bees nor natural enemies. This included flies (other than the previously mentioned Syrphids), Hemiptera (other than Reduviidae), butterflies and moths (order Lepidoptera) and beetles (order Coleoptera).

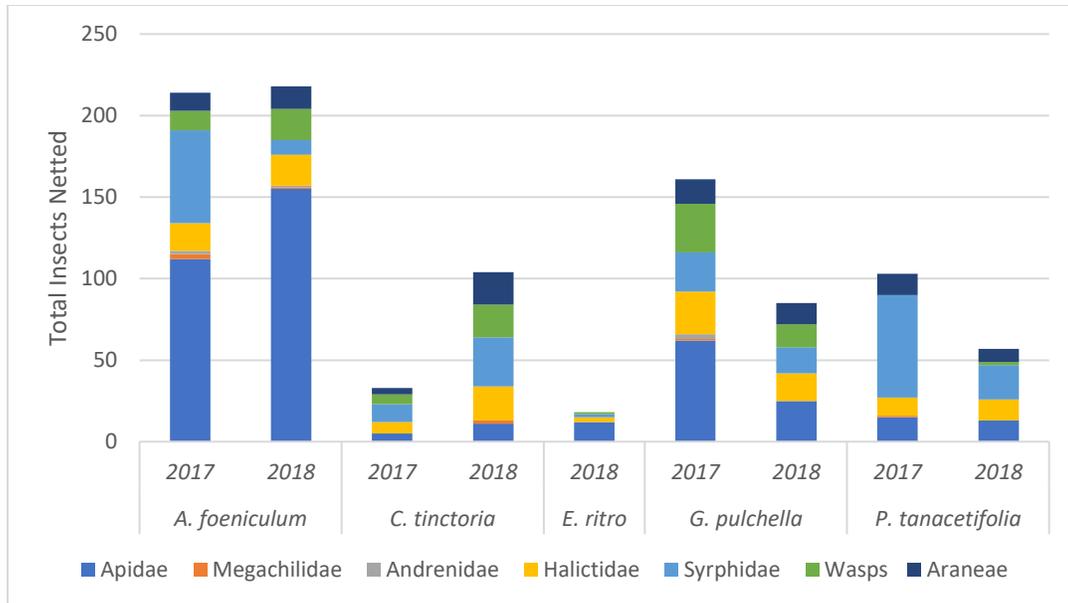


Figure 2. Bees and natural enemies netted by plant species in 2017 & 2018

There were many different types of insects netted in the survey. From family Apidae there were many *Bombus impatiens* netted, as well as some *Bombus bimaculatus*. There were also *A. mellifera*, *Xylocopa virginica*, *Peponapis pruinosa*, *Ceratina dupla* and *Ceratina strenua*. In family Megachilidae *Anthidium* and *Coelioxys* were netted. The main genera of Andrenidae netted was *Andrena*. The bees collected from family Halictidae were *Agapostemon*, *Halictus* and *Lasioglossum*. The bees collected from family Colletidae were all *Hylaeus*.

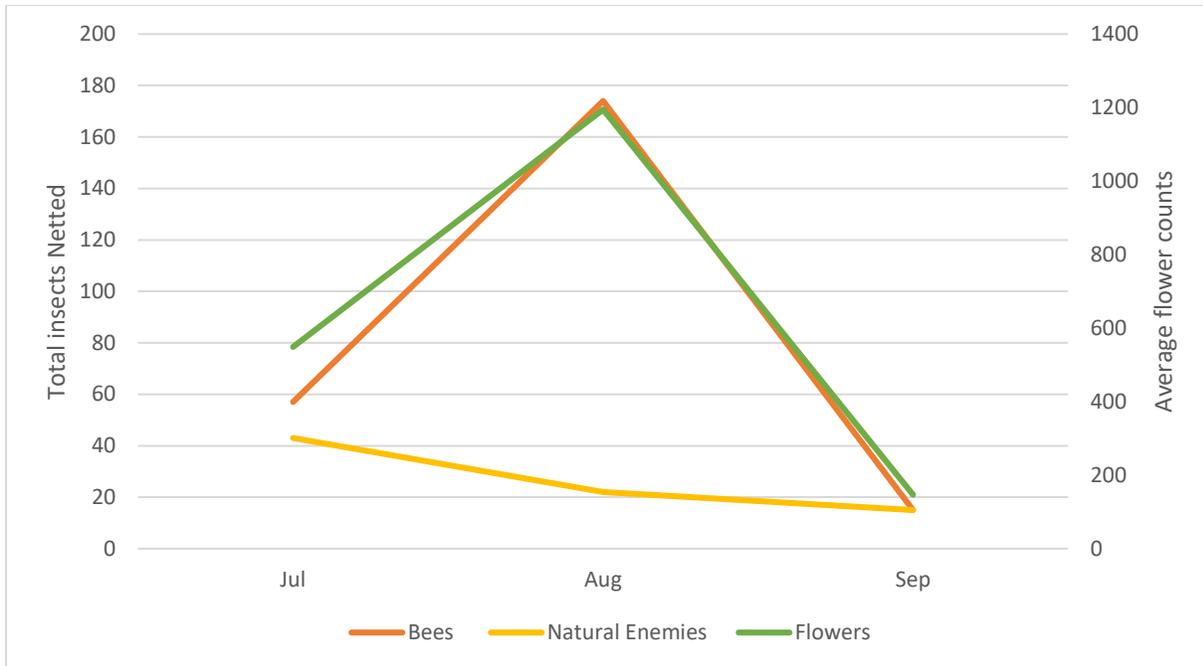


Figure 3. Total numbers of bees and natural enemies netted on *Agastache foeniculum* in 2017. Average flower counts per plot are included.

On *A. foeniculum* there were 134 bees, 80 natural enemies and 184 other insects netted in 2017. In 2018 there were 242 bees, 45 natural enemies and 184 other insects netted. In 2017 the number of bees netted and flowers counted both peaked in August (Figure 3). The next summer it also peaked in August, but the bloom started and ended a month earlier, running from June until October (Figure 4).

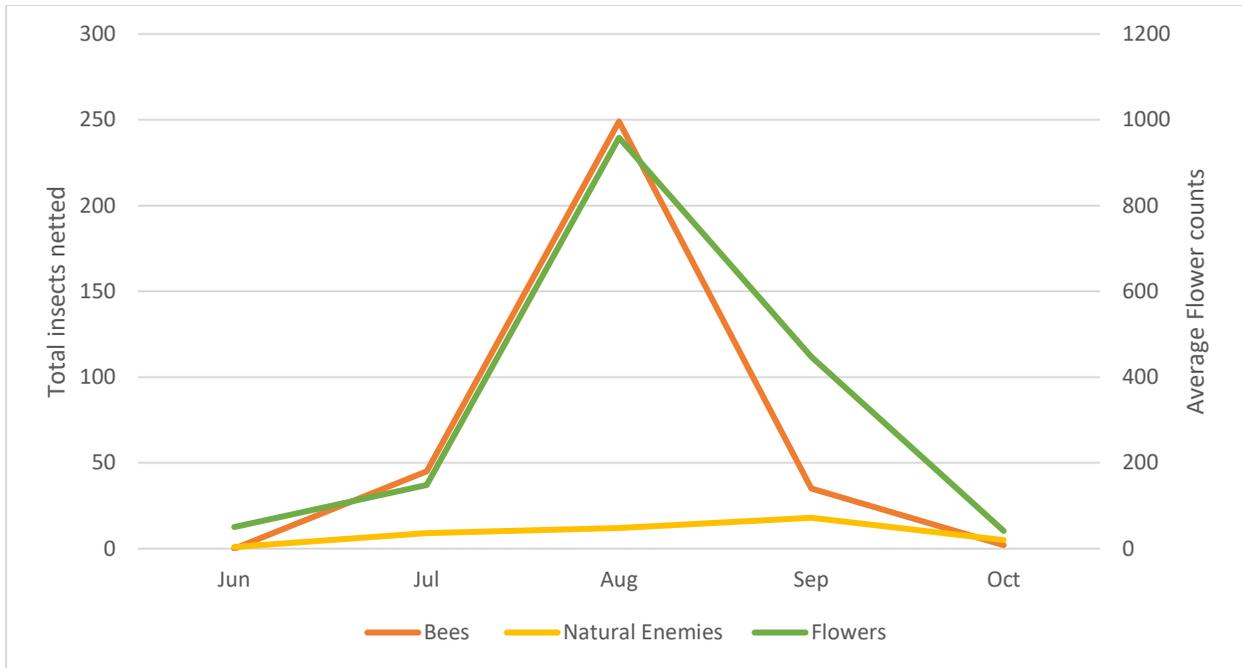


Figure 4. Total numbers of bees and natural enemies netted on *Agastache foeniculum* in 2018. Average flower counts per plot are included.

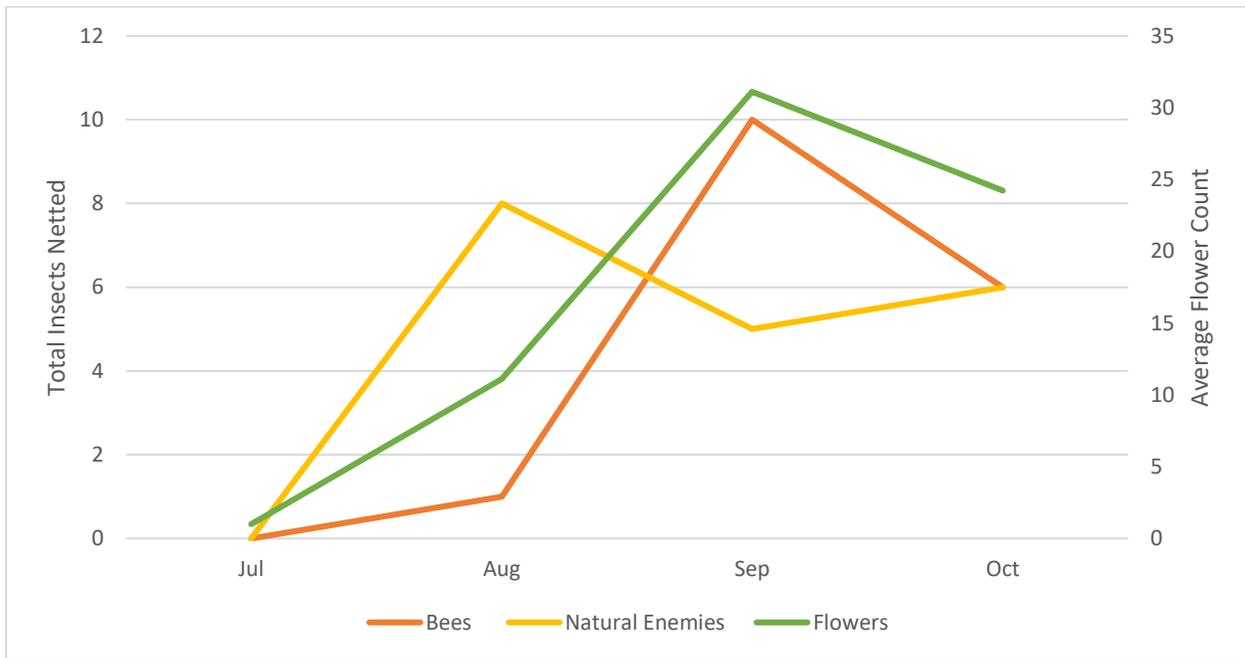


Figure 5. Total numbers of bees and natural enemies netted on *Cota tinctoria* in 2017. Average flower counts per plot are included.

The *C. tinctoria* had a long establishment period but did bloom in the first year, and only 12 bees and 19 natural enemies were netted. Both the flower count and number of bees netted peaked in September, but there were more natural enemies netted in August than in September (Figure 5). In 2018, 75 insect natural enemies and 45 bees were netted from *C. tinctoria*. However, the number of bees netted did not follow the flower count data as well as it had in 2017 (Figure 6).

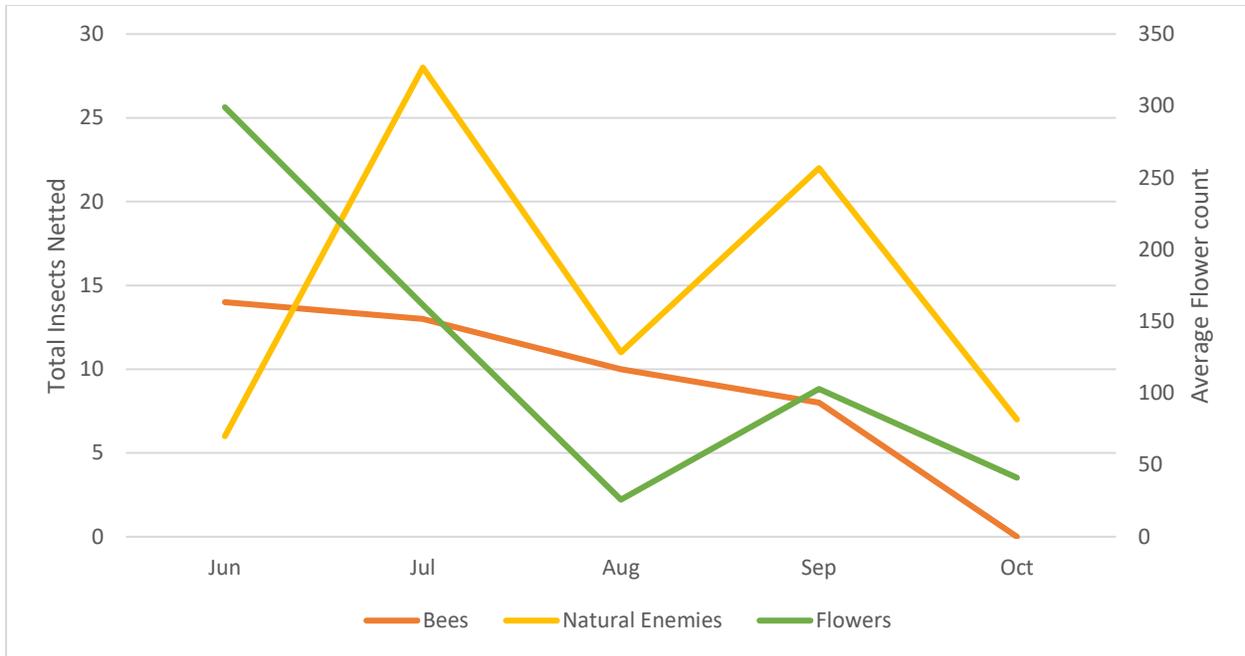


Figure 6. Total numbers of bees and natural enemies netted on *Cota tinctoria* in 2018. Average flower counts per plot are included.

The *E. ritro* was planted in June 2017, later than the other plants due to a seed backorder, so it was not ready to bloom in the first year. The second year only 14 insects were netted from this plant, 12 of which were *Bombus*. All of these 14 insects were netted in July and August, (Figure 7). The *E. ritro* bloomed in September and October as well, but in this time no insects were netted.

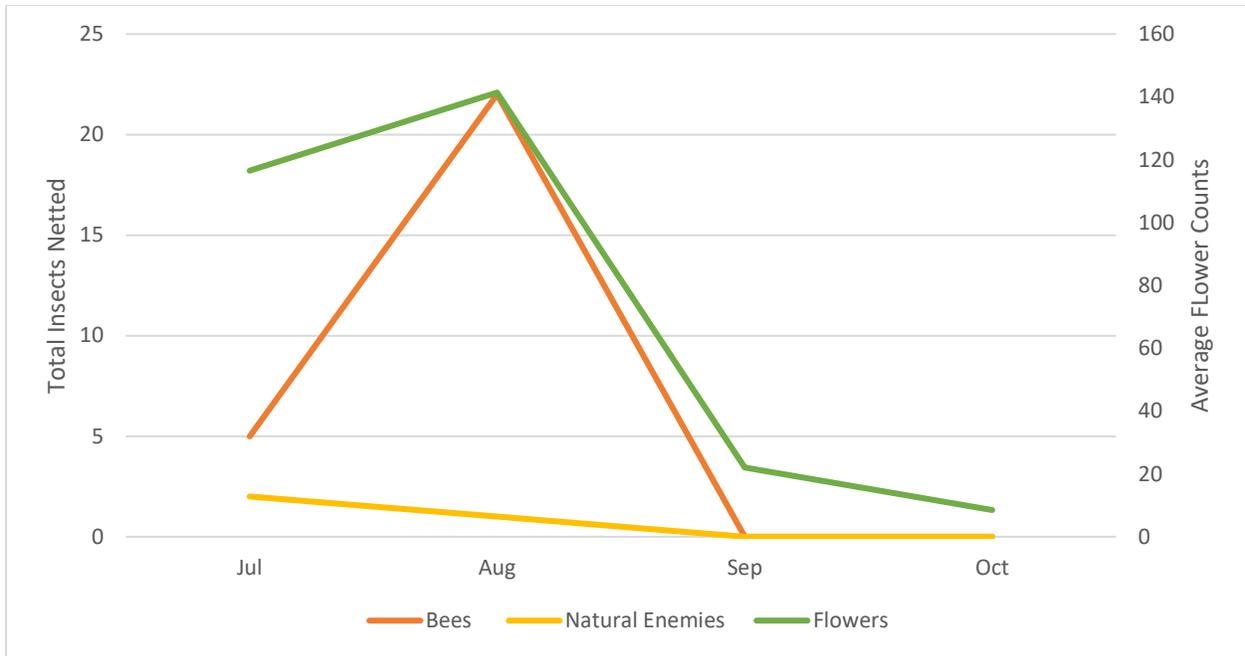


Figure 7. Total numbers of bees and natural enemies netted on *Echinops ritro* in 2018. Average flower counts per plot are included.

In 2017, 94 bees and 69 natural enemies were netted from *G. pulchella*. In 2017 the greatest number of bees and natural enemies were netted in August, while the flower count did not peak until September (*Figure 8*). In the second year only 58 bees and 43 natural enemies were netted. These results coincide with a decrease in the average number of flowers of *G. pulchella*, from 98 in 2017 down to 38 in 2018 (*Figure 9*).

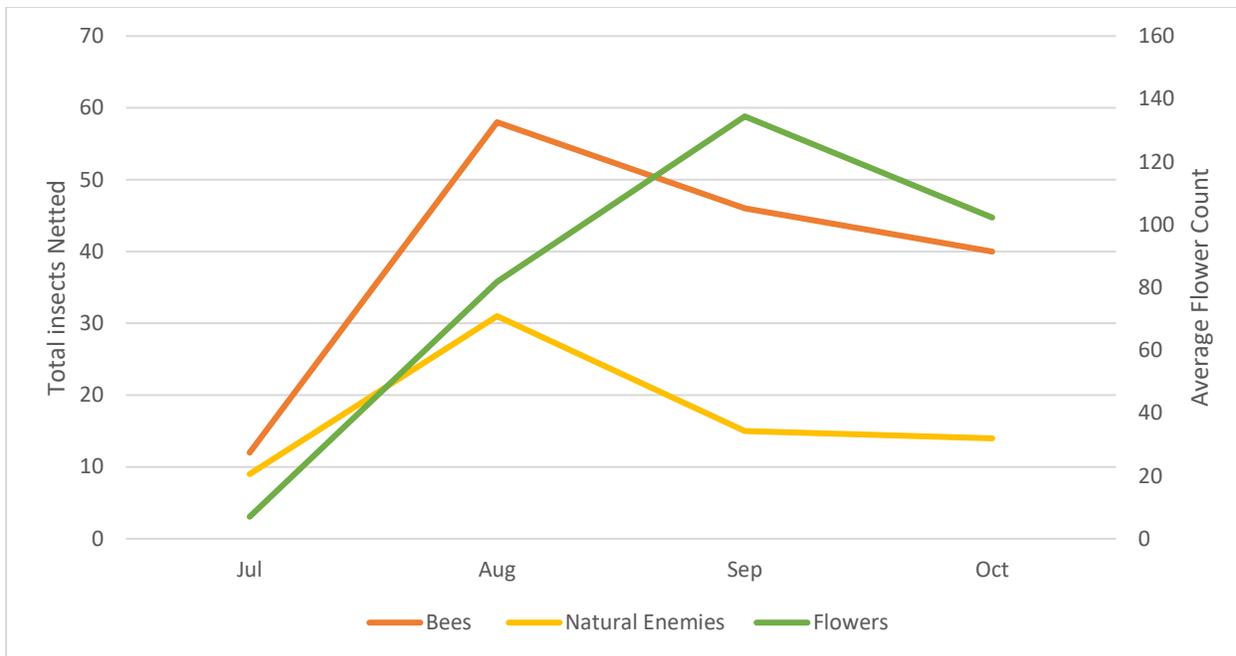


Figure 8. Total numbers of bees and natural enemies netted on *Gaillardia pulchella* in 2017. Average flower counts per plot are included.

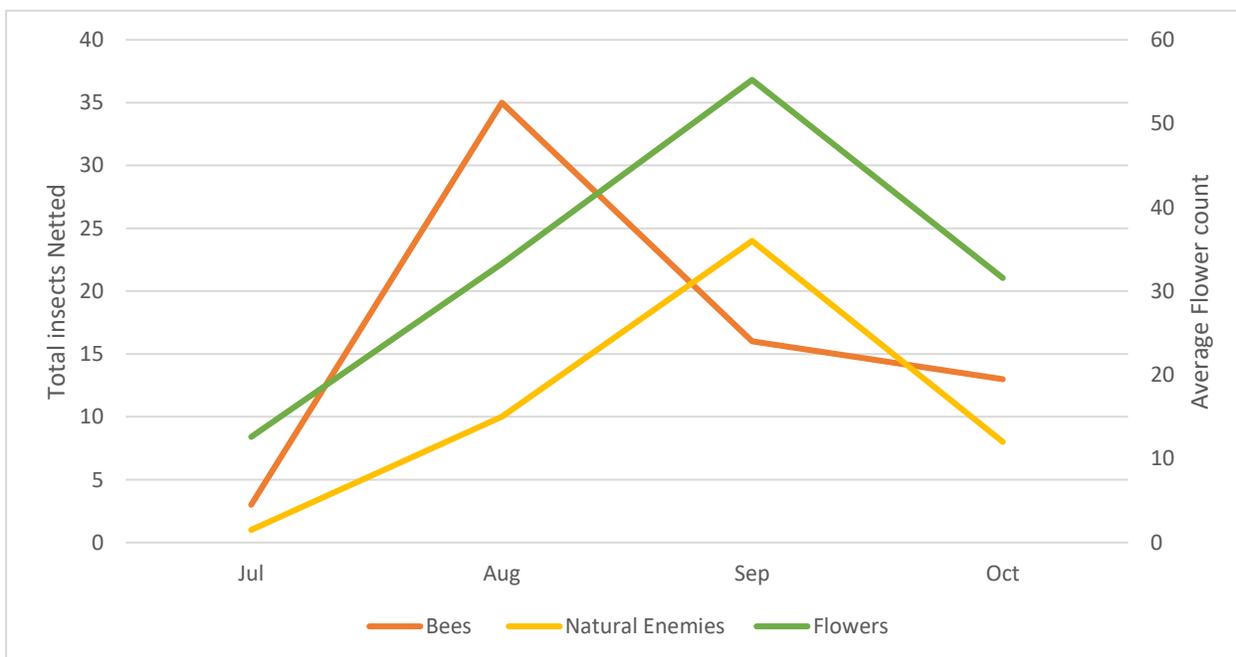


Figure 9. Total numbers of bees and natural enemies netted on *Gaillardia pulchella* in 2018. Average flower counts per plot are included.

In 2017 *P. tanacetifolia* was the first of the study plants to bloom, and 27 bees and 76 natural enemies were netted from it. The 2017 graph was not included as all beneficial insects, except one Syrphid, were caught in July. In 2018, 26 bees and 31 natural enemies were netted. The majority of this netting activity took place in July, as the *P. tanacetifolia* bloomed early, and the second and third plantings were not as successful (Figure 10). This graph includes all *P. tanacetifolia* plantings from 2018.

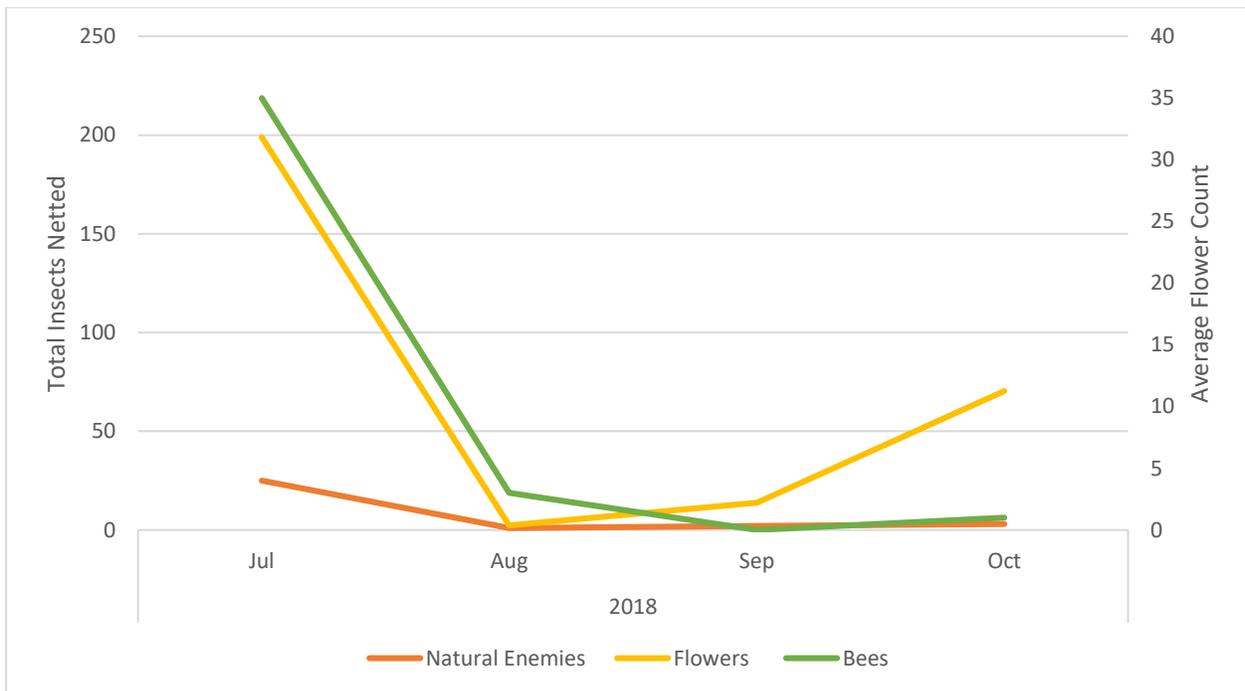


Figure 10. Total numbers of bees and natural enemies netted on *Phacelia tanacetifolia* in 2018. Average flower counts per plot are included.

The total number of Apidae collected in 2017 from the 5 plants examined was significantly different (chi-squared = 32.78, df = 2, *P*-value = 7.62e-08). The pairwise test then revealed that there were significant differences between *A. foeniculum* and *C.*

tinctoria (P -value = 7.8e-08), and between *G. pulchella* and *C. tinctoria* (P -value= 5.8e-05).

Taxa	Plants			p-value
	<i>Agastache foeniculum</i>	<i>Cota tinctoria</i>	<i>Gaillardia pulchella</i>	
Apidae	112	5	62	<0.001
Megachilidae	3	0	1	0.390
Andrenidae	2	0	3	0.340
Halictidae	17	7	26	0.099
Syrphidae	57	11	24	0.160
Wasps	12	6	30	0.140
Araneae	11	4	15	0.131
Hemiptera	64	29	67	0.123
Diptera	104	34	41	0.003
Coleoptera	8	2	5	0.255
Lepidoptera	8	3	15	0.283

Table 2. Total number of insects collected per plant type in 2017. P-values of difference between plants calculated with the Kruskal-Wallis test.

The only other insect group that had significant differences between plant groups was the order Diptera (chi-squared = 11.741, df = 2, P -value = 0.002822). The *C. tinctoria* (P -value =0.012) and *G. pulchella* (P -value =0.012) were both significantly different from *A. foeniculum*, which had a much higher concentration of Diptera netted. *P. tanacetifolia* was not included in this analysis, due to its low numbers of netting events and the majority of its blooms taking place before other plants were in flower.

Taxa	Plants				<i>p</i> -value
	<i>Agastache foeniculum</i>	<i>Cota tinctoria</i>	<i>P. tanacetifolia</i>	<i>G. pulchella</i>	
Apidae	155	11	13	25	<0.001
Megachilidae	1	2	0	0	0.493
Andrenidae	1	0	0	0	0.520
Halictidae	19	21	13	17	0.835
Syrphidae	9	30	21	16	0.055
Wasps	19	20	2	14	0.176
Araneae	14	20	8	13	0.685
Hemiptera	113	67	41	39	0.004
Diptera	111	107	21	48	0.003
Coleoptera	24	10	2	2	0.004
Lepidoptera	18	16	2	16	0.123

Table 3. Total number of insects collected per plant type in 2018. P-values of difference between plants calculated with the Kruskal-Wallis test.

For the 2018 data, the analysis did include *P. tanacetifolia*, but did not include *E. ritro*, as not enough *E. ritro* netting events took place. In 2018 the distribution of *Apidae* was significantly different (chi-squared = 41.104, df = 3, *P*-value = 6.215 e-09) across the four plant species. There were significantly more *Apidae* on *A. foeniculum* than on *C. tinctoria* (*P*-value = 4.8e-08), *G. pulchella* (*P*-value = 0.0014), or *P. tanacetifolia* (*P*-value = 0.0012). In 2018 the largest number of *Apidae* was collected from *A. foeniculum*.

The number of *Syrphidae* collected from the plant species was significantly different to a *P*-value of 0.05474, which makes it insignificant at the standard $p < 0.05$ level, but it was close enough to warrant mention.

The number of order Hemiptera, or “true bugs”, was also significantly different between plant species (chi-squared = 13.435, df = 3, *P*-value = 0.003785). The differences were between *A. foeniculum* and *C. tinctoria* (*P*-value = 0.0043). The number of *Diptera* (chi-squared = 14.137, df = 3, *P*-value = 0.002725) collected from *P.*

tanacetifolia and *A. foeniculum* (P -value = 0.0206) was significantly different, as well as the number between *C. tinctoria* and *P. tanacetifolia* (P -value = 0.0028). The number of order coleoptera (chi-squared = 13.226, df = 3, P -value = 0.004173) was different between *A. foeniculum* and *G. pulchella* (P -value = 0.024).

Taxa	Plants			p -value
	<i>Agastache foeniculum</i>	<i>Cota tinctoria</i>	<i>Gaillardia pulchella</i>	
Bumble bee	391	5	240	<0.001
Honey bee	49	8	236	<0.001
Carpenter bee	0	0	2	0.219
Hairy Leg bee	5	0	6	0.155
Hairy Belly bee	12	2	2	0.011
Large Dark bee	2	1	4	0.404
Small Dark bee	4	18	29	0.004
Green Sweat Bees	0	1	13	<0.001
Syrphid fly	39	40	35	0.114
Natural Enemy	9	3	6	0.148
Other	58	27	26	0.006

Table 4. Total number of insects observed per plant type in 2017. P-values of difference between plants calculated with the Kruskal-Wallis test.

The distribution of the observational data was analyzed using the same methods as the netting data. Significant differences were found in 2017 in the number of *Bombus*, *Apis*, “hairy belly bee”, “small dark bee”, and “other” insect groups observed across the four plants. There were significant differences in distribution of the genus *Bombus* (chi-squared = 97.2, df = 2, p -value < 2.2e-16) between the *A. foeniculum* and *C. tinctoria* (P -value = <2e-16) as well as between *C. tinctoria* and *G. pulchella* (P -value = <2e-16). For the genus *Apis* (chi-squared = 69.826, df = 2, P -value = 6.879e-16) there were significant differences in the number observed on *A. foeniculum* versus *C. tinctoria* (P -value = 0.00013), between *A. foeniculum* and *G. pulchella* (P -value = 1.3e-06) and between *G. pulchella* and *C. tinctoria* (P -value = 5.1e-14). The 2017 netting data for *Apis* was similar except there was no difference between *A. foeniculum* and *G.*

pulchella. For the “hairy belly bees” (chi-squared = 9.0565, df = 2, *P*-value = 0.0108), the only differences were between *A. foeniculum* and *G. pulchella* (*P*-value = 0.030). “Small Dark bees” (chi-squared = 11.053, df = 2, *p*-value = 0.00398) had significant differences between *A. foeniculum* and both other plant species (both with *P*-value = 0.013). The group of “other” insects (chi-squared = 10.083, df = 2, *P*-value = 0.006465) had a significantly different distribution between *A. foeniculum* and *G. pulchella* (*P*-value = 0.0091).

The observations from 2018 were similar for some groups but different for others. Again, there were significant differences within the genera *Bombus* and *Apis*, and the small dark bees, but this time the hairy belly bees and “other” insects were not significant at the *p*-value > 0.05 level. However, there were differences within the hairy leg bees, large dark bees, Family Syrphidae and natural enemies.

Taxa	Plants				<i>p</i> -value
	<i>Agastache foeniculum</i>	<i>Cota tinctoria</i>	<i>Gaillardia pulchella</i>	<i>Phacelia tanacetifolia</i>	
Bumble bee	893	20	55	44	<0.001
Honey bee	38	7	11	1	<0.001
Carpenter bee	1	0	0	1	0.477
Hairy Leg bee	0	1	7	0	<0.001
Hairy Belly bee	1	0	1	0	0.577
Large Dark bee	1	18	4	1	0.002
Small Dark bee	16	73	41	43	0.001
Green Sweat bee	9	4	75	2	<0.001
Syrphid fly	21	84	3	30	<0.001
Natural Enemy	91	37	30	7	<0.001
Other	14	14	5	0	0.106

Table 5. Total number of insects observed per plant type in 2018. P-values of difference between plants calculated with the Kruskal-Wallis test.

The number of genus *Bombus* observed (chi-squared = 158.93, df = 3, *p*-value < 2.2e-16) was significantly different between the plant species. *Agastache foeniculum*

had significant differences in numbers of *Bombus* observed between *C. tinctoria* (p -value $< 2e-16$), *G. pulchella* (p -value = $9.4e-13$), and *P. tanacetifolia* (P -value = $4.4e-12$). Additionally, *C. tinctoria* was significantly different from *G. pulchella* (P -value = $3.1e-05$) and with *P. tanacetifolia* (P -value = 0.0012). There were significant differences in the number of *Bombus* on all species except *P. tanacetifolia* and *G. pulchella*.

In the number of *Apis* observed (chi-squared = 29.918, df = 3, P -value = $1.436e-06$) the only significant differences were between *A. foeniculum* and *C. tinctoria* (P -value = 0.00031), and between *A. foeniculum* and *P. tanacetifolia* (P -value = 0.00048). The number of Hairy Leg bee observations (chi-squared = 21.312, df = 3, P -value = $9.068e-05$) had a significant difference between *G. pulchella* and *A. foeniculum* (P -value = 0.007) and between *G. pulchella* and *C. tinctoria* (P -value = 0.036). For the Small Dark bees (chi-squared = 16.679, df = 3, P -value = 0.0008227) *A. foeniculum* had significant differences with *C. tinctoria* (P -value = 0.00091), *G. pulchella* (P -value = 0.01244), and *P. tanacetifolia* (P -value = 0.00310).

The number of family Syrphidae observed (chi-squared = 35.102, df = 3, P -value = $1.159e-07$) were significantly different between *A. foeniculum* and *C. tinctoria* (P -value = 0.00018), *G. pulchella* and *C. tinctoria* (P -value = 0.00990), and between *G. pulchella* and *P. tanacetifolia* (P -value = 0.02216). The group of natural enemies (chi-squared = 22.478, df = 3, P -value = $5.188e-05$) had significant differences in observations between *A. foeniculum* and *C. tinctoria* (P -value = 0.01491), and between *A. foeniculum* and *P. tanacetifolia* (P -value = 0.00011).

Rainfall data was collected to compare between months, as plants and flowers would be affected by water availability, and this may impact bee visitation rates. Monthly

rainfall totals collected from Bradley International Airport. In 2017 there was a total of 60.38 cm (23.77 inches) between June and October. In 2018 there was a total of 70.61 cm (27.80 inches) of rainfall during the same period.

Discussion

The overwhelming majority of insect visitors to *A. foeniculum* were in family Apidae. This is consistent with results from previous studies (Robson et al. 2017). A study of pollinator visitation to gardens in San Luis Obsipo, California documented similar pollinators visiting *Gaillardia pulchella* as to what this project found. Their study found *G. pulchella* was visited primarily by *Apis*, *Melissodes*, and Halictids and Megachilids (Pawelek et al. 2009). This study found all of these taxa on *G. pulchella*, but also a large number of *Bombus impatiens*. In this study the number of *Bombus* was actually the taxa with the highest number netted, while the California study had no *Bombus*, or few enough not to report. This could be because their study was in a different part of the country, in a more agricultural setting, and they used *Gaillardia* “Oranges & Lemons” and *Gaillardia x grandiflora cvs.*, which are more ornamental strains of *Gaillardia*.

The diversity of bee genera, but not species, netted on *P. tanacetifolia* were similar to results found in other studies (Carreck and Williams 2002). This study took place in England so the same species were not collected (except for the cosmopolitan *A. mellifera*) but many of the genera were represented. In our study, species of the genus *Bombus*, *Halictus*, *Lasioglossum*, and *Vespula* were also found on *Phacelia*.

While the majority of bees were common to the area there were several less-common bees netted. The genera *Bombus*, *Apis*, *Halictus*, *Agapostemon* and *Lasioglossum* were most common. However, one *Coelioxys* (Megachilidae) was netted from *A. foeniculum*. This bee is “kleptoparasitic” meaning it lays its eggs in the nests of other bees, rather than making and provisioning its own nest (Rozen and Kamel 2007, 2008). The *Coelioxys* bees then hatch and consume the floral resources intended for the hosts larvae. Another less common Megachilidae, *Anthidium oblongatum* was caught on *A. foeniculum* a month later.

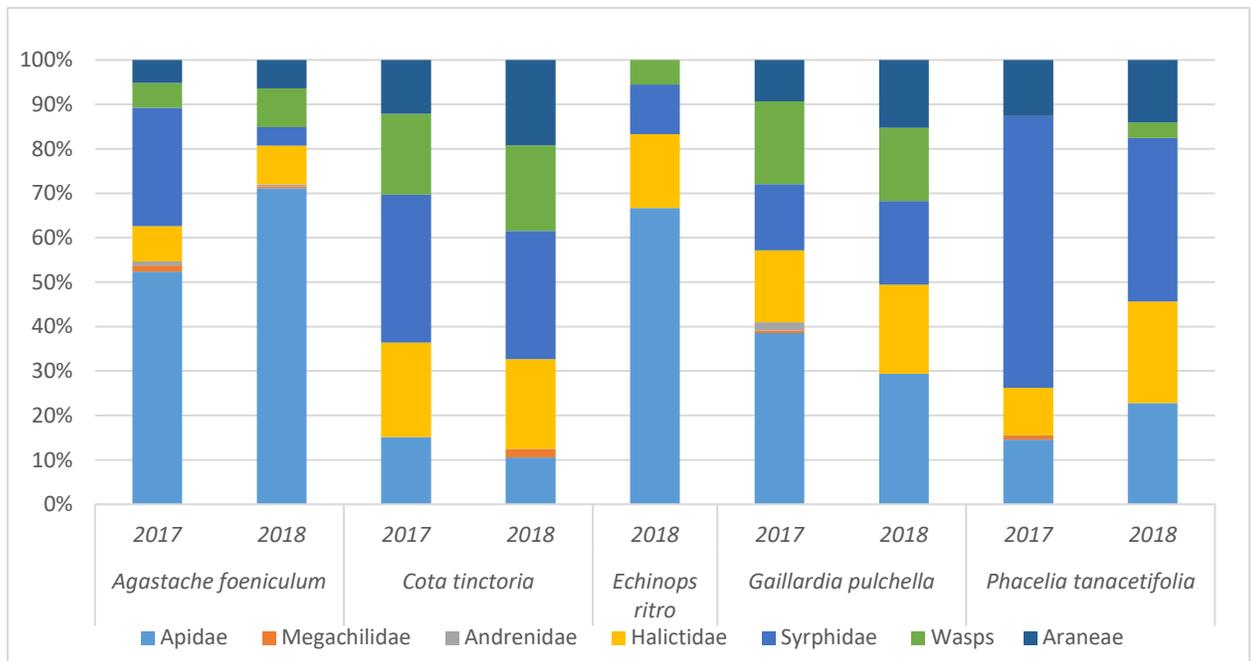


Figure 11: Distribution of netted insects by groups 2017 & 2018

For the most part the distribution of these netted insects did not change over the two years of the study (Figure 11). However, one change was the proportion of syrphids

decreasing between 2017 and 2018. Both *A. foeniculum* and *P. tanacetifolia* had Syrphid netting decrease by at least 20%, but *C. tinctoria* decreased by much less. There were many more insects netted from *C. tinctoria* in 2018, so while Syrphids were a smaller percentage, the total number of Syrphids netted actually increased. The *G. pulchella* had an increased Syrphid proportion in 2018, but that plant had fewer visitors in 2018 so its total Syrphid netted count actually decreased.

While the distribution of insects stayed mostly the same, the total number of flowers varied widely. In 2017 there was a total of 45,942 *A. foeniculum* flowers and only 29,221 flowers counted in 2018. As a perennial, most of the *A. foeniculum* successfully over-wintered and some new plants were added into the field but overall it was not as prolific in 2018. The *C. tinctoria* was actually much more successful in 2018, increasing from 1,197 to 10,143 flowers in the second year. This perennial had very sluggish growth in the first year, only blooming in middle to late summer. It survived the winter very well and was established enough to have an eightfold increase in flowers counted, and start blooming much earlier in the season. In 2017 there was a total of 7,258 *G. pulchella* flowers counted, and only 2,035 counted in 2018. *G. pulchella* is listed as a perennial rated for USDA hardiness zones 2 – 11. This study was conducted in zone 6a, where *G. pulchella* might not have the same success as a perennial as it does in zone 11 due to colder temperatures. There was more rainfall in 2018 than there was in 2017, so it was unlikely to be the result of inadequate rainfall. The *P. tanacetifolia* had 1,755 flowers counted in 2017 and 5,593 were counted in 2018. In the first year *P. tanacetifolia* only bloomed until the end of July, and there was nothing to net for the rest of the season. In 2018 it was planted in alternating plots, ensuring a continuous bloom.

The flowering time was considerably lengthened, but curiously there were actually fewer bees and fewer natural enemies netted in 2018 than there were in 2017.

Bee activity correlated with total flower counts (P -value= 0.0198), but natural enemies (P -value= 0.509) and 'other' insects (P -value= 0.291) did not. For example, *A. foeniculum* bloomed July through September in 2017, and June through October in 2018. Each year the highest number of insects netted was in August, which is also when the highest flower counts occurred. The amount of bees netted off of *G. pulchella* appears to correlate with the flower count in 2017, however in 2018 the greatest number of bees netted is a month earlier than the peak bloom. *C. tinctoria* bloomed in midsummer 2017 with an average of 22 flowers, but it bloomed much earlier in 2018 with an average of 128 flowers. Interestingly, even with the earlier bloom time the composition of insects netted on *C. tinctoria* remained largely the same, even though there were roughly three times as many bees and enemies netted from in 2018.

E. ritro did not bloom at all in the first year. It bloomed in the second year with an average of 114 flowers each week but had the lowest number of insects netted in the entire study. This reduction in the number of other bees could be due to the difficulties netting *E. ritro* due to its flower shape. The globular flower is hard to net without damaging it, so the softer swings might have made it easier for the smaller bees to escape. The disturbance of the netting also could have frightened some insects into flying away before they were netted. Additionally, flower shape and flower type could have also had an impact on the number of insects collected. For example, the higher

number of insects netted on *A. foeniculum* could be caused by its higher flower counts due to its compound flowers.

The results were also impacted because some of the plant species were not in flower for the entire study. The *P. tanacetifolia* was not included in the first year's statistical analysis, and the *E. ritro* was not included in the second year's analysis. This naturally led to fewer comparisons between plants and could only decrease the number of statistical differences found among them.

Having two different methods of data collection helped address the biases inherent to each method. Larger insects such as *Bombus* and *Xylocopa* are much easier to spot from a distance. This would lead to their almost certainly being counted in the observations, while a smaller insect, like a Halictid, might be easily overlooked. With the netting data, a more representative sample of the bees on the plants is collected. However, plenty of other insects who are not feeding on the flowers will get swept up in the net, such as insects who landed on the flower stems or were just flying by. While observations may underestimate the true number of insects feeding from the flowers, the netting may overestimate this number.

Overall there were many more pollinators netted than natural enemies. This could be due to the fact that much of the surrounding turf grass fields had few flowers. Also, in a more agriculturally intensive landscape there would likely be more pests for the natural enemies to feed on. More natural enemies might be found if this experiment is repeated in a more agriculturally intensive area.

While each of the plants in the study had both pollinator and natural enemies as visitors, they had different concentrations of each type of insect. *A. foeniculum* had the most pollinators, specifically the most from family Apidae. The *P. tanacetifolia* had the greatest amount of Syrphids and other natural enemies. Both the *G. pulchella* and the *C. tinctoria* attracted roughly equal amounts of pollinators and natural enemies. The *E. ritro* did not have many visitors but the majority of them were pollinators from family Apidae.

A. foeniculum, *G. pulchella*, and *P. tanacetifolia* proved to be satisfactory pollinator plants for this region. However, *C. tinctoria* can also provide for pollinators if planted early enough in the season, or in its second year. *C. tinctoria*, *G. pulchella*, and *P. tanacetifolia* all demonstrated their ability to attract natural enemies of agricultural pests. *E. ritro* did not attract many pollinators nor natural enemies. Perhaps if it was grown under different conditions it may attract greater numbers of beneficial insects, but in these conditions, *E. ritro* cannot be recommended as an attractant for pollinators or natural enemies.

Chapter 3: Water-stressed plants and pollinator attraction

Introduction

Pollinators and other beneficial insects rely on the pollen and nectar in flowers as their primary food source. These resources can be compromised by drought, resulting in decreased availability. Drought conditions can impact the number of flowers per plant and the number of flowers with nectar (Phillips et al. 2018). Once the conditions become too dry, plants compensate by closing their stomata to prevent water-loss. This reduces the amount of carbon dioxide the plants can take in, which reduces the photosynthesis rates (Khan et al. 2010). This could negatively impact plant growth, in turn affecting the number and diversity of beneficial insects these plants can support. Potentially, this may increase competition between bees over scarce resources (Paini 2004).

Drought is becoming more of a concern for our ecosystems. Due to our excessive greenhouse gas emissions, the Earth's climate is changing (Hansen et al. 1981). Many regions of the world will experience different climate regimes and weather patterns, which may no longer be amenable to the pollinator plants traditionally grown there. The state of Connecticut is predicted to receive more precipitation overall, but in larger, less frequent storms (Frumhoff et al. 2007). Less frequent rainfall events mean longer periods without water, which may pose a challenge to the plants that traditionally supplied pollinator floral resources. By testing the drought-resistance of different pollinator plants, we could potentially analyze their utility as floral resources in drier climates. Additionally, there was an attempt to quantify the nectar volume and

concentration of the plants, but this was not successful. It was difficult to get consistent, or sometimes any, results from the nectar measurements.

As reported in the previous chapter, the experiment was focused on observing the number and diversity of insects visiting five species of drought-resistant plants under normal field conditions. The objective of this study was to test whether some of these plants were able to withstand drought conditions and still attract similar numbers and diversity of beneficial insects. This second experiment was conducted to determine how many days plants can last without water before bees stop visiting and seek out other food sources. Ideally, all of the plants in the previous study would have been tested, but this was not possible because the plants were not at the right stage at the beginning of the experiment. Buckwheat was used for comparison as it was not known to be drought-resistant.

Methods

For the experiment there was a control group and an experimental group of *Agastache foeniculum* OG. (Lamiaceae) and another control and experimental group for *Fagopyrum esculentum* (Polygonaceae). The *A. foeniculum* was from Johnny's Selected Seeds. The *F. esculentum* was from Kent Nutrition Group, but unfortunately the variety was not stated. All groups were planted in June and July 2018 and grown to maturity in 3-gallon plastic pots filled with Sungro 3b potting soil. The study took place in the same field (50m x 54m) as the previously described insect netting survey at the Plant Science Research Facility. There were six blocks, and two treatments, for a total

of twelve plant pots. Each of these twelve plant pots were sampled six times for a total of 72 observations.

The blocks ran north-south through the field with the pots placed at the ends of the blocks. Pots were arranged so that the control and experimental group were not on the same side of the field as the adjacent block. (For example, block 2 had the experimental plant on the south side of the block and the control on the north side of the block, so blocks 1 and 3 had the control on the south side and the experimental plant on the north side).

The experiment was conducted on the control and experimental groups of *A. foeniculum* first from August 24 until September 3, 2018, and then the control and experimental group of *F. esculentum* were tested from September 14 – 21, 2018. The control group was watered daily to excess, and the experimental group was watered only on the first day of the experiment, which led to increased water-stress in the experimental group. The plants were placed on impermeable black plastic to prevent absorption of groundwater to ensure the experimental group did not receive any water. All plants were brought inside the greenhouse overnight when there was a chance of rain.

The dryness of the soil was measured in kPa with the use of an Irrrometer Co. (Riverside, CA) analogue tensiometer. These tensiometers were placed in the potting mix that the plants were growing in and data was recorded at the time of insect observations.

Observations of the visitors to these plants occurred over a seven-day period, and consisted of two methods. First a pre-observation walkthrough determined the insect activity at the beginning of the experiment. Starting between 10am and 3pm, the observer walked block by block through the field and recorded the number of visitors on each plant. The observer stood no closer than one meter from the plants. The observer randomly selected on which block to start the observations. The “bees” category included all bees mentioned in the Xerces Society Pennsylvania Native Bee Survey Citizen Science Monitoring Guide (*Figure 1*). The “natural enemy” category included Syrphid flies, wasps, and spiders. “Other” included any insects that did not fit into these categories, such as butterflies and caterpillars.

Similarly, the timed observation started on a randomly selected block and continued block by block through the field. However, this observation consisted of a five-minute observation of each plant, in which the observer recorded how long insects visited the flower. All of these observations took place between 9:30 A.M. and 4:00 P.M. The observer focused on one insect and recorded the length of time it remained on the flower. If it left before the five minutes were up, additional insects were observed. However, once the five minutes were up the observer left for the next plant, regardless of how many insects remained on the plant. The data were analyzed with the Kruskal-Wallis test due to the lack of normality of the data’s distribution. The number of flowers were recorded each day after all blocks were observed.

Results

The *A. foeniculum* study was conducted first and consisted of six sampling events over an eight-day period (*Table 6*). On the pre-observation walkthrough there were no significant differences found between the well-watered and water-stressed *A. foeniculum*. Similarly, there were no differences between the groups of *F. esculentum*.

	<i>Agastache foeniculum</i>			<i>Fagopyrum esculentum</i>		
	well-watered	water-stressed	<i>P-value</i>	well-watered	water-stressed	<i>P-value</i>
Bees	101	137	0.0944	5	5	0.7608
Natural Enemies	0	1	0.6065	12	7	0.1820
Other	9	10	0.9314	3	3	0.7809

Table 6. Number of beneficial insects observed on well-watered and water-stressed plants during pre-observation walkthrough. *P-values* of difference between plant treatments calculated with a paired t-test. The *Agastache foeniculum* was observed 8/24/18 until 9/2/18 and the *Fagopyrum esculentum* was observed 9/14/18 – 9/21/18.

After the pre-observation walkthrough counts, the flowers were then separately observed for five minutes (*Table 7*). These data seem to align with the walkthrough observations taken immediately before the five-minute observations. The highest number of bees was found on the *A. foeniculum*, with a slightly higher amount on the water-stressed plants. For the timed observations, the total number of seconds of bee visitation was highest on *A. foeniculum* water-stressed plants, and the second highest was on the *A. foeniculum* well-watered plants. The only statistically significant difference was found between the number of bees visiting the well-watered *F. esculentum* plants and the water-stressed *F. esculentum* plants. The numbers of flowers counted changed

little throughout the study, with an average of 130 *A. foeniculum*, and 202 *F. esculentum* counted.

	<i>Agastache foeniculum</i>			<i>Fagopyrum esculentum</i>		
	well-watered	water-stressed	<i>P</i> -value	well-watered	water-stressed	<i>P</i> -value
Bees	12,739	13,199	0.951	1,233	272	0.003
Natural Enemies	0	117	0.083	3,558	3,279	0.091
Other	361	835	0.356	1,245	740	0.626

Table 7. Total seconds of visitation of beneficial insects to well-watered and water-stressed plants during 5-minute observations. *P*-values of difference between plant treatments calculated with a paired t-test. The *Agastache foeniculum* was observed 8/24/18 until 9/2/18 and the *Fagopyrum esculentum* was observed 9/14/18 – 9/21/18.

The soil of the water-stressed treatment continued to dry throughout the experiment. By day 7, the tensiometer readings of the *A. foeniculum* pots were an average of -33 kPa. On day 7, the tensiometer readings of the *F. esculentum* pots were -26 kPa (Table 8).

<i>Agastache foeniculum</i>		<i>Fagopyrum esculentum</i>	
Date	Average kPa	Date	Average kPa
8/25/18	0	9/14/18	0
8/26/18	-5	9/15/18	0
8/27/18	-10	9/16/18	-4
8/28/18	-16	9/17/18	-7
8/29/18	-16	9/18/18	-14
8/30/18	-24	9/19/18	-20
8/31/18	-26	9/20/18	-26
9/1/18	-33	9/21/18	-26

Table 8. Average soil kPa readings from water-stressed pots of *Agastache foeniculum* and *Fagopyrum esculentum* throughout the experiment. Data from the well-watered plants were not included as it consistently recorded a zero.

Discussion

It is interesting that the *A. foeniculum* did not have any significant differences in visitation between the well-watered and water-stressed plants. While *A. foeniculum* is known as a drought-resistant plant, these results imply that its pollinator-attraction does not greatly diminish after one week of drought. In actuality this might be an underestimation of the pollinator attraction resilience, as the plant would have more groundwater to draw from than just the three gallons of potting mix in its pot. However, the *A. foeniculum* did not have as many natural enemies or “other” insects visiting as it had pollinators. It was either less attractive to the natural enemies, or perhaps there were too many pollinators for the natural enemies to get in or near the flowers. Additionally, perhaps there were not enough pest species nearby to support a large population of natural enemies. The natural enemies and “other” insects did also not decrease in average visitation length over the course of the experiment. Like with the pollinators, it appears that even the water-stressed plants were able to attract natural enemies and “other” insects just as well as the adequately watered plants.

The *F. esculentum* is a cover crop without great drought-resistant properties (Tadina et al. 2007). Even before the seventh day the *F. esculentum* plants were looking visibly wilted, and must have been less attractive to the bees, as significant differences were found between the water-stressed and well-watered plants. This plant attracted many fewer bees than the *A. foeniculum* did, even before the drought. This could have been due to the timing of the experiments, as the *F. esculentum* was tested

two weeks later into the fall, when insect numbers start to decline. The *F. esculentum* plants did attract more natural enemies and “other” insects, and these insects had similar numbers between the well-watered and water-stressed plants. It is important to note that this study took place in mid-September which is when the bee population starts to decline for the year. This could have impacted the study, and future studies should consider starting the experiment earlier, or having multiple trials throughout the year.

These observational results are consistent with other studies. *A. foeniculum* was found to be primarily pollinated by bees from the family Apidae (Quaranta and Ricciardelli D’Albore 1993). *F. esculentum* has been found to attract small wasps and flies (Taki et al. 2009). Additionally, *A. foeniculum* is considered to be somewhat drought-resistant (Saeedfar et al. 2015) which may explain why there were no significant differences in visitation length between the well-watered and water-stressed plants. This further suggests that *A. foeniculum* should be considered a suitable pollinator plant for areas in Northeast Connecticut that may experience drought. However, the water-stressed *F. esculentum* did not provide for pollinators as well as the well-watered plants did. The water-stressed *F. esculentum* was better at retaining the visitation of natural enemies as there were no significant differences between the experimental groups. While *F. esculentum* may be effective at attracting natural enemies, it cannot be recommended as a pollinator plant while extreme drought conditions are present.

This study underestimates the maximum amount of time insects spent visiting the flowers, due to the methodological limitations. The five-minute maximum was selected

considering the amount of time needed for the researcher to collect the data, and the amount of time the entire day's observations would take. The experiment had six blocks, each with two pots, for a total of 10 minutes per block or 60 minutes of total data collection time. In future studies additional research assistants could be hired to increase the length of time spent on observations.

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