

ATTRACTIVENESS OF ENGLISH THYME (*THYMUS VULGARIS* L.)  
TO ARTHROPOD NATURAL ENEMIES AND ITS  
SUITABILITY AS A DUAL USE RESOURCE

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Master of Science in Agriculture with a specialization in Plant Protection Science

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to Arthropod Natural Enemies and Its Suitability as a  
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## ABSTRACT

### Attractiveness of English Thyme (*Thymus vulgaris* L.) to Arthropod Natural Enemies and Its Suitability as a Dual Use Resource

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Current agroecosystem management practices have a negative effect on natural enemies and their ability to control insect pests. Conservation biological control through the addition of flowering resources can manage food resources for natural enemies. These floral resources can also provide multiple ecosystem services. Study goals were to determine if perennial *Thymus vulgaris* L. was attractive to natural enemies and if so, could it be a dual use resource encouraging pest management and providing harvestable product. In 2018 plots in three locations were used to examine the effect of habitat throughout the growing season on the attractiveness of *T. vulgaris*. Large numbers of Thysanoptera and Hemiptera were collected in all locations, represented by phytophagous Aphididae and Thripidae, and predatory Anthocoridae. Location influenced other families to varying degrees. Seasonal specimen counts were influenced by vegetation density, floral phenology, and predator/prey relationships. In 2019 replicated plots of three treatments were used to examine if harvesting plant material affected the attractiveness of *T. vulgaris* to natural enemies. Total specimens in 2019 were not significantly different among treatments, indicating removal of blooms did not significantly affect the attractiveness of *T. vulgaris*. Significant numbers of Thysanoptera and Hemiptera were again collected in all treatments, represented by phytophagous Aphididae and Thripidae. Greater numbers of Diptera and Hymenoptera were also collected. Significant numbers of Thripidae, Aphididae, Mymaridae, and Platygastriidae were found in the Family level analyses. Results from both years indicate *T. vulgaris* was attractive to natural enemy and phytophagous Families. Data from 2018 suggest natural enemy families were attracted to alternative prey and hosts utilizing the foliage rather than flowers but the use of nectar and pollen cannot be ruled out. Data from 2019 suggest the presence of flowers played an important role in the attractiveness of *T. vulgaris* to micro-hymenopteran parasitoids, Syrphidae, and native Apidae. In conclusion, *Thymus vulgaris* has the potential to be a dual use floral resource that benefits growers through supporting native enemy populations and pollination services, as well as provide income from the harvest of foliage. It could also be used as a beneficial, harvestable floral resource in urban gardens to encourage pollinator conservation and natural pest control.

**Keywords:** *Thymus vulgaris*, Natural Enemy, Conservation Biological Control, Floral Resource, Alternative Prey, Dual Use, Ecosystem Service, Regulating, Provisioning.

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## 1 INTRODUCTION

Large-scale monoculture, the removal of non-crop habitat, and the intensive use of pesticides have all contributed to the simplification of agroecosystems (Bianchi et al., 2006; Wilkinson & Landis, 2005). Unfavorable environments for arthropod natural enemies are created that affect their ability to suppress herbivorous pest populations and overall survival (Landis et al., 2000; Wilkinson & Landis, 2005). Conservation biological control (CBC) protects and enhances natural enemy populations by decreasing their mortality rates through altering farming practices or providing resources to encourage their survival and efficacy (Landis et al., 2000; Rusch et al., 2017; Shields et al., 2019). CBC focuses primarily on habitat management techniques that improve environmental conditions for natural enemies and increase their populations (Landis et al., 2000). The addition of non-crop flowering plants, or floral resources, is especially effective for managing agroecosystems for natural enemies by providing shelter and overwintering sites, alternative prey or hosts, and food such as pollen and nectar (Fiedler et al., 2008; Landis et al., 2000).

Selecting an appropriate floral resource species is critical as flower morphology, color, and odor play important roles in attraction and accessibility to natural enemies (Fiedler & Landis, 2007b; Patt et al., 1999; Wäckers, 2004). The type of floral resource also can affect longevity and reproductive success of natural enemies (Araj & Wratten, 2015; Pumariño et al., 2012; van Rijn et al., 2013; Witting-Bissinger et al., 2008). The majority of early studies have focused on annual floral resources (Fiedler et al., 2008), but researchers have begun to

consider perennial plant species which offer year-round access to food resources and overwintering habitat (Cahenzli et al., 2019; Ganser et al., 2019; Pfiffner et al., 2018).

Perennial floral resources also have the potential to provide multiple ecosystem services (Fiedler et al., 2008; Amoabeng et al., 2019), which are the processes and functions that support life (Daily, 1997). These include supporting, regulating, provisioning, and cultural services (Fiedler et al., 2008; Westphal et al., 2015; Wratten et al., 2012). Floral resources can provide regulating services by supporting pollinators and natural enemies and may also double as harvestable commodities (Barbir et al., 2016; Bugg et al., 2008; Hogg et al., 2011a; Wojciechowicz-Żytka & Jankowska, 2017). This dual use potential is especially promising in the Lamiaceae, which has several species whose foliage is used in culinary, pharmaceutical, and agricultural applications (Naghibi et al., 2005). English thyme, *Thymus vulgaris* L. is one such plant. Native to the Mediterranean region, *T. vulgaris* is grown commercially around the world for both its edible foliage and essential oils (Thyme Production, 2012; Kassahun et al., 2016). These oils have been found to be effective against agricultural pests (Pavela, 2011; Rasiukevičiūtė et al., 2018; Szczepanik et al., 2012; Werdin-González et al., 2011) and are being tested for their anti-microbial, anti-fungal, anti-oxidant, and anti-cancer properties (Hosseinzadeh et al., 2015; Prasanth et al., 2014; Salehi et al., 2019). Horticulturally, *T. vulgaris* is a low maintenance, drought tolerant, and long-blooming sub-shrub (Stahl-Biskup & Sáez, 2002). Only two studies have been published which looked at the attractiveness of *T. vulgaris*

to natural enemies, and both were in Poland (Kelm et al., 2009; Wojciechowicz-Żytka & Jankowska, 2017). The flowering plants were found to attract several European species of syrphid flies, however the dual use potential of *T. vulgaris* as a harvestable commodity was not addressed.

The goals of this research were to determine if the perennial species *Thymus vulgaris* is attractive as a floral resource to natural enemies in California and to evaluate the potential of *T. vulgaris* as a dual use resource. The objectives were 1) in 2018 to compare differences in the density and diversity of arthropod fauna attracted to *T. vulgaris* in three distinct habitats throughout the growing season, and 2) in 2019 to determine the effects of three harvesting treatments on the density and diversity of arthropod fauna attracted to *T. vulgaris*, exploring the dual use potential of harvesting marketable plant material while still maintaining its use as a floral resource as a tool in non-chemical approaches to pest management.

The significance of this study applies to both agroecosystems and urban gardens. Perennial floral resources such as *T. vulgaris* may become a viable option for attracting natural enemies into fields and home gardens for natural pest control, especially as agribusiness and homeowners become more interested in alternatives to chemical pesticides. The drought-tolerant and low-maintenance aspects of *T. vulgaris* may also make it a practical substitution for the water-intensive annual floral crops currently used in some systems. The potential for harvestable foliage from the *T. vulgaris* plants may also be an important economic incentive for setting aside a portion of arable land for this

perennial floral resource. *Thymus vulgaris* has the potential to be an added tool for providing non-chemical pest management and pollination services, as well as offering a harvestable resource to the grower, making it a valuable plant to investigate.

## 2 LITERATURE REVIEW

### 2.1 Biological Control

Biological control is the use of living organisms, including parasites, predators, and pathogens, to control pest populations below a certain damage threshold (Eilenberg et al., 2001; Ehler, 1998; van den Bosch et al., 1982). While the term 'biological control' was first used in the early twentieth century (DeBach, 1974), the history of using organisms to regulate agricultural pests goes back centuries. The Chinese were using colonies of predatory ants [*Oecophylla smaragdina* (Dru.)], to control pests in their mandarin groves as early as 300 A.D., and Arabs also used ants in their date groves during the medieval period (Gurr et al., 2000a). Examples in recent history include the introduction of the vedalia beetle [*Rodolia cardinalis* (Muls)], and the parasitic fly *Cryptochaetum iceryae* (Williston), in the early 1880's to control cottony-cushion scale (*Icerya purchasi* Mask) (Barrett et al., 2018; Gurr et al., 2000a), and the first use of the parasitoid *Encarsia formosa* Gahan in the 1920's to inundate outbreaks of greenhouse whitefly (*Trialeurodes vaporariorum* Westwood) (Gurr et al., 2000a). The development of chemical pesticides following World War II slowed research into biological control (Gurr et al., 2000a; van den Bosch et al., 1982). Negative public reactions to the effects of pesticides on the environment in the early 1960's (Barratt et al., 2018) and ongoing and increasing pest resistance to overused pesticides (Shields et al., 2019; Wilson & Tisdell, 2001) has created a renewed interest in finding more sustainable methods of managing agricultural pest populations.



Biological control is divided into three categories: classical or importation; augmentative, which includes inundative and inoculative methods; and conservation (Eilenberg et al., 2001; Gardiner et al., 2009).

#### 2.1.1 Classical Biological Control

Classical biological control, or importation, involves the introduction of a non-native natural enemy to control a pest which is either native or exotic (Eilenberg et al., 2001), with the goal of creating a self-sustaining population of natural enemies that can provide long term pest regulation without further introductions (Hajek, 2004). In the case of exotic pests, this typically requires returning to the organism's native range to find natural enemy species that keep the populations in check (Eilenberg et al., 2001). Successful classical biological control programs in California agriculture include the aforementioned vedalia beetle brought from Australia to control cottony-cushion scale on citrus, and the introduction of the parasitic wasp *Trioxys pallidus* (Haliday) from France and Iran in the late 1950's to control walnut aphid [*Chromaphis juglandicola* (Kaltenbach)] (van den Bosch et al., 1982). Unfortunately, not all introductions are effective; Hajek (2004) found only 33.5% of released natural enemies become established, and just 33.5% of these yielded complete or substantial control of the pest. There has also been concern in the past over the unintended effects of introduced species on non-target species (Barratt et al., 2018), but today there are strict guidelines for the safe importation and release of exotic natural enemies (Schulten, 1997).

### 2.1.2 Augmentative Biological Control

Augmentative biological control involves increasing the effect of existing natural enemies on pest populations by rearing and releasing large numbers of individuals into the agroecosystem (Gardiner et al., 2009; van Lenteren et al., 2018). This technique is often subdivided into two methods: inundative and inoculative (Eilenberg et al., 2001; Hajek, 2004; van Lenteren et al., 2018). Inundative biological control anticipates pest control will be achieved solely by the individuals being released; there is no expectation the control agent will reproduce or survive long-term in the system (Eilenberg et al., 2001; Hajek, 2004). Inundation is often used with short term monocultures or for those crops with low damage thresholds for rapid control of emerging pest issues (Hajek, 2004; van Lenteren et al., 2018). Examples include the mass release of predatory mites to control thrips and spider mites, Coccinellids to control aphids and mealybugs, and *Trichogramma* sp. parasitoids to control Lepidopteran pests (Hajek, 2004; van Lenteren et al., 2018). Inoculative biological control also involves the release of large numbers of natural enemies, but there is an expectation they will reproduce in response to prey density, creating successive generations to provide longer term control, but still not establishing a permanent population (Eilenberg et al., 2001; Hajek, 2004). Inoculative releases are often used with crops that have a longer production cycle (van Lenteren et al., 2018) and in greenhouse systems which are cleared at the end of each season (Eilenberg et al., 2001). An example is the use of the egg parasitoid *Pediobius foveolatus* Crawford, which is released in the United States each spring to control

the Mexican bean beetle (*Epilachna varivestis* Mulsant) in snap and soybeans (Hajek, 2004).

### 2.1.3 Conservation Biological Control

Conservation biological control (CBC) focuses on supporting existing natural enemy populations rather than releasing new ones. There are two components to CBC: first, limiting detrimental agricultural practices such as pesticide use and tillage regimes, and second, managing resources to enhance the survival, fecundity and effectiveness of natural enemies (Begg et al., 2017; Eilenberg et al., 2001; Gurr et al., 2000b; Hajek, 2004; Landis et al., 2000). Habitat management is considered a subset of CBC and involves diversifying the vegetation within or adjacent to agroecosystems to enhance natural enemy activity (Gurr et al., 2016). The ultimate goal is the dispersal of natural enemies out into the agroecosystem for increased pest control (Landis et al., 2000). This spillover from vegetation in the crop margins has been demonstrated in parasitoids (Scarratt et al., 2008; Lavandero et al., 2005) and syrphid flies (Inclán et al., 2016; Gillespie et al., 2011; Pollier et al., 2019). One aspect of habitat management that has been extensively studied is the addition of non-crop flowering plants, called floral resources, to agroecosystems for managing predator and parasitoid populations (Baggen et al., 1999; Wäckers, 2004).

## 2.2 Floral Resources

Floral resources can provide shelter and overwintering sites, alternate prey or hosts, and floral foods such as nectar and pollen (Gurr et al., 2016; Landis et al., 2000; Wilkinson and Landis, 2005).

### 2.2.1 Shelter and Overwintering

The management practices of modern agroecosystems often disturb natural enemy populations (Wilkinson & Landis, 2005). Pesticide applications and seasonal tillage can destroy individuals both in the crop and in the soil (Gurr et al., 2016). Non-flowering floral resources along the margins of a field or in the larger landscape can provide a more stable environment during the growing season for natural enemies (Landis et al., 2000). These refuges protect individuals from environmental extremes, offering drier conditions, less wind, or more moderate temperature microclimates (Gillespie et al., 2016; Gontijo, 2019; Wilkinson & Landis, 2005), and can act as dispersal corridors between agroecosystems (Griffiths et al., 2008; Gurr et al., 2016). Shelter vegetation can limit intraguild predation and competition by providing refuge to natural enemies from each other, as well as supporting several species of prey for predators (Gontijo, 2019). Studies have found landscape composition and complexity play an important role, with semi-natural or remnant perennial vegetation increasing the abundance of a variety of natural enemies in adjacent crops (Ingrao et al., 2017; Schirmel et al., 2017; Thomson & Hoffmann, 2010). Perennial vegetation also provides natural enemies with secure overwintering habitats (Ganser et al., 2019; Gillespie et al., 2016), including alternative prey and hosts (Landis et al., 2000). Lowery et al. (2007) found *Anagrus* spp., important egg parasitoids of leafhopper pests of wine grape, overwintered within alternative leafhopper hosts on a variety of perennial vegetation, and suggested further studies to select species that could be used as refuge around vineyards. Overwintering shelter

can be an important factor in allowing natural enemies to respond earlier to pest populations in adjacent crops. (Landis et al., 2000). Alignier et al. (2014) determined spring abundance of natural enemies in the crop was related to the surrounding landscape, with early abundance of hover flies related to the amount of woodlands, while late abundance of parasitoids related to hedges and grasslands.

### 2.2.2 Alternative Prey or Hosts

The availability of alternative prey or hosts outside of the crop can support natural enemies in overwintering shelter vegetation and may also allow populations to establish in crops before pests arrive (Landis et al., 2000). An example is the banker plant system, where non-crop plants are infested with non-pest species and placed into the agroecosystem, providing prey or hosts for natural enemies before primary crop host populations become established (Frank, 2010). This technique has been used in greenhouse production with *Encarsia sophia* (Girault & Dodd) against *Bemisia tabaci* (Gennadius) (Gurr et al., 2016), and with *Aphidius colemani* L. to suppress *Aphis gossypii* Glover and *Myzus persicae* (Sulzer) (Frank, 2010). Banker plants have also been used in the field. Zheng et al. (2017) investigated the grass *Leersia sayanuka* Ohwi as a banker plant for protecting rice fields from the rice brown planthopper (*Nilaparvata lugens* Stål). They found the egg parasitoid *Anagrus nilaparvatae* Pang et Wang could use the non-crop pest *Nilaparvata muii* China planthoppers as alternative hosts, leading to a significant decrease of brown planthoppers in rice fields when banker plants were used (Zheng et al., 2017). Generalist

predators may also use alternative prey attracted to floral resources, especially when crop pest levels are low (Wilkinson & Landis, 2005; Wyss, 1996). This can negatively affect biological control when the alternative prey is more attractive or abundant than pest populations in the crop (Bickerton & Hamilton, 2012; Symondson et al., 2002), but generalists can maintain their populations on alternative prey longer than most specialists and can respond quicker to pest population density than parasitoids (Symondson et al., 2002).

### 2.2.3 Nectar and Pollen

Extensive efforts have been made to understand the role of floral resources in providing nectar and pollen for natural enemies. Research has demonstrated the importance of these foods on survival and performance of both parasitoids and predators. The use of pollen by parasitoids is uncommon (Gurr et al., 2016), but several studies have demonstrated the longevity of parasitoids increases with the availability of nectar (Araj & Wratten, 2015; Arnó et al., 2018; Berndt & Wratten, 2005; Géneau et al., 2012; Lee et al., 2004; Rahat et al., 2005; Witting-Bissinger et al., 2008; Wratten et al., 2003b). Many of these same studies found parasitoid lifetime fecundity also improved, but this may be a result of longer lifespans rather than increases in actual daily fecundity (Berndt & Wratten, 2005). Offspring sex ratios can be influenced by nectar availability, with some research finding a higher number of female offspring (Berndt & Wratten, 2005), while others reporting a more male bias, perhaps due to the longer lifespan of females (Markó et al., 2012; Witting-Bissinger et al., 2008). This may affect the primary goal of increasing parasitism of crop pests (Rusch et al., 2017); in some

studies parasitoids showed an increase in parasitism rates (Balmer et al., 2014; Díaz et al., 2012; Zhu et al., 2017; Winkler et al., 2006), but other researchers found no difference in parasitism rates between control and floral resource plots (Berndt et al., 2002; Lee et al., 2006; Nicholls et al., 2000; Rebek et al., 2006). Predators have also been found to benefit from nectar and pollen resources. The longevity and fecundity of the omnivorous *Orius insidiosus* Say increased when provided with nectar and pollen (Pumariño et al., 2012). A similar result was found for the omnivorous lacewing *Micromus tasmaniae* Walker (Robinson et al., 2008), but a decrease in prey consumption was also noted, indicating pollen and nectar resources may be preferred over prey when available. Bertolaccini et al. (2008) reported the egg production and oviposition period of *Hippodamia variegata* (Goeze) increased with the availability of floral resources, although they note aphids are still required for successful reproduction. Syrphids are known to utilize protein for reproductive development (Branquart & Hemptinne, 2000), and access to pollen is an important factor in successful oviposition (Hickman & Wratten, 1996; Hogg et al., 2011b; Laubertie et al., 2012; van Rijn et al., 2006). Nectar is also important for syrphid longevity (Pinheiro et al., 2013; van Rijn et al., 2013), and they have been found to store nutrients for an extended time, allowing for movement between foraging in the floral resources and finding oviposition sites within the crop (van Rijn et al., 2013).

### 2.3 Selection of Floral Resources

The selection of appropriate plant species is a critical consideration when considering the addition of a floral resource to a habitat for pollen or nectar

(Fiedler & Landis, 2007a; Vattala et al., 2006). Variables influencing a plant's suitability for natural enemies include flower attractiveness, accessibility, and nectar and pollen quality and quantity.

### 2.3.1 Flower Attractiveness

The attractiveness of a plant as a floral resource for natural enemies is related to numerous traits. Flower color can affect the visibility of floral resources, making them more or less likely to be visited by natural enemies (Wäckers, 2004). Syrphids have been shown to be attracted to white, yellow, and blue flowers (Lövei et al., 1993; Sutherland et al., 1999;), while parasitoids were attracted to yellow and white flowers (Begum et al., 2004; Wäckers, 1994). Age (Sutherland et al., 1999), hunger level (Wäckers, 1994), and the species of natural enemy (Haslett, 1989b; Klecka et al., 2018) can also affect color preferences. Floral volatiles, or odors, also play an important role in the recognition of suitable floral resources by natural enemies (Patt et al., 1999; Wäckers, 2004). Volatiles can assist natural enemies in locating food sources in the landscape (Bianchi & Wäckers, 2008; Foti et al., 2016; Wäckers, 1994), identifying nectar sources within the flower (Patt et al., 1997a), and may be important for developing associations between nectar rewards and certain odors (Wäckers, 2004). When given a choice of controls or volatiles from a variety of plant species, different natural enemies show preferences for odors emitted by some plants over others (Foti et al., 2016; Wäckers, 2004). Differences in the attractiveness of volatiles released by a plant's foliage versus its flowers have also been noted (Foti et al., 2016). Chemical analysis of flower volatiles suggests



insects may be responding positively to certain constituents including linalool, limonene, estragole, and 2- and 3-methylbutanoic acids (Foti et al., 2016; Wäckers, 2004), while being repelled by odors containing acetophenone, camphor, and 1,8-cineole (Wäckers, 2004). Flower height and size can affect the attractiveness of blooms to different species of syrphids (Klecka et al., 2018; Sutherland et al., 1999), but may not affect parasitoids (Sivinski et al., 2011). Flower area, pertaining to the density of blooms, was found to be attractive to natural enemies in general (Fiedler & Landis, 2007b), as well as to syrphids (Miller et al., 2013) and parasitoids depending on species (Sivinski et al., 2011), suggesting researchers may need to focus on choosing species with larger displays as potential floral resources (Fiedler & Landis, 2007b). Flower phenology must align with the life cycle of the natural enemy, providing pollen and nectar at the appropriate development stage and before pests reach economic damage thresholds (Fiedler & Landis, 2007b; Colley & Luna, 2000). Closely related to phenology is the life cycle of the floral resource. Annual exotic plants such as sweet alyssum [*Lobularia maritima* (L.)], buckwheat [*Fagopyrum esculentum* (Moench)], phacelia [*Phacelia tanacetifolia* (Benth)], and coriander [*Coriandrum sativa* (L.)] have been frequently used in attraction studies (Balzan and Wäckers, 2013; Colley & Luna, 2000; Begum et al., 2006; Hogg et al., 2011a; Lavandero et al., 2006; Pumariño et al., 2012), in part because of their quick development and amenability to short term cropping systems (Hogg et al., 2011a). Research has also been conducted using perennial species (Tschumi et al., 2016; Uyttenbroeck et al., 2015). Unlike annuals, perennials provide

attractive long-term shelter and overwintering sites for a wide variety of natural enemies (Frank et al., 2008), have the potential to increase in attractiveness as the plants mature (Grab et al., 2018; Toivonen et al., 2018), require fewer seasonal inputs reducing expenses (Buchanan et al., 2018; Fiedler & Landis, 2007a), and are suitable for perennial agroecosystems such as orchards and vineyards (Cahenzli et al., 2019; Gurr et al., 2003; Pfiffner, 2018).

### 2.3.2 Flower Accessibility

Plants that are attractive to foraging natural enemies may not have accessible resources (Wäckers, 2004), in particular nectar. This discrepancy is caused by the interaction of flower architecture (e.g. corolla depth and/or width) (Fiedler & Landis, 2007b; Nave et al., 2016; Sivinski et al., 2011; van Rijn & Wäckers, 2016) and the location and type of floral nectaries (e.g. exposed, hidden, or extra-floral) (Nave et al., 2016; Patt et al., 1997a), with the morphology of the natural enemy itself (Gilbert, 1981; Nave et al., 2016; Patt et al., 1997a; Vattala et al., 2006). Deeper corollas may be inaccessible to smaller natural enemy species or those with shorter proboscises (Nave et al., 2016; Patt et al., 1997a; van Rijn & Wäckers, 2016; Vattala et al., 2006), although some parasitoids have been documented chewing holes in the base of flowers to access hidden nectaries (Russell, 2015). Flowers with corollas that are too narrow may prevent parasitoids with large heads or thoraces from entering the flower (Sivinski et al., 2011; Vattala et al., 2006), but smaller species may be able to fit inside (Stang et al., 2006). Other flower structures, such as anthers or guard hairs, may also block access to nectar (Nave et al., 2016; Sivinski et al., 2011;

van Rijn & Wäckers, 2016). Blooms with wide, shallow corollas have been found to be accessible to many parasitoids (Nave et al., 2016; Patt et al., 1997a; van Rijn & Wäckers, 2010; Vattala et al., 2006) and syrphid flies (Blackmore & Goulson, 2014; Stang et al., 2006), with width often being a more important dimension than depth (Sivinski et al., 2011). For example, species in the Apiaceae such as coriander, dill (*Anethum graveolens* L.), wild carrot (*Daucus carota* L.), and wild fennel (*Foeniculum vulgare* Mill.), have an open floral architecture, allowing access to the shallow nectaries for most natural enemy species (Nave et al., 2016; Patt et al., 1997a; Patt et al., 1997b; van Rijn & Wäckers, 2010; Wäckers et al., 1996). Research on the accessibility of flowers in different plant Families has shown mixed results. Plants in the Fabaceae also have narrow and deep corollas, limiting access to most natural enemies unless they are able to force their way down through the unfused petals to the floral nectar (Nave et al., 2016; Stang et al., 2006; Vattala et al., 2006; Wäckers et al., 1996), or if the plant has extra-floral nectaries that are more readily accessible (Baggen et al., 1999; Langoya & van Rijn, 2008; Wäckers et al., 1996). Sweet alyssum, an annual species in the Brassicaceae, has been shown to be accessible to syrphids (Bugg et al., 2008; Hogg et al., 2011a) and some species of parasitoids (Winkler et al., 2005), but not to others depending on parasitoid head size (Patt et al., 1997a; Vattala et al., 2006). Longer tongued species of syrphids have been recorded visiting plants in the Asteraceae (Branquart & Hemptinne, 2000), but the narrow disc flowers prevent nectar accessibility for most other short tongued natural enemies (Patt et al., 1997; Pinheiro et al., 2013;

Wäckers et al., 1996). Even so, some late blooming Asteraceae species attract high numbers of natural enemies (Fiedler & Landis, 2007b), suggesting there may be a pooling of nectar that occurs on the disc, making it more accessible than would be expected (Fiedler & Landis, 2007b). Syrphids have been found to be attracted to several species in the Lamiaceae, including *T. vulgaris*, but the accessibility of its nectar was not examined (Kelm et al., 2009). Oregano (*Origanum vulgare* L.) has been found to be attractive but only moderately accessible to parasitoids (Wäckers, 2004; Winkler et al., 2005), while the narrow corolla of rosemary (*Rosmarinus officinalis* L.) restricted access to a potentially rich nectar source (Furtado et al., 2016). While pollen is an important component of some natural enemy diets, especially syrphids, no research has been conducted on its accessibility. This may be because flowers have evolved to provide accessible pollen, with the pollen holding anthers usually exposed above or within the flower allowing direct or inadvertent access (Meeuse, 2020). Pollen may be ingested directly, as with syrphids (Gilbert, 1981; Haslett, 1989a; Irvin & Bowie, 1999), or indirectly by parasitoids with nectar (Gurr et al., 2016) or during grooming (Patt et al., 1997a). Because of the accessibility of pollen it is unlikely to be a limiting resource in comparison to nectar (van Rijn & Wäckers, 2016).

### 2.3.3 Nectar and Pollen Quality and Quantity

The quality (i.e. chemical composition) and the quantity of nectar in a floral resource must be considered alongside its attractiveness and accessibility (Foti et al., 2016). Disparity in longevity rates may also be related to the chemical composition of the various nectars (Nave et al., 2017; Vattala et al., 2006), which

differs across plant Families (Baker & Baker, 1983). For example, the amounts and ratios of glucose, fructose, hexose, and sucrose in nectar are linked to longevity of parasitoids (Furtado et al., 2016; Nafziger & Fadamiro, 2011; Vattala et al., 2006). Both male and female parasitoids have increased longevity when fed on collected nectar of either sucrose- or hexose- rich plants (Furtado et al., 2016; Nave et al., 2017), but sucrose-rich species containing pyrrolizidine alkaloids deterred feeding (Furtado et al., 2016). When considering nectar sugar ratios, glucose/fructose ratios may be similar across plant species, but sucrose/(glucose+fructose) ratios can vary (Vattala et al., 2006), affecting parasitoid longevity. Laboratory tests of nectar quality indicate which sugar types and ratios can be important when choosing floral resources for natural enemies (Vattala et al., 2006), but other factors must be taken into consideration, in particular nectar accessibility. For example, collected nectar of *R. officinalis* and *Calamintha nepeta* (L.) Savi subsp. *nepeta* both increased parasitoid lifespan in relation to water controls, but longevity was reduced when parasitoids were fed using actual flowers of these same plant species, most likely due to the floral architecture being inaccessible (Furtado et al., 2016). Other considerations that affect nectar availability include nectar viscosity, which can prevent natural enemies from being able to ingest nectar (Winkler et al., 2009), and horticultural varieties, such as double variants of flowers, which have little to no nectar (Corbet et al., 2001).

#### 2.3.4 Floral Resources Selectivity

A primary concern of providing floral resources for natural enemies is these same resources will be attractive and accessible to crop pests (Baggen & Gurr, 1998; Lavandero et al., 2006; Winkler et al., 2003), or fourth level predators and parasitoids of natural enemies (Araj et al., 2009; Jonsson et al., 2009). For instance, some species of annual floral resources improved longevity and parasitism rates by *Copidosoma koehleri* Blanchard, but two of the most recommended species – buckwheat and coriander – also increased the longevity of the potato moth *Phthorimaea operculella* (Zeller) (Baggen & Gurr, 1998). Baggen & Gurr (1998) encouraged research into floral resources that support natural enemy but not pest populations and coined the term selective food plant to describe such species. Another study found even though *Pieris rapae* L. theoretically could access the nectar in eleven floral species, only three significantly increased longevity, indicating the importance of examining the actual accessibility of nectar and the effects on longevity and fecundity on a pest (Winkler et al., 2003). Since then, several studies have detailed commonly used floral resources benefiting pests. Alyssum was shown to increase longevity and fecundity of the leaf miner *Tuta absoluta* Meyrick (Balzan & Wäckers, 2013) and the leafroller *Epiphyas postvittana* (Walker) (Irvin et al., 2006), and increased the energy level of *Plutella xylostella* (L.) (Winkler et al., 2009). Buckwheat also increased longevity of *P. xylostella* (Lavandero et al., 2006; Pandey et al., 2018) and the number of eggs and larvae of *P. rapae* in an adjacent Brussels sprout crop (Winkler et al., 2010), and phacelia was found to be attractive to three crop

pests in a broccoli system (Ambrosino et al., 2006). Additional studies have shown contradicting results, including one where alyssum was not used by *E. postivitana* larvae or adults (Begum et al., 2006), and others where buckwheat did not have any effects on longevity or fecundity of the cabbage moth *Mamestra brassicae* (L.) (Géneau et al., 2012) or the sugar levels of *P. xylostella* specimens (Winkler et al., 2009). There have also been mixed results of the effects of floral resources on hyperparasitism. Buckwheat increased hyperparasitism of the omnivorous lacewing *M. tasmaniae* (Walker) (Jonsson et al., 2009), and of *Aphidius ervi* (Haliday) (Araj et al., 2008), but had no effect on hyperparasitism rates of *Diadegma insulare* (Cresson) (Lee & Heimpel, 2005). Perennial floral resources have been found to attract phytophagous species as well (Fiedler & Landis, 2007a), in particular generalists which utilize the diversity in the mixed borders (McCabe et al., 2017). One final consideration is the potential of a floral resource to vector disease organisms. Irvin et al. (2014) demonstrated four frequently used floral resources in California vineyards – buckwheat, vetch, sweet alyssum and coriander – could host *Xylella fastidiosa* Wells, the pathogen responsible for Pierce's disease, allowing potential transmission back to grapevines by the glassy-winged sharpshooter *Homalodisca vitripennis* (Germar).

## 2.4 Floral Resources for the Provision of Ecosystem Services

The intent of conservation biological control is to improve environmental conditions for and provide needed resources to natural enemies to enhance phytophagous pest control (Begg et al., 2017; Eilenberg et al., 2001; Gurr et al.,

2000b; Hajek, 2004; Landis et al., 2000). Habitat management, through the use of floral resources, attempts to provide shelter, alternative prey or hosts, and nectar and pollen, increasing natural enemy longevity, fecundity, and by extension, impact on pest populations (Gurr et al., 2016; Landis et al., 2000). Recently researchers have focused on the potential of floral resources to provide multiple ecosystem services and function as dual use resource to farmers. Ecosystem services are processes and functions that support life on this planet (Daily, 1997). Agroecosystem services include support services (photosynthesis, soil formation, and decomposition), provisioning services (production of food, fiber, and pharmaceuticals), regulating services (biological pest control, pollination, and water purification), and cultural services (recreational, aesthetic, and spiritual beliefs) (Fiedler et al., 2008; Westphal et al., 2015; Wratten et al., 2012). Floral resources have primarily been used for regulating services, providing pest management or pollination services. Several studies have sought to stack these services, choosing floral resources attractive to both natural enemies and pollinators, with mixed results. Balzan (2017) found an increase in both natural enemies and pollinators and a reduction in crop damage from Lepidopteran pests, but others noted a decrease in parasitoids due to competition (Campbell et al., 2012) or little effect on pest populations and crop yields (Balzan et al., 2016; Sutter et al., 2016). There is also a potential for floral resources to play a larger role in provisioning services as dual use resources for food, bio-insecticides, or pharmaceuticals (Fiedler et al., 2008; Amoabeng et al., 2019). Many of the plant species currently used as floral resources for habitat



manipulation are members of Families with a history of culinary use. Annual herbs in the Apiaceae – including coriander, dill, and fennel – have been shown to be attractive to natural enemies (Al-Doghairi & Cranshaw, 1999; Baggen et al., 1999; Balzan et al., 2014; Luis et al., 2017), and are included many commercial insectary seed mixes (Forehand et al., 2006; Pontin et al., 2006). The flowers of perennial culinary herbs in the Lamiaceae including oregano, rosemary, and thyme are also attractive (Belz & Balmer, 2013; Furtado et al., 2016; Wojciechowicz-Zytka & Jankowska, 2017), and have the added benefit of providing harvests for several years (Bugg et al., 2008). Many Families also have potential for producing bio-insecticidal extracts – including Apiaceae, Asteraceae, and Lamiaceae (Amoabeng et al., 2019; Digilio et al., 2008; Grdiša & Gršic, 2013) – which have been found to breakdown rapidly in the environment, show lower toxicity to nontarget species, and function through multiple modes of action (Campos et al., 2019; Amoabeng et al., 2019). Others are known for their use in traditional medicine and pharmaceuticals (Fiedler et al., 2008; Pinheiro et al., 2013). The Lamiaceae, and *Thymus vulgaris* in particular, has been used for medicinal purposes for centuries and continues to be a subject of research (Hosseinzadeh et al., 2015; Naghibi et al., 2005; Prasanth et al., 2014). If harvested with both regulating and provisions services in mind, these dual-resource plants may provide floral resources for natural enemies as well as income for growers (Bugg et al., 2008), providing economic incentive for the incorporation of conservation biological control methods in their agroecosystems (Bugg et al., 2008; Hogg et al., 2011a).

## 2.5 English Thyme, *Thymus vulgaris* L.

One perennial species that may have potential as a dual use resource is *Thymus vulgaris* L. Commonly called common thyme, garden thyme, or English thyme, *T. vulgaris* is a species of flowering plant in the Lamiaceae. It is native to southern Europe from the western Mediterranean to southern Italy. It is a bushy, evergreen subshrub growing to 15–30 cm tall by 40 cm wide with small, highly aromatic, grey-green leaves. The flowers can be white, pink or purple, and are borne in whorls in early spring or summer depending on the conditions (Brickell and Zuk, 1997; Flo et al., 2018). The corolla is two-lipped and tubular, 6-8 mm long, and four pollen-bearing stamens protrude from the corolla. The nectaries are located at the base of the corolla.

Thyme has been used horticulturally, culinarily, and medicinally since medieval times (Stahl-Biskup and Saez, 2002). Horticulturally, thyme is a drought tolerant, pest resistant plant that is attractive to pollinators (Brenzel, 2012). It is an important fresh component of many cuisines, including French, Mediterranean, and Asian (Baker and Grant, n.d.), and its essential oils are used to flavor many products including soft drinks, liquors and toothpaste (Bown, 2005; Stahl-Biskup and Saez, 2002). Medicinally, it has traditionally been used to treat digestion issues, muscle spasms, fungal infections, and coughing (Bown, 2005).

Thyme's essential oils are the subject of extensive research. There are estimated 17 to 21 compounds identified in *T. vulgaris* (Abedini et al., 2014; Özgüven and Tansi, 1998); thymol and carvacrol are the main phenolic

compounds of thyme oil, and p-cymene is the major non-phenolic compound (Özgüven and Tansi, 1998). Several studies have found these essential oils to be antimicrobial, acting as a natural food preservative (Agnieszka et al., 2013; Kumar et al., 2008; et al., 2016; Salehi et al., 2019), antiseptic (Borugă et al., 2014; Pecarski et al., 2016; Rota et al., 2008; Sahakyan et al., 2017), and antiprotozoal (Eraky et al., 2016; Garza-González et al., 2017; Santoro et al., 2007). The compounds have also been shown to be antifungal (Al-Shahrani et al., 2016; Rasiukevičiūtė et al., 2018; Razzaghi-Abyaneh et al., 2009), anticancer (Abaza et al., 2015; Kubatka et al., 2019; Sertel et al., 2011), and an antioxidant (El-Nekeety et al., 2011; Lee et al., 2005).

Thyme has agricultural applications as well. Thymol binds and stimulates GABA receptors, and carvacrol has demonstrated fungicidal activity against several pathogens (Campos et al., 2019). Thymol has been demonstrated to have ovicidal activity against the green stink bug (*Nezara viridula* (Linnaeus)) (Werdirn González et al., 2011), and insecticidal activity against adult maize weevils, *Sitophilus zeamais* (Motschulsky) (Bittner et al., 2008). It also acts as a repellent against adult pollen beetles, *Meligethes aeneus* (Fabricius) (Pavela, 2011), and a feeding deterrent for the tobacco cutworm, *Spodoptera litura* Fabricius (Hummelbrunner and Isman, 2001). It is especially effective insecticide against cabbage aphids, *Brevicoryne brassicae* (L.) (Görür et al., 2008) and green peach aphids, *Myzus persicae* (Sulzer) (Digilio et al., 2008). It has also been found to prevent the growth of *Fusarium graminearum*, teleomorph *Gibberella zeae* (Schwein.) Petch (Rasiukevičiūtė et al., 2018) and *Botrytis*

*cinerea* Pers. (Valiuškaitė et al., 2018). There is currently one thyme oil-based insecticide/repellent on the market, EcoVia WD from Rockwell Labs Ltd. (USA) (Campos et al., 2019). Studies on the impact of *T. vulgaris* essential oils on parasitoids have shown it to have a low impact on *Trichogramma galloi* Zucchi (Parreira et al., 2017) and *Trissolcus basalis* (Wollaston) (Werdin González et al., 2013), but a greater effect on *Trichogramma pretiosum* Riley longevity and immature stages (Parreira et al., 2018), and therefore should be used with caution.

The proper harvest time for *T. vulgaris* is of major importance, especially for the obtaining the best quality essential oils utilized in the medicinal and commercial markets. Fresh market thyme is usually harvested in mid-summer before plants bloom, although the blooms are also edible and used by some for garnishing (Egel, 2019). Studies pertaining to the harvest of foliage for essential oil production have had varying results. Some recommend harvesting at beginning bloom (Moisa et al., 2019; Naghdi Badi et al., 2004; Salehi et al., 2014), full bloom (Özgüven and Tansi, 1998; Zantar et al., 2015), and even after bloom (Özgüven and Tansi, 1998; McGimpsey et al., 1994), depending on the type, quality, and quantity of essential oil desired. Other factors affecting essential oil content include the age of the plant (Hudaib et al., 2002; Król & Kiełtyka-Dadasiewicz, 2015), spacing in cultivation (Naghdi Badi et al., 2004), and climatic conditions such as rainfall, humidity, and temperature (Özgüven and Tansi, 1998).

The essential oils of *T. vulgaris* are showing promise in the medical and agricultural fields. Limited research has demonstrated the flowers are attractive to natural enemies, in particular, syrphid flies (Kelm et al., 2009; Wojciechowicz-Żytko & Jankowska, 2017). This opens up the possibility *T. vulgaris* may have potential as a dual use resource, providing a harvestable crop to growers as well as a floral resource to natural enemies (Bugg et al., 2008). Proper design and timing of harvest may allow for a marketable product of either fresh material or essential oil production while maintaining the plants ability to provide shelter, food, and alternative prey or hosts to natural enemies, supporting pest control in neighboring agricultural systems.

### 3 MATERIALS AND METHODS

#### 3.1 Overview

The goals of this research were to determine if the perennial species *Thymus vulgaris* is attractive as a floral resource to natural enemies in California and to evaluate the potential of *T. vulgaris* as a dual use resource. This study was conducted in two phases. Objective 1) to compare differences in the density and diversity of arthropod fauna attracted to *T. vulgaris* in three distinct habitats throughout the growing season. In 2018, an attraction study was conducted using *T. vulgaris* plots in three locations within San Luis Obispo, CA: Cal Poly Home Garden, Cal Poly Leaning Pine Arboretum, and UC Master Gardeners Garden of the Seven Sisters Demonstration Garden. Objective 2) determine the effects of three harvesting treatments on the density and diversity of arthropod fauna attracted to *T. vulgaris*. The Cal Poly Home Garden site was chosen for a replicate study in 2019 for two reasons. First, the preliminary data from 2018 indicated there was little difference in species diversity among the three locations, and second, the focus in 2018 was on natural enemies which were common in agroecosystem habitats. The purpose of the treatments was to determine if natural enemies were attracted to the flowers or if they also utilized the plant as a source of alternative prey or hosts. These treatments helped explore the dual use potential of harvesting marketable plant material while still maintaining its use as a floral resource as a tool in non-chemical approaches to pest management.

## 3.2 2018 Attraction Study

### 3.2.1 2018 Study Locations

Three locations in San Luis Obispo, CA were used for the 2018 attraction study (Fig. 1 and Fig. 2). Two were on the Cal Poly University Campus at the north end of the city: the Cal Poly Home Garden (hereafter referred to as either Home Garden or HG, 35°18'05.1"N 120°40'13.5"W) and the California Native Plant Collection at Cal Poly Leaning Pine Arboretum (hereafter referred to as either Leaning Pine Arboretum or LPA, 35°18'35.5"N 120°39'39.4"W). The third location was at the south-east end of the city at the UC Master Gardeners Garden of the Seven Sisters Demonstration Garden (hereafter referred to as either Master Gardeners Demo Garden or MG, 35°16'29.6"N 120°38'52.7"W). Each site was chosen to represent a different habitat (Fig. 3): the HG location represented a simple annual cropping agroecosystem planted with cultivars of organic tomatoes (*Solanum lycopersicum* L.), peppers (*Capsicum annuum* L.), corn (*Zea mays* L.), summer squash (*Cucurbita pepo* L.), and annual flowers; the LPA location represented a native California coastal scrub habitat bordering on an area of natural vegetation; and the MG location represented a complex agroecosystem similar to an urban home garden with a dense mix of crops and ornamental plantings. No pesticides were used on or adjacent to any of the plots during the study period.

### 3.2.2 2018 Plant Material

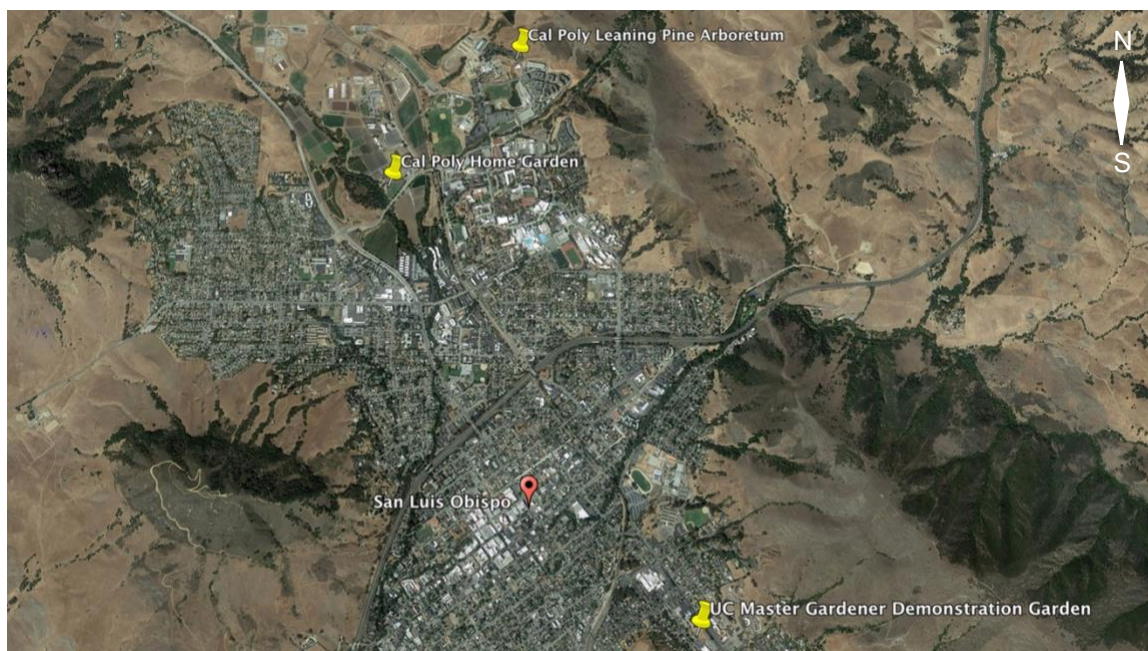
Sixty-four non-flowering, 4-inch potted *Thymus vulgaris* plants were purchased from Miner's Ace Hardware (San Luis Obispo, CA) in March 2018. On

31 March 2018 the plants were potted up into #2 black plastic nursery containers (assorted sources, supplied by Cal Poly Leaning Pine Arboretum) using a 1-1-1 peat/perlite/fir bark nursery substrate and approximately ¼ cup of fertilizer per container (Espoma Organic Garden-tone Herb & Vegetable Food 3-4-4, The Espoma Company, Millville, NJ). Plants were maintained outdoors in the Cal Poly Leaning Pine Arboretum nursery until being moved to the three study locations on 15 April 2018.

### 3.2.3 2018 Study Design

One 1m x 1m plot was established in each location on 15 April 2018. Each plot consisted of 16 potted *T. vulgaris* plants set in a four by four design on top of a 1.5m x 1.5m sheet of black woven weed-block cloth (Fig. 4). Each plot was equipped with a drip irrigation system consisting of 1-gph pressure compensating drip emitters inserted into ½" black polyethylene drip irrigation tubing, with one emitter positioned over each pot. Each system was controlled by a battery-powered timer, and irrigation times were adjusted over the data collection period depending on plant maturity and outdoor temperature, ranging from 5 minutes every 48 hours at the beginning of the study up to 5 minutes every 12 hours during the warmer days later in the collection period.





**Figure 1:** The three locations in San Luis Obispo, CA used for the 2018 attraction study. Google Earth image, 7 September 2018.



**Figure 2:** Closer views of the three attraction study locations in San Luis Obispo, CA used for the 2018 attraction study. Left to right: Home Garden, Leaning Pine Arboretum, and the Master Gardeners Demo Garden. Google Earth images, 7 September 2018.



**Figure 3:** Surrounding vegetation in the three locations in San Luis Obispo, CA used for the 2018 attraction study. Left to right: Home Garden simple annual agroecosystem on 19 August 2018, Leaning Pine native California scrub habitat on 28 May 2018, and the Master Gardeners Demo Garden complex agroecosystem on 12 August 2018.



**Figure 4:** Plot layout and irrigation set up in the three locations in San Luis Obispo, CA used for the 2018 attraction study. Left to right: Home Garden, Leaning Pine Arboretum, and the Master Gardeners Demo Garden on 14 April 2018.

### 3.2.4 2018 Data Collection

Data collection was performed in the field from 22 April through 18 August 2018, for a total sample size of 18 repeated collections per plot. Peak bloom (approximately 100% of the test plot in bloom) was on 18 June 2018. Samples were collected at all three locations once a week (primarily on Sunday) during either mid-morning (beginning at 09:00) or afternoon (beginning at 13:00). Plot

order was rotated each week, so each plot was sampled beginning at 09:00 or 13:00 at least two times over the course of the study. The date, time, temperature, wind speed and wind gust speed (using the app WindCompass, Anapa Apps 2013), and the relative cloud cover (clear, mostly clear, partly cloudy, and cloudy) were recorded at the beginning of each sampling period.

The 2018 sampling methodology consisted of two parts. First, a 15-minute collection was conducted at each plot using an insect aspirator without moving the pots. Foliage and flowers of all 16 pots were sampled, and any insects flying over the plot during this time that were larger than the aspirator opening or too fast for aspirator collection were collected using a sweep net. Second, each pot was lifted and moved to a staging area where the foliage and flowers were physically shaken over a collection surface (folding bed tray with a white laminate surface placed over a white sheet), and all insects dislodged from the plants were collected using the insect aspirator. All sample vials were immediately stored in a cooler containing ice packs to chill the specimens, reducing possible predation in the vials. Vials were transferred to a freezer upon return from the field and frozen for a minimum of two hours. Specimens were then transferred to glass vials containing 70% isopropyl alcohol in preparation for sorting and identification in the laboratory. All specimens from both methods were combined for data analysis.

### 3.2.5 2018 Specimen Identification

A binocular stereo zoom microscope (Olympus SZ, McBain Instruments, Westlake Village, CA) was used to sort and count specimens at the Cal Poly

University Entomology Laboratory. Unknown specimens were photographed through the microscope then identified with the assistance of Cal Poly University Professor Dr. David Headrick, as well as associates at [www.bugguide.net](http://www.bugguide.net). All insects collected were identified to Order and to Family if possible. Specimens were also categorized into one of seven feeding styles: parasitoid, predator, predator/phytophagous, phytophagous/piercing, phytophagous/chewing, beneficial, and other (which included decomposers and specimens whose feeding style were unknown). All specimens were stored by Order in 70% alcohol.

### 3.3 2019 Dual Use Study

#### 3.3.1 2019 Study Location

The Home Garden at Cal Poly University, San Luis Obispo (hereafter referred to as either Home Garden or HG, 35°18'05.1"N 120°40'13.5"W) was chosen for the 2019 study site. The HG field is divided between an organic annual row crops field (west half) and a non-organic annual flower field used for growing cut flowers for the annual Cal Poly Tournament of Roses Parade float (east half). The vegetation surrounding the HG field includes a native oak woodland along Stenner Creek (western border), a mixed hedgerow of non-native trees and shrubs along the Highland Drive entrance to campus (southeastern border), and a mix of native and non-native trees and shrubs along an unpaved access road (northern border) (Fig. 5). No pesticides were used on or adjacent to the plots during the study period.



A 15 square meter site was designated for the study on the north-west side of the field. The soil is a heavy clay, and due to an extremely wet spring, the field could not be tilled until late April 2019. A dressing of Cal Poly compost was turned into the soil the week of 23 April 2019 and the study site was pre-irrigated to germinate dormant seeds; all spontaneous vegetation in the study site was controlled by manual tilling and flaming until the soil was dry enough to prevent additional germination. An organic crop of tomatoes and summer squash were planted east of the study site in late May, and an organic pumpkin crop was planted between the first crop and the study site in mid-July.



**Figure 5:** Cal Poly Home Garden in San Luis Obispo, CA with approximate location of the 15m x 15m 2019 dual use study site. Google Earth image, 7 September 2018. Image is not reflective of the actual plantings in 2019.

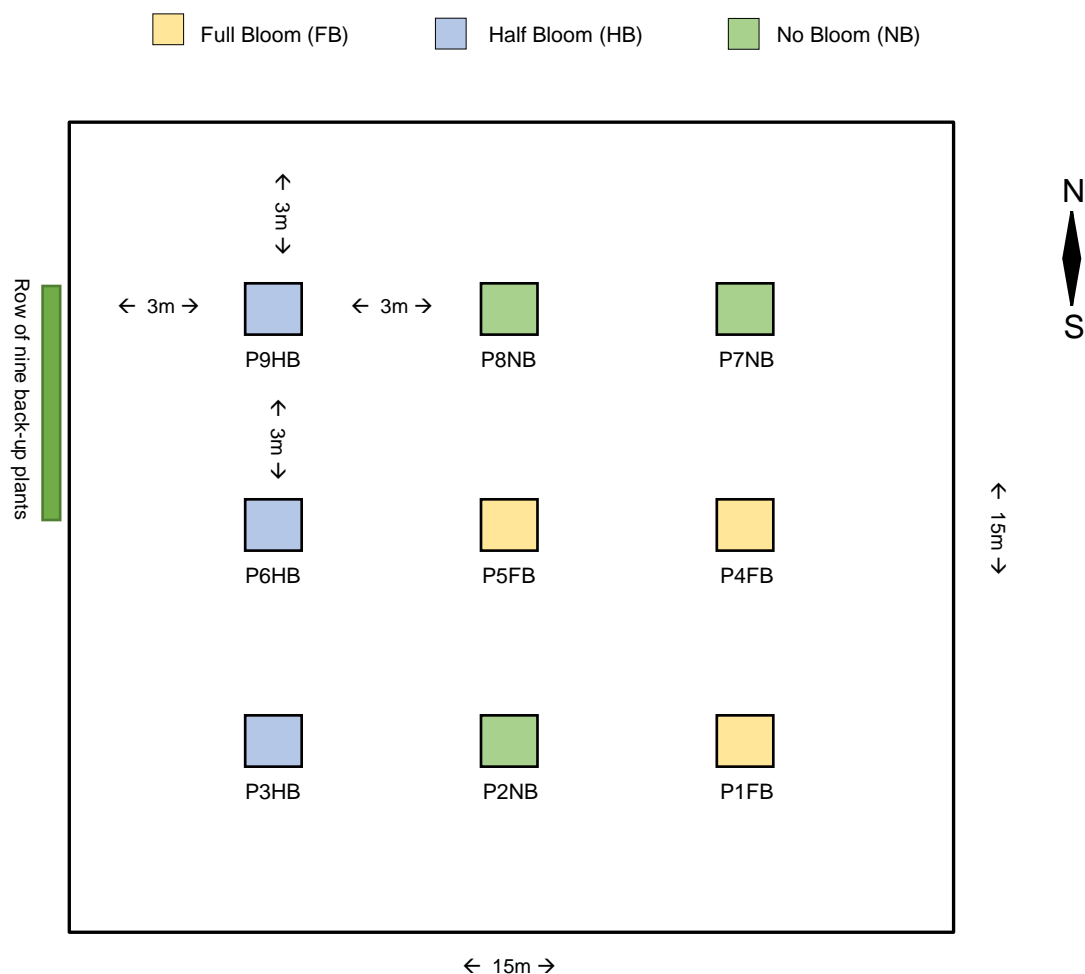
### 3.3.2 2019 Plant material

Ninety non-flowering, organically grown, 4-inch potted *Thymus vulgaris* plants were purchased from Miner's Ace Hardware (San Luis Obispo, CA) on 24 April 2019. Plants were maintained in their original containers until the planting date of 5 May 2019.

### 3.3.3 2019 Study Design

Three rows containing three 1m x 1m plots were laid out within the 15m x 15m site. Each plot was separated by 3m on all sides from adjacent plots and the site margins (Fig. 6). Each plot was planted with nine *T. vulgaris* in a three by three planting design on 5 May 2019 (Fig. 7), for a total of 81 plants over the entire site. The remaining nine plants were planted along the west border of the site as back-up material in case plot plants were lost.

A drip irrigation system was installed on 12 May 2019 consisting of 1-gph partial pressure compensating in-line drip emitters on ¼" black polyethylene tubing inserted into ½" black polyethylene irrigation tubing. The irrigation was divided into two systems to ensure even water pressure – five plots on one, four plots and the back-up plant row on the other – with each system controlled by a battery-powered timer. Irrigation times were adjusted over the data collection period depending on plant maturity and temperature, ranging from 5 minutes every 48 hours at the beginning of the study up to 5 minutes every 12 hours during the warmer days later in the collection period.



**Figure 6:** Plot and treatment layout for the 2019 dual use study in the Home Garden location in San Luis Obispo, CA. P# = Plot number, FB = Full Bloom treatment, HB = Half Bloom treatment, NB = No Bloom treatment. The entire site was 15m x 15m, with three rows of three 1m x 1m plots, each containing nine *Thymus vulgaris* plants. Plots were separated from each other and the site margins by 3m. An additional row of nine back-up *T. vulgaris* plants were planted along the west site margin.



**Figure 7:** View of the entire 15m x 15m site in the Home Garden location in San Luis Obispo, CA (left) and an example of an individual 1m x 1m plot planted with nine *Thymus vulgaris* plants (right) from 12 May 2019. All plots were planted on 5 May 2019 and irrigation was added 12 May 2019.

#### 3.3.4 2019 Treatments

Focusing the 2019 study in one location allowed for a replicate design. Each plot was randomly assigned one of three treatments (see Fig. 6). In the Full Bloom (FB) treatment, plants were not harvested throughout the study period, simulating a standing floral resource. In the Half Bloom (HB) treatments, half the of the plant material in the plot was harvested prior to bloom and all new blooms on that half were removed over the study period, while the other half was allowed to bloom throughout the study period, simulating a dual use crop that provides both standing floral resource and harvestable material. In the No Bloom (NB), all of the plant material in the plot was harvested prior to bloom and all new blooms were removed over the study period, simulating a fully harvested crop.

Treatments were initiated on 5 June 2019 (Fig. 8). Hand-held pruning shears were used to cut back all plants in the NB plots to a height of approximately 10 cm, removing all blooms and flower buds. In the HB plots the



three eastern plants were cut back to 10cm, the three center row plants had half of the foliage cut back to 10cm and half left uncut, and the three western plants were left uncut. All FB plot plants were left uncut. Treatments were maintained over the course of the study by hand pinching all blooms off the NB and half of the HB plants approximately every other day, and always on the day before each collection period. Foliage was allowed to grow on all three treatments throughout the study.



**Figure 8:** Treatments in the Home Garden location in San Luis Obispo, CA were initiated on 5 June 2019. Left to right: Full Bloom, with no harvest of *T. vulgaris*; Half Bloom, with half of the *T. vulgaris* harvested to 10cm prior to bloom and the remaining plants no harvest; and No Bloom, with all *T. vulgaris* harvested to 10cm prior to bloom. Treatments were maintained by pinching of blossoms and foliage was allowed to grow on *T. vulgaris* in all plots over the study.

### **2019 Data Collection**

Data collection was performed in the field from 25 May 2019 through 20 August 2019 for a total of seven sampling dates (Table 1). Initially, samples were collected using two methods: yellow pan traps and vegetation cuttings. An

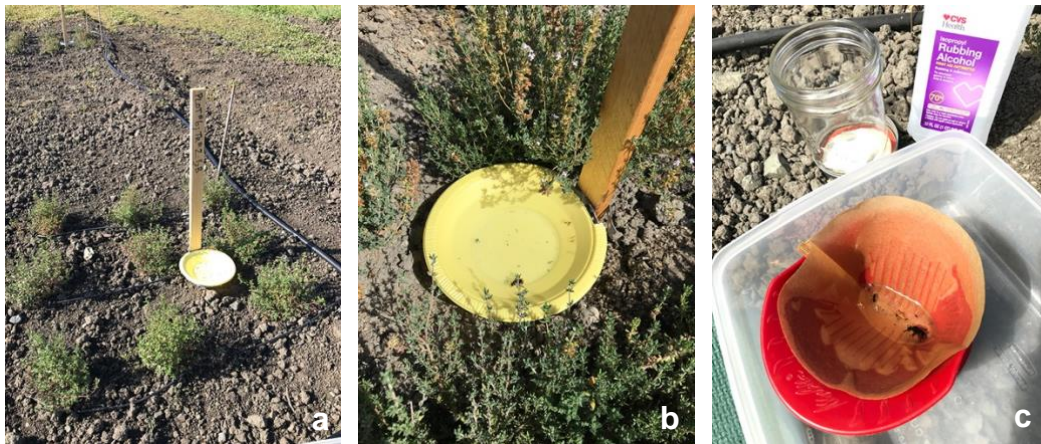
observation survey was added starting on 13 August to provide data on syrphid flies that were observed visiting the plots but not being collected by the pan traps. Ten observation surveys were conducted (Table 2).

The yellow pan trap design consisted of a two-foot wooden plot identification stake with a circular metal bracket attached at vegetation level to hold the pan (bowl). Two yellow 12oz. plastic bowls (DTSC Imports, imported by Greenbrier International Inc., Chesapeake, VA) set within each other were placed into the bracket, with the bottom bowl taped to the bracket to prevent the bowls from being disturbed by the wind. (Fig. 9a). Traps were located in the same location in all plots but were not in the center of the plot due to the three by three layout of the nine plants. Traps were filled with 200ml of water containing a few drops of unscented dishwashing detergent (Ecos Hypoallergenic Dishmate Dish Soap, Earth Friendly Products, Cypress, CA) to break the surface tension of the water (Fig. 9b). Traps were set out approximately every three weeks in early afternoon (14:30-15:00) and collected 48 hours later (see Table 1). Specimens were removed from the traps by lifting the top bowl and pouring the contents into a paper filter cone (Melitta Coffee Filters #2 Natural Brown, Melitta USA, Inc., Clearwater, FL) placed in a plastic coffee dripper set into a collection pan (Fig. 9c). To ensure all specimens were removed from the collection bowl the filtered water was poured back into the bowl and re-filtered through the same filter cone. Once the water had completely drained the filter cone was rinsed with 70% alcohol to remove any remaining soap and to flush the specimens to the bottom of the filter. The filter cone was removed from the dripper, carefully trimmed to

remove the top half while retaining the specimens in the bottom half, and then placed into lidded glass pint jars containing 70% alcohol for later sorting and identification.

**Table 1:** 2019 Yellow pan trap set dates, pan trap recovery dates, and vegetation sampling dates for *Thymus vulgaris* plots in the Home Garden location in San Luis Obispo, CA. Vegetation sampling was conducted after collecting pan traps to prevent the inadvertent collection of additional specimens.

Pan Trap Set Date	Pan Trap Recovery Date	Vegetation Sampling Date
5/25/19	5/27/19	5/27/19
6/8/19	6/10/19	6/10/19
6/28/19	6/30/19	6/30/19
7/19/19	7/21/19	7/21/19
8/11/19	8/13/19	8/13/19
8/30/19	9/1/19	9/1/19
9/20/19	9/22/19	9/22/19



**Figure 9:** Example of (a) yellow pan trap set at vegetation level within a *Thymus vulgaris* plot in the Home Garden location in San Luis Obispo, CA (b), close up view of a yellow pan trap filled with water, dish detergent, and specimens, and (c) sample processing method consisting of a plastic filter cone lined with a paper filter. Pan trap contents were poured through the filter cone and flushed with 70% alcohol, then the filter paper with specimens was transferred to a glass storage jar for further lab analysis.

Vegetation cuttings were taken on the same days pan traps were collected after each pan trap was processed to prevent inadvertently frightening additional specimens into the pan traps (see Table 1). Each plant in a plot was inspected for 30 seconds for aphids and syrphid eggs and/or larvae. If either were found in the time frame, the branch containing the specimen(s) was collected for further lab inspection. If neither was found in the time frame, a healthy branch with new vegetative growth was chosen at random and collected for further lab inspection. Nine cuttings (one per plant) were taken from each plot, for a total of 81 cuttings per collection period. Cuttings were stored in plastic zip lock bags in a refrigerator for 48 to 72 hours and then processed in the Cal Poly Entomology Laboratory.

Observation surveys were initiated on 13 August 2019 and were conducted in the field approximately every four to five days, starting at 14:30 (Table 2). A total of ten observation surveys were made. Surveys consisted of five-minute observations of each plot, recording all insects entering or utilizing a plot, with a focus on Syrphidae, Chrysomelidae, Apidae, Lepidoptera, and Diptera. Yellow pan traps were not present in the plots during observation surveys to prevent any influence.

**Table 2:** 2019 Observation survey dates on *Thymus vulgaris* plots in the Home Garden location in San Luis Obispo, CA. Observation surveys consisted of five minute surveys at each plot every four to five days for ten sessions.

Observation Survey Date
8/13/19
8/18/19
8/22/19
8/27/19
9/1/19
9/5/19
9/9/19
9/12/19
9/17/19
9/22/19

### 3.3.6 2019 Specimen Identification

A dissecting microscope was used to sort and count yellow pan trap specimens in the Cal Poly University Entomology Laboratory. Unknown specimens were photographed through the microscope then identified with the assistance of Cal Poly University Professor Dr. David Headrick and associates at [www.bugguide.net](http://www.bugguide.net). All insects collected were identified to Order and to Family if possible. They were also categorized into one of six feeding styles: parasitoid, predator, phytophagous/piercing, phytophagous/chewing, beneficial, and other (which included decomposer and those whose feeding style were unknown). All specimens were stored by Order in 70% alcohol.

Vegetation cuttings were examined using a dissecting microscope. All specimens found on the cuttings were recorded but only syrphid specimens were preserved in 70% alcohol.

No specimens were collected or identified beyond visual identification to Order (Diptera, Lepidoptera) or Family (Syrphidae, Apidae, Chrysomelidae) during the observation surveys.

### 3.4 Data Analysis

Data for both years were organized using Excel and transferred into JMP statistical software (SAS Institute, 2012) for tabulation and Minitab 19 (Minitab LLC, 2019) for statistical analysis.

Variables for 2018 included: Collection Location, Collection Date, Order, Family, and Feeding Style. Variables for 2019 included: Treatment, Collection Date, Order, Family, and Feeding Style. Family level analyses for both years were conducted using only the top agriculturally important Families collected each year; this included natural enemies, phytophagous insects, and pollinators commonly monitored in agricultural ecosystems or which have been subjects of previous biological control studies or pollination studies. Sixteen Families were selected in 2018 (those with  $\geq 100$  specimens, which included ten natural enemies, seven phytophagous insects, and one pollinator) and 13 Families in 2019 (those with  $\geq 20$  specimens, which included six natural enemies, six phytophagous insects, and one pollinator).

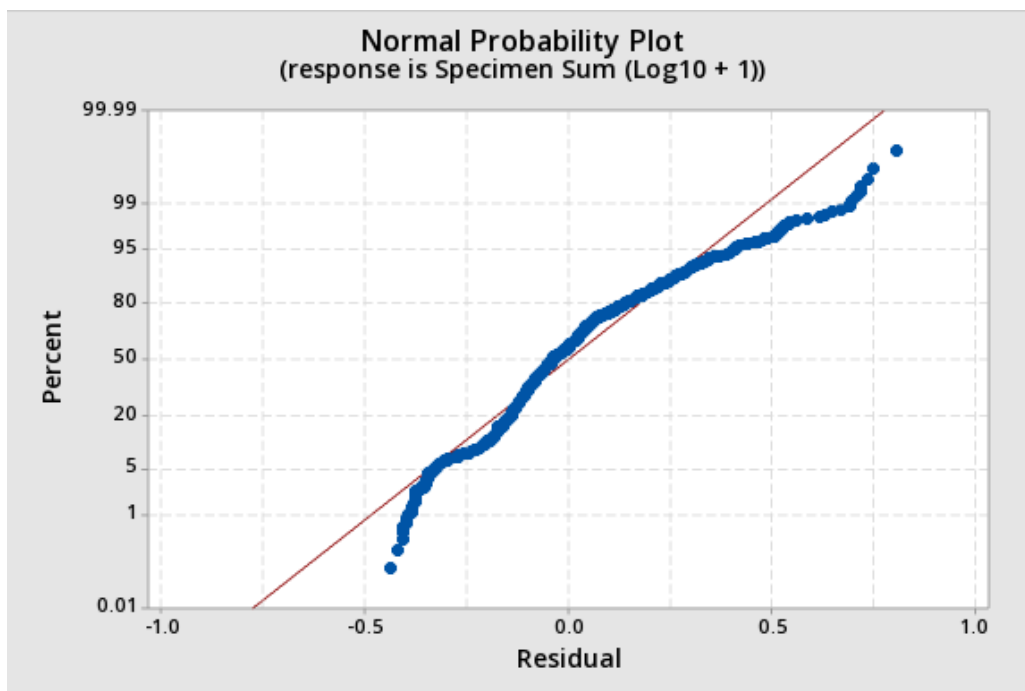
Data for 2018 were analyzed using total specimen sum comparisons at the level of Order, Family and Feeding Style in relation to Collection Location and Collection Date. Tabulated summary reports of descriptive statistics for 2018 were created in JMP and included total specimen sums (N) and the percentage

of total specimens (% Total) for each variable. Graphical representations for all analyses used total specimen sums.

Data for 2019 were analyzed at the level of Order, Family, and Feeding Style in relation to Treatment. Minitab 19 was used to conduct multi-factor ANOVA tests, followed by Tukey comparisons for any significant values. Due to the non-normal distribution of the raw specimen counts, data were transformed using  $\text{Log}_{10} + 1$  to improve normalcy, and probability plots were created for each analysis to check for normalcy (Fig. 10 for an example of a four factor ANOVA Normal Probability Plot). Tabulated summary reports of descriptive statistics for 2019 were created in JMP and included total specimen sums (N), means (Mean) and standard error (SE), and the percentage of total specimens (% Total) for each variable. Graphical representations for all analyses used mean and standard error values. Treatment, Order, and Feeding Style analyses were conducted using all specimen sum data in a four factor ANOVA test with variables Treatment, Collection Date, Order, Feeding Style against mean Specimen Sum( $\text{Log}_{10} + 1$ ). Family level analyses used only the specimen sum data for the 13 top agriculturally important Families, and separate analyses were conducted for the six phytophagous Families, six natural enemy Families, and the one pollinator Family. For the phytophagous and natural enemy Family comparisons, a three factor ANOVA test was conducted using the variables Treatment, Collection Date, and Family against mean Specimen Sum( $\text{Log}_{10} + 1$ ). For the pollinator Family, a two factor ANOVA test was conducted using the

variables Treatment and Collection Date against mean Specimen Sum( $\log_{10} + 1$ ).

In 2019, Shannon and Simpson diversity indices were used to compare the diversity of Orders, Families, and Feeding Styles among the three treatments and analyzed using ANOVA. Richness in Order and Family among treatments was also analyzed using ANOVA. Cutting data from 2019 was tabulated. Observational survey data from 2019 was analyzed using a Chi-square Test of Independence.



**Figure 10:** Example of a Normal Probability Plot produced in Minitab 19 for a four factor ANOVA test using 2019 data. Variables included Treatment, Collection Location, Order, Feeding Style, and the dependent variable was mean Specimen Sum ( $\log_{10} + 1$ ).



## 4 RESULTS

### 4.1 2018 Collection Location Analyses

A total of 32,236 specimens from 14 Orders (including the Subclass Collembola) and 97 sub-groups (including 10 listed by Order, unid. Family) were collected across the three locations in 2018 (Table 3) over 18 sample dates ( $n = 18$ ). The greatest number of specimens were collected in the MG plot ( $N = 12093$ , 37.52% total specimens), followed by LPA plot ( $N = 10987$ , 34.08% of total specimens), and the HG plot ( $N = 9156$ , 28.40% of total specimens) (Table 4, Fig. 11), suggesting the habitat surrounding may have influenced insects densities in the plots.

Differences among the three Collection Locations in relation to the variables Collection Date, Order, Family, and Feeding Style will be reviewed below.

**Table 3:** Family insect specimen sums at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden	Total
Order/Family	N	N	N	
<b>Araneae</b>	<b>652</b>	<b>434</b>	<b>349</b>	<b>1435</b>
Araneae, unid. Family	32	36	36	104
Clubionidae	25	23	41	89
Linyphiidae	426	27	92	545
Lycosidae	2	2	4	8
Oxyopidae	10	67	22	99
Philodromidae	1	32	2	35
Salticidae	6	7	5	18
Sciaridae	0	0	1	1
Tetragnathidae	5	1	1	7
Theridiidae	76	111	61	248
Thomisidae	69	128	84	281
<b>Coleoptera</b>	<b>598</b>	<b>685</b>	<b>312</b>	<b>1595</b>
Anthicidae	0	4	0	4
Brentidae	1	0	0	1
Chrysomelidae	138	14	16	168
Coccinellidae	75	184	65	324
Coleoptera, unid. Family	4	11	23	38
Corylophidae	15	38	10	63
Dermestidae	0	6	0	6
Elateridae	2	0	0	2
Latridiidae	3	9	0	12
Melyridae	14	7	1	22
Mordellidae	6	3	0	9
Scaptiidae	0	8	0	8
Staphylinidae	11	7	2	20
Tenebrionidae	319	394	194	907
Throscidae	10	0	1	11
<b>Collembola</b>	<b>2171</b>	<b>1920</b>	<b>2692</b>	<b>6783</b>
Collembola, unid. Family	6	3	33	42
Dicyrtomidae	8	21	11	40
Entomobryidae	2157	1896	2638	6691
Entomobryomorpha	0	0	9	9
Neanuridae	0	0	1	1
<b>Dermaptera</b>	<b>29</b>	<b>2</b>	<b>8</b>	<b>39</b>
Forficulidae	29	2	8	39
<b>Diptera</b>	<b>261</b>	<b>156</b>	<b>363</b>	<b>780</b>
Agromyzidae	0	0	2	2
Chamaemyiidae	2	0	0	2
Chloropidae	7	0	0	7
Diptera, unid. Family	32	21	29	82
Drosophilidae	0	0	1	1
Ephydriidae	6	4	10	20
Phoridae	1	0	0	1
Psychodidae	1	0	0	1
Sarcophagidae	0	0	2	2

**Table 3 cont.:** Family insect specimen sums at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

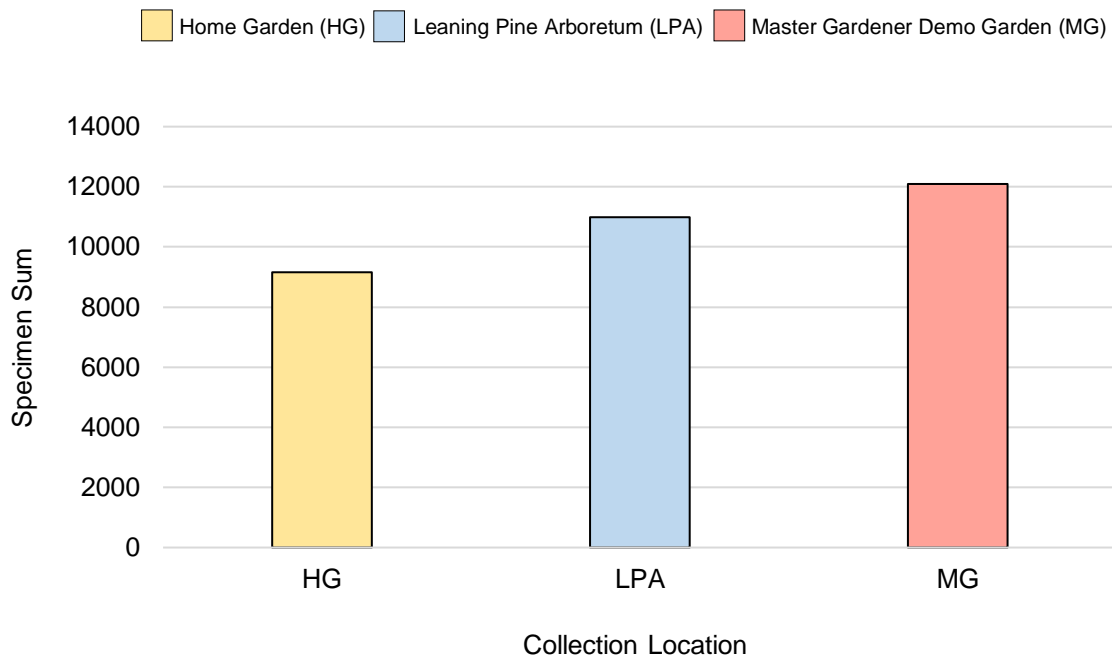
	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden	
Order/Family	N	N	N	Total
<b>Diptera cont.</b>				
Sciaridae	141	83	262	486
Simuliidae	9	4	1	14
Sphaeroceridae	31	1	3	35
Syrphidae	27	43	51	121
Tachinidae	4	0	1	5
Therevidae	0	0	1	1
<b>Hemiptera</b>	<b>2846</b>	<b>3477</b>	<b>5231</b>	<b>11554</b>
Aleyroididae	0	1	0	1
Anthocoridae	824	736	789	2349
Aphididae	1250	2462	3667	7379
Cicadellidae	139	88	109	336
Coreidae	1	0	0	1
Delphacidae	0	2	0	2
Geocoridae	112	63	64	239
Hemiptera, unid. Family	81	19	100	200
Kinnaridae	5	5	0	10
Largidae	2	0	0	2
Miridae	348	71	457	876
Nabidae	63	9	32	104
Pentatomidae	11	2	3	16
Piesmatidae	1	0	0	1
Pseudococcidae	0	3	0	3
Rhopalidae	9	4	9	22
<b>Hymenoptera</b>	<b>298</b>	<b>1003</b>	<b>720</b>	<b>2021</b>
Aphelinidae	18	14	16	48
Apidae	75	58	48	181
Bethylidae	2	1	0	3
Braconidae	38	30	37	105
Chalcidoidea	2	0	0	2
Cynipoidea	0	1	2	3
Diapriidae	1	0	0	1
Encyrtidae	6	49	4	59
Eulophidae	4	20	2	26
Eurytomidae	0	0	2	2
Figitidae	1	1	4	6
Formicidae	113	786	587	1486
Hymenoptera, unid. Family	2	1	1	4
Ichneumonidae	1	0	0	1
Megaspilidae	13	3	4	20
Mymaridae	2	11	3	16
Platygastridae	9	13	4	26
Proctotrupidae	4	9	2	15
Pteromalidae	5	3	3	11
Scelionidae	0	1	0	1
Trichogrammatidae	2	2	1	5

**Table 3 cont.:** Family insect specimen sums at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden	
Order/Family	N	N	N	Total
<b>Lepidoptera</b>	<b>33</b>	<b>13</b>	<b>20</b>	<b>66</b>
Crambidae	1	0	7	8
Hesperiidae	1	2	1	4
Lepidoptera, unid. Family	31	11	42	84
Tortricidae	0	0	3	3
<b>Mesostigmata</b>	<b>33</b>	<b>11</b>	<b>20</b>	<b>64</b>
Mesostigmata, unid. Family	33	11	20	64
<b>Neuroptera</b>	<b>10</b>	<b>5</b>	<b>16</b>	<b>31</b>
Chrysopidae	10	5	16	31
<b>Orthoptera</b>	<b>1</b>	<b>20</b>	<b>2</b>	<b>23</b>
Acrididae	0	19	1	20
Tettigoniidae	1	1	1	3
<b>Psocodea</b>	<b>4</b>	<b>5</b>	<b>3</b>	<b>12</b>
Psocodea, unid. Family	4	5	3	12
<b>Thysanoptera</b>	<b>2151</b>	<b>3202</b>	<b>2266</b>	<b>7619</b>
Aeolothripidae	167	121	74	362
Thripidae	1984	3081	2192	7257
<b>Trombidiformes</b>	<b>69</b>	<b>54</b>	<b>58</b>	<b>181</b>
Anystidae	25	13	19	57
Bdellidae	22	7	6	35
Trombidiformes, unid. Family	22	34	33	89

**Table 4:** Insect specimen sums and % of total specimens for three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

Collection Location	N	% Total
Home Garden	9156	28.40
Leaning Pine Arboretum	10987	34.08
Master Gardeners Demo Garden	12093	37.52



**Figure 11:** Insect specimen sums at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

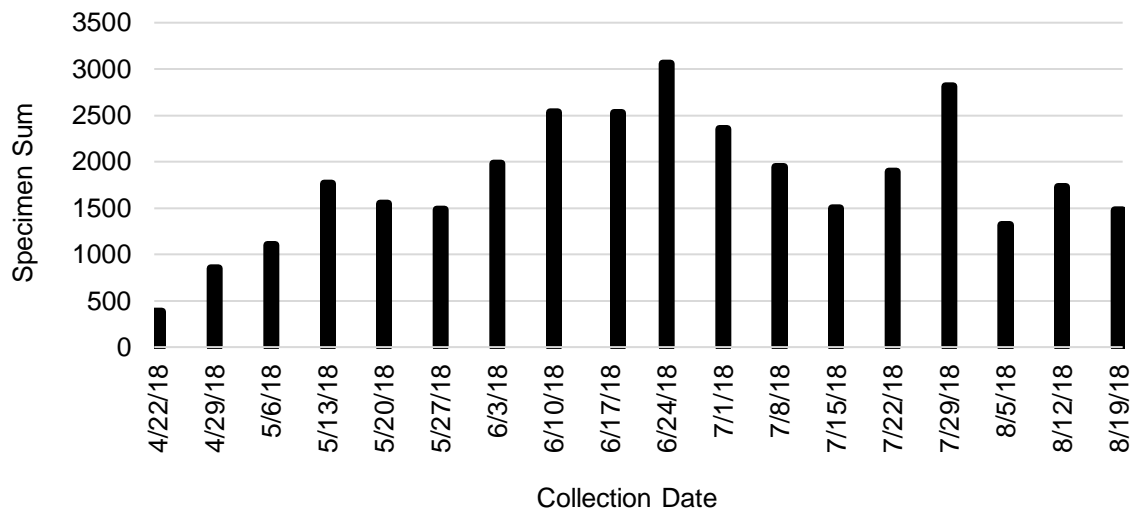
#### 4.2 2018 Collection Date Analyses

Over the 18 sampling dates ranging from 22 April to 18 August 2018, the greatest number of total specimens were collected on 6/24/18 (N = 3061, 9.50% of total specimens) which was the peak bloom date across all locations, followed by 7/29/18 (N = 2810, 8.72% of total specimens), and 6/10/18 (N = 2533, 7.86%

of total specimens), both of which corresponded with a spike in Thripidae counts (Table 5, Fig. 12). While specimen numbers peaked in both density and diversity in mid-summer, total Family diversity peaks did not match density peak dates. The greatest Family diversity was recorded on 7/8/18 (N = 57), followed by 6/24/18 (N = 56), and 7/1/18 (N = 54). Total arthropod populations varied over the study period with seasonal population fluctuations were taking place within each location (Table 6, Fig. 13). Density numbers over the sampling dates were mostly driven by Thripidae and Aphididae populations, while diversity numbers likely reflected a response of arthropods to the increasing availability of floral resources such as food, and alternative prey or hosts as plants matured and bloomed over the season.

**Table 5:** Insect specimen sums and % of total specimens by Collection Date at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

Collection Date	N	% of Total
4/22/18	382	1.19
4/29/18	849	2.63
5/6/18	1103	3.42
5/13/18	1761	5.46
5/20/18	1550	4.81
5/27/18	1485	4.61
6/3/18	1981	6.15
6/10/18	2533	7.86
6/18/18	2526	7.84
6/24/18	3061	9.50
7/1/18	2351	7.29
7/8/18	1942	6.02
7/15/18	1495	4.64
7/22/18	1892	5.87
7/29/18	2810	8.72
8/5/18	1318	4.09
8/12/18	1725	5.35
8/19/18	1472	4.57

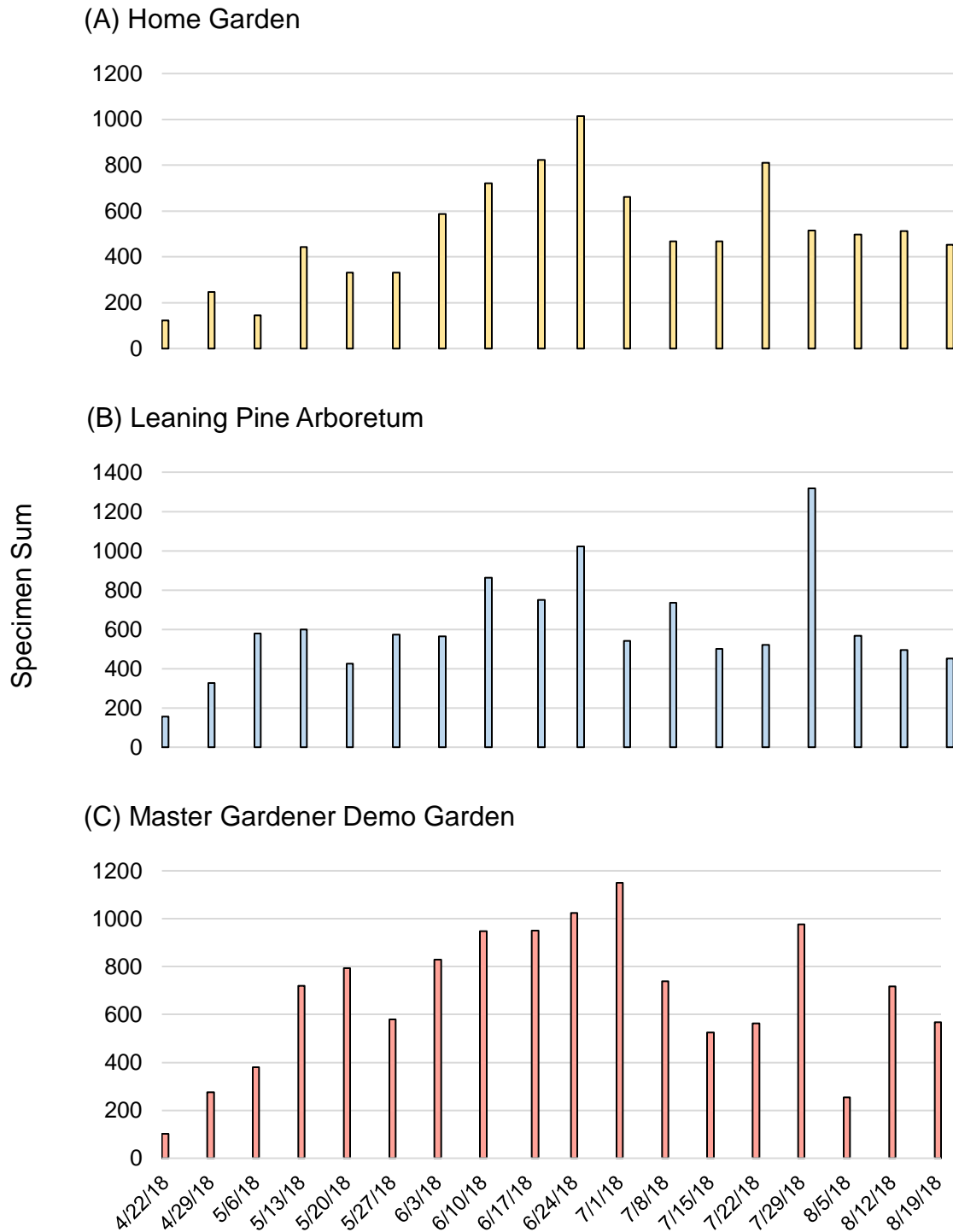


**Figure 12:** Insect specimen sums by Collection Date at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

**Table 6:** Insect specimen sums by Collection Date and Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	<b>Home Garden</b>	<b>Leaning Pine Arboretum</b>	<b>Master Gardeners Demo Garden</b>
<b>Collection Date</b>	<b>N</b>	<b>N</b>	<b>N</b>
4/22/18	122	157	103
4/29/18	247	327	275
5/6/18	144	579	380
5/13/18	443	599	719
5/20/18	332	425	793
5/27/18	332	574	579
6/3/18	588	565	828
6/10/18	721	864	948
6/18/18	824	751	951
6/24/18	1014	1022	1025
7/1/18	662	540	1149
7/8/18	469	734	739
7/15/18	469	500	526
7/22/18	810	520	562
7/29/18	515	1318	977
8/5/18	498	566	254
8/12/18	512	495	718
8/19/18	454	451	567





**Figure 13:** Insect specimen sums for Collection Date by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

### 4.3 2018 Order Level Analyses

Fourteen Orders were collected (including Subclass Collembola), with the greatest number of total specimens across all locations from Hemiptera (N = 11554, 35.84% of total specimens), followed by Thysanoptera (N = 7619, 23.64% of total specimens), and Collembola (N = 6783, 21.04% of total specimens) (Table 7). These three Orders/Subclasses were also attracted to *T. vulgaris* plots in greater numbers within all three locations, indicating they were common in each of the study habitats. Collembola specimens were collected in the greatest numbers in the MG plot (MG: N = 2692, HG: N = 2171, LPA: N = 1920). Collembola are common in soil and may have been overrepresented in the collections due to the substrate mix used; since Collembola are not considered an agricultural pest or natural enemy they were removed from further analyses and were not recorded in 2019. Hemiptera specimens were collected in the greatest numbers in the MG plot (MG: N = 5231, LPA: N = 3477, HG: N = 2846). This Order was represented by 15 Families, six of which had  $\geq 100$  specimens collected across all locations: phytophagous Aphididae, Cicadellidae, and Miridae, and the predatory Anthocoridae, Geocoridae, and Nabidae. Thysanoptera specimens were collected in the greatest numbers in the LPA plot (LPA: N = 3202, HG: N = 2151, MG: N = 2266). This Order was represented by only two Families, the phytophagous Thripidae and predatory Aeolothripidae.

Only four of the remaining Orders had  $\geq 100$  specimens recorded across all three locations (Table 8, Fig. 14). Predatory Araneae specimens were collected in the greatest numbers in the HG plot (HG: N = 652, LPA: N = 434,

MG: N = 349). This Order was represented by 10 Families, three of which had  $\geq$  100 specimens collected across all locations: Linyphiidae, Theridiidae, and Thomisidae. Coleoptera specimens were collected in the greatest numbers in the LPA plot (LPA: N = 685, HG: N = 598, MG: N = 312). This Order was represented by 14 Families, two of which had  $\geq$  100 specimens collected across all locations: phytophagous Chrysomelidae and predatory Coccinellidae. It also included high numbers of Tenebrionidae which were not included in Family level analyses because while they are common phytophagous insects they were not a pest of concern in this study. Diptera specimens were collected in the greatest numbers in the MG plot (MG: N = 363, HG: N = 261, LPA: N = 156). This Order was represented by 14 Families, one of which had  $\geq$  100 specimens collected across all locations: predatory Syrphidae. It also included high numbers of Sciaridae which were not included in Family level analyses because they are primarily soil dwelling insects that under most conditions are not considered agricultural pests. Hymenoptera specimens were collected in the greatest numbers in the LPA plot (LPA: N = 1003, MG: N = 720, HG: N = 298). This Order was represented by 20 Families, two of which had  $\geq$  100 specimens collected across all locations: parasitic Braconidae and beneficial Apidae. It also included high numbers of Formicidae which were not included in Family level analyses because they were not considered a phytophagous insect or a natural enemy in this study.

Seven Orders were all collected in numbers under 100 in each location and were therefore not included in further Family level analyses. Dermaptera was

collected in the greatest numbers in the HG plot (HG: N = 29, MG: N = 8, LPA: N = 2), Lepidoptera in the MG plot (MG: N = 53, HG: N = 33, LPA: N = 13), Mesostigmata in the HG plot (HG: N = 33, MG: N = 20, LPA: N = 11), Neuroptera in the MG plot (MG: N = 16, HG: N = 10, LPA: N = 5), Orthoptera in the LPA plot (LPA: N = 20, MG: N = 2, HG: N = 1), Psocodea in the LPA plot (LPA: N = 5, HG: N = 4, MG: N = 3), and Trombidiformes in the HG plot (HG: N = 69, MG: N = 58, LPA: N = 54).

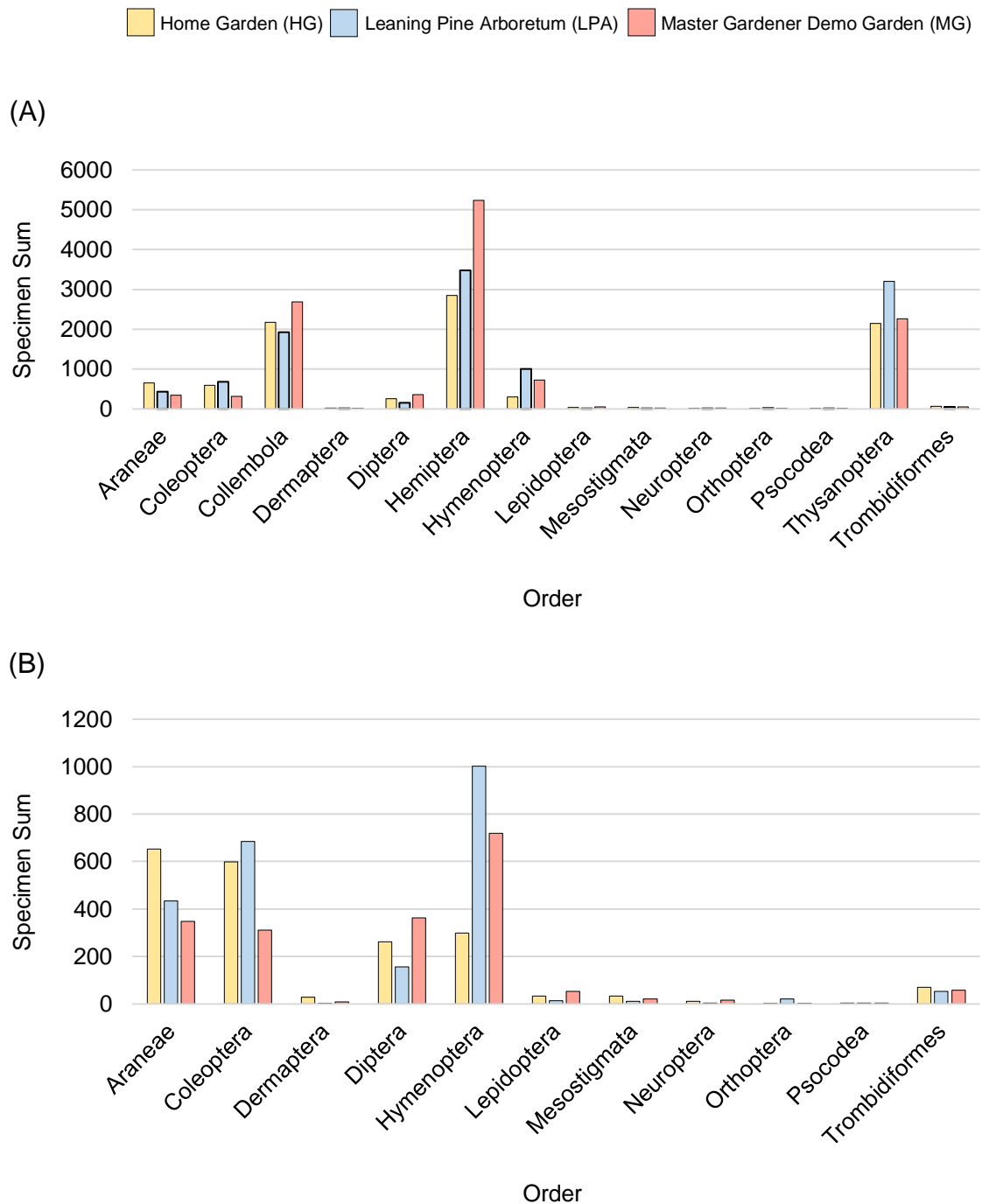
Differences among the three locations for each Order may be due to an influence of the surrounding habitat on the attractiveness of the plot and will be discussed in the Family level analyses.

**Table 7:** Insect specimen sums and % of total specimens by Order at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

Order	N	% of Total
Araneae	1435	4.45
Coleoptera	1595	4.95
Collembola	6783	21.04
Dermaptera	39	0.12
Diptera	780	2.42
Hemiptera	11554	35.84
Hymenoptera	2021	6.27
Lepidoptera	99	0.31
Mesostigmata	64	0.20
Neuroptera	31	0.10
Orthoptera	23	0.07
Psocodea	12	0.04
Thysanoptera	7619	23.64
Trombidiformes	181	0.56

**Table 8:** Insect specimen sums by Order and Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden
Order	N	N	N
Araneae	652	434	349
Coleoptera	598	685	312
Collembola	2171	1920	2692
Dermaptera	29	2	8
Diptera	261	156	363
Hemiptera	2846	3477	5231
Hymenoptera	298	1003	720
Lepidoptera	33	13	53
Mesostigmata	33	11	20
Neuroptera	10	5	16
Orthoptera	1	20	2
Psocodea	4	5	3
Thysanoptera	2151	3202	2266
Trombidiformes	69	54	58



**Figure 14:** Insect specimen sums for Order by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n = 18). (A) all Orders and (B) Orders without Collembola, Hemiptera, and Thysanoptera.

## 4.4 2018 Family Level Analyses

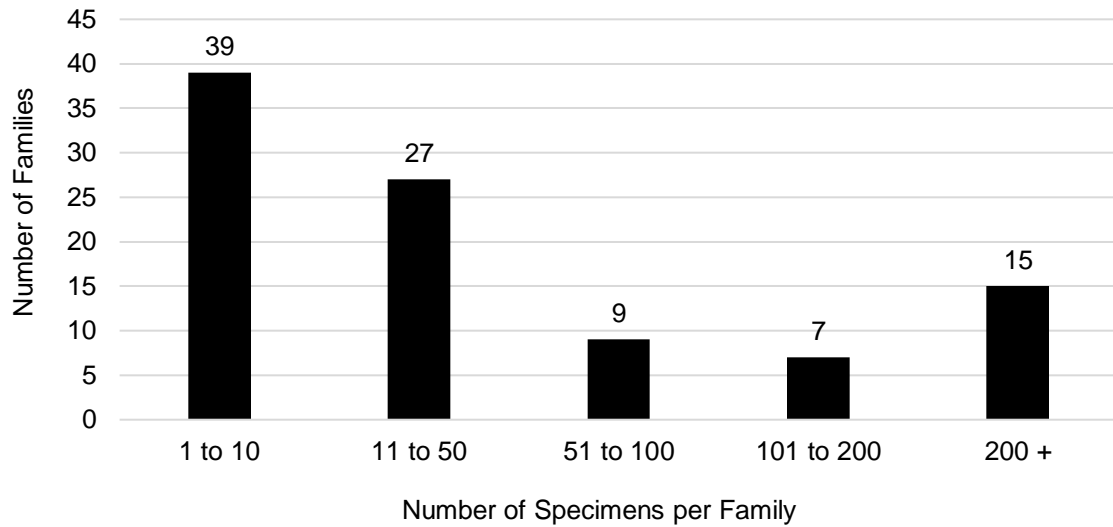
### 4.4.1 2018 Overall Family Categorized by Specimen Sums

Ninety-seven Families were collected (including 10 listed by Order, unid. Family) with more than half (68%) having 50 or fewer specimens per Family collected across all three locations (Fig. 15). Families represented by fewer than 10 specimens were likely transitory; for example one Brentidae weevil in the HG plot and two Delphacidae planthoppers in the LPA plot. Families in the 11 to 50 group may have been collected in smaller numbers due to lower site densities or sampling techniques; for example, ground dwelling Families such as Staphylinidae and Forficulidae were less common in the potted plants and fast flying micro-hymenopterans such as Mymaridae and Platygasteridae were difficult to capture with the aspirator. Only 22 Families had 101 or more specimens across all three locations (Table 9) and included the phytophagous Aphididae, Cicadellidae, Miridae, and Thripidae; parasitic Braconidae; specialist predators Aeolothripidae, Anthocoridae, Coccinellidae, and Syrphidae; and general predators Geocoridae, Nabidae, and multiple Families in Araneae. The presence of both phytophagous and natural enemy Families in the plots suggests *T. vulgaris* was attractive as a resource for floral food or alternative prey.

When grouped by Collection Location, the greatest Family diversity was found in the HG plot (N = 80), followed by the MG (N = 75) and LPA (N = 54) plots. The high diversity of Families in the HG plot indicates the surrounding habitat provided a greater diversity of specimens to be attracted to the plot than in the LPA and MG sites. The majority of Families in each location had only 1 to

10 specimens collected: HG = 43 Families, LPA = 35, and MG = 41 (Fig. 16), suggesting more than half of the Families in each location could be considered transitory. Ten Families had 101 to 200 specimens collected in each location: HG = 6 Families, LPA = 4, and MG = 2, with no Family being found across all three locations (Table 10). This group included the phytophagous Chrysomelidae and Cicadellidae, and predatory Aeolothripidae, Geocoridae, Coccinellidae, plus Theridiidae and Thomisidae, two spider Families. Family diversity for the 200+ specimens group was similar across all three locations: HG = 7 Families, LPA = 6, and MG = 7. This group included phytophagous Aphididae, Miridae and Thripidae, and predatory Anthocoridae and Linyphiidae. Three of these Families – Anthocoridae, Aphididae, and Thripidae – were found in all locations, confirming their presence in the sites and their attraction to *T. vulgaris* regardless of habitat.

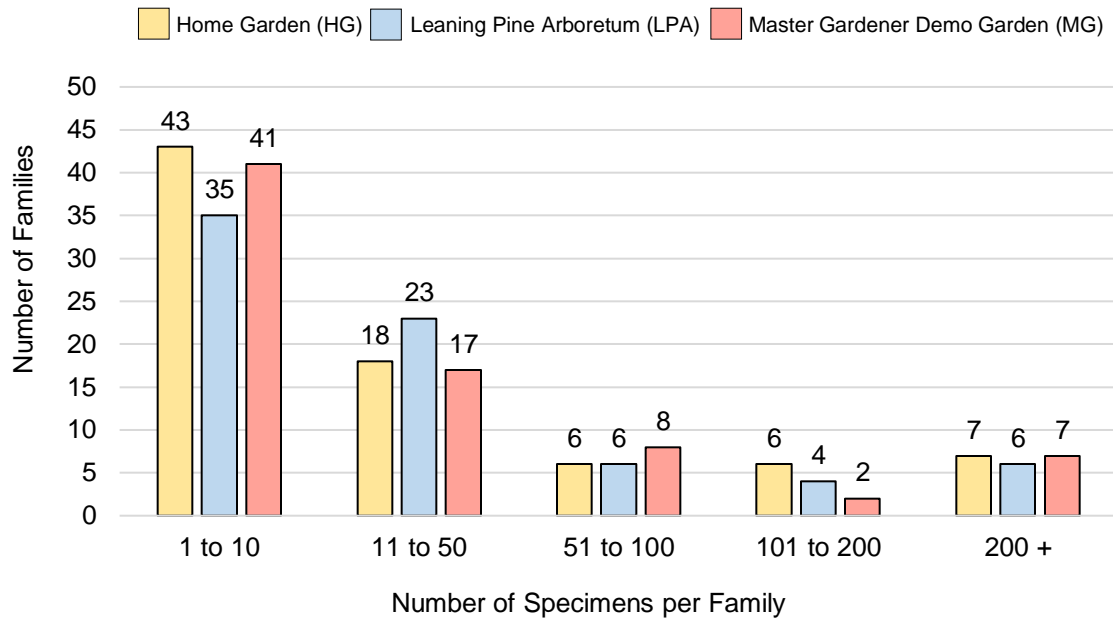




**Figure 15:** Number of insect specimen Families categorized by specimen sums per Family collected at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

**Table 9:** Insect specimen sums and feeding styles for Families with 101 to 200 or 200+ specimens collected at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	Family	N	Feeding Style
<b>101 to 200</b>	Araneae, unidentified Family	104	predator
	Nabidae	104	predator
	Braconidae	105	parasitoid
	Syrphidae	121	predator
	Chrysomelidae	168	phytophagous/chewing
	Apidae	181	beneficial
	Hemiptera, unidentified Family	200	phytophagous/piercing
<b>201 +</b>	Geocoridae	239	predator
	Theridiidae	248	predator
	Thomisidae	281	predator
	Coccinellidae	324	predator
	Cicadellidae	336	phytophagous/piercing
	Aeolothripidae	362	predator
	Sciaridae	487	other
	Linyphiidae	545	predator
	Miridae	876	phytophagous/piercing
	Tenebrionidae	907	phytophagous/chewing
	Formicidae	1486	predator
	Anthocoridae	2349	predator
	Entomobryidae	6691	other
	Thripidae	7257	phytophagous/piercing
	Aphididae	7379	phytophagous/piercing



**Figure 16:** Insect specimen Families by Collection Location and specimen sums per Family collected at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

**Table 10:** Insect specimen sums and feeding styles for Families with 101 to 200 or 200+ specimens by Collection Location collected at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18). HG = Home Garden, LPA = Leaning Pine Arboretum, MG = Master Gardeners Demo Garden.

	Collection Location	Family	N	Feeding Style
<b>101 to 200</b>	HG	Aeolothripidae	167	predator
	HG	Chrysomelidae	138	phytophagous/chewing
	HG	Cicadellidae	139	phytophagous/piercing
	HG	Formicidae	113	predator
	HG	Geocoridae	112	predator
	HG	Sciaridae	141	other
	LPA	Aeolothripidae	121	predator
	LPA	Coccinellidae	184	predator
	LPA	Theridiidae	111	predator
	LPA	Thomisidae	128	predator
	MG	Cicadellidae	109	phytophagous/piercing
	MG	Tenebrionidae	194	phytophagous/chewing
<b>200 +</b>	HG	Anthocoridae	824	predator
	HG	Aphididae	1250	phytophagous/piercing
	HG	Entomobryidae	2157	other
	HG	Linyphiidae	426	predator
	HG	Miridae	348	phytophagous/piercing
	HG	Tenebrionidae	319	phytophagous/chewing
	HG	Thripidae	1984	phytophagous/piercing
	LPA	Anthocoridae	736	predator
	LPA	Aphididae	2462	phytophagous/piercing
	LPA	Entomobryidae	1896	other
	LPA	Formicidae	786	predator
	LPA	Tenebrionidae	394	phytophagous/chewing
	LPA	Thripidae	3081	phytophagous/piercing
	MG	Anthocoridae	789	predator
	MG	Aphididae	3667	phytophagous/piercing
	MG	Entomobryidae	2638	other
	MG	Formicidae	587	predator
	MG	Miridae	457	phytophagous/piercing
	MG	Sciaridae	263	other
	MG	Thripidae	2192	phytophagous/piercing

#### 4.4.2 2018 Top Agriculturally Important Families Analyses

Sixteen agriculturally important Families (natural enemies, phytophagous insects, and pollinators commonly monitored in agricultural ecosystems or which have been subjects of previous biological control studies or pollination studies) with  $\geq 100$  specimens collected across all locations during the 2018 study were selected for further analysis. This subgroup included five phytophagous Families, ten natural enemy Families, and one pollinator Family (Table 11). Miridae had specimens classified as both phytophagous/piercing and predator/phytophagous but were treated as phytophagous/piercing for this analysis as it is more commonly considered phytophagous.

Phytophagous Aphididae and Thripidae (Table 12, Fig. 17) were attracted to the *T. vulgaris* plots in greater numbers than all other Families in all three locations. The prevalence of Aphididae and Thripidae in all three locations corresponds with results from the Order level analysis and indicates they are common in each study habitat. Aphididae were collected in the greatest numbers in the MG plot (MG: N = 3667, LPA: N = 4262, HG: N = 1250), while Thripidae were collected in the greatest numbers in the LPA plot (LPA: N = 3081, MG: N = 2192, HG: N = 1984), suggesting the surrounding habitat was having a different effect on the populations of each Family in the plots.

Predatory Anthocoridae were found in greater numbers than all other natural enemy Families in all locations (HG: N = 824, LPA: N = 736, and MG: N = 789) (Table 13, Fig. 18). Anthocoridae populations, along with Aeolothripidae (HG: N = 167, LPA: N = 121, and MG: N = 74), are likely in response to the

availability of aphids and thrips for alternative prey, suggesting these foliage feeders were important factors in the predator/prey relationships that developed.

Surrounding habitat had a stronger influence on the attraction of certain Families over others. The HG plot was attractive to agricultural phytophagous insects and natural enemies. Numbers of phytophagous Chrysomelidae were greatest in the HG plot (HG: N = 138, MG: N = 16, LPA: N = 14), as were numbers of the general predator Nabidae (HG: N = 63, MG: N = 32, LPA: N = 9), which may be a result of existing populations from previous crops in the area. Linyphiidae was collected in the greatest numbers in the HG plot (HG: N = 426, MG: N = 92, LPA: N = 27) and were likely attracted to *T. vulgaris* plants for the availability of prey and perhaps the shelter of the vegetation. Other natural enemy Families found in the greatest numbers in the HG plot include aphid and thrips predators Aeolothripidae (HG: N = 167, LPA: N = 121, MG: N = 74) and Anthocoridae (HG: N = 824, LPA: N = 736, and MG: N = 789), the aphid parasitoid Braconidae (HG: N = 38, MG: N = 37), and the general predator Geocoridae (HG: N = 112, MG: N = 64, LPA: N = 63). The HG plot also had the greatest counts of phytophagous Cicadellidae (HG: N = 139, MG: N = 109, LPA: N = 88) and the pollinator Apidae (HG: N = 75, LPA: N = 58, MG: N = 48).

The LPA plot attracted the greatest numbers of aphidophagous Coccinellidae (LPA: N = 184, HG: N = 75, MG: N = 65). Many of the coccinellids collected in the LPA plot were small predatory native species that were not as common in the HG and MG plots. The LPA plot also had the greatest numbers of

Theridiidae (LPA: N = 111, HG: N = 76, HG: N = 61) and Thomisidae (LPA: N = 128, MG: N = 84, LPA: N = 69) spiders that were in search of prey.

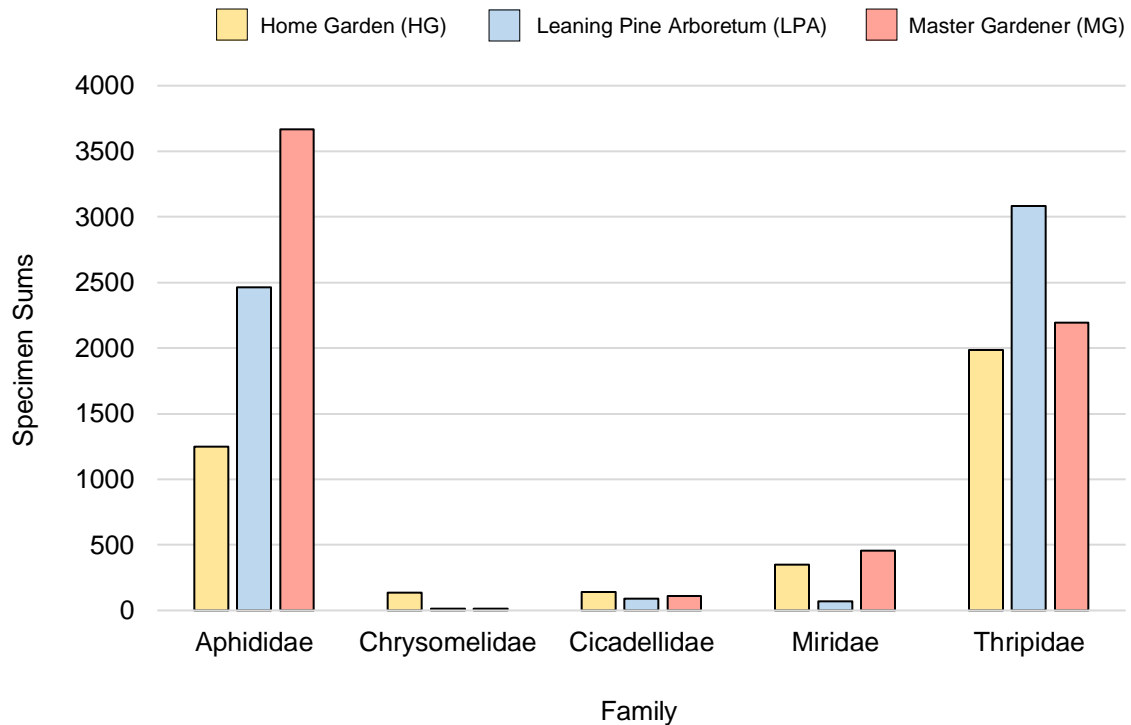
The MG plot was most attractive to phytophagous Miridae (MG: N = 457, HG: N = 348, LPA: N = 71) and the aphidophagous Syrphidae (MG: N = 51, LPA: N = 43, HG: N = 27), both of which may have benefited from the diversity and density of the vegetation available surrounding the plot.

**Table 11:** Insect specimen sums, % of total specimens, and Feeding Style of top agriculturally important Families collected at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).\* = top Families in both 2018 and 2019.

Family	Sum	% of Total	Feeding Style
Apidae*	181	0.75	pollinator
Aeolothripidae*	362	1.50	predator
Anthocoridae	2349	9.76	predator
Coccinellidae	324	1.35	predator
Geocoridae	239	0.99	predator
Linyphiidae	545	2.27	predator
Nabidae	104	0.43	predator
Syrphidae	121	0.50	predator
Theridiidae	248	1.03	predator
Thomisidae	281	1.17	predator
Braconidae	105	0.44	parasitoid
Chrysomelidae*	168	0.70	phytophagous/chewing
Aphididae*	7379	30.67	phytophagous/piercing
Cicadellidae*	336	1.40	phytophagous/piercing
Thripidae*	7257	30.16	phytophagous/piercing
Miridae	876	3.64	phytophagous/piercing & predator/phytophagous

**Table 12:** Insect specimen sums for the top phytophagous Families by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden
Family	N	N	N
Aphididae	1250	2462	3667
Chrysomelidae	138	14	16
Cicadellidae	139	88	109
Miridae	348	71	457
Thripidae	1984	3081	2192

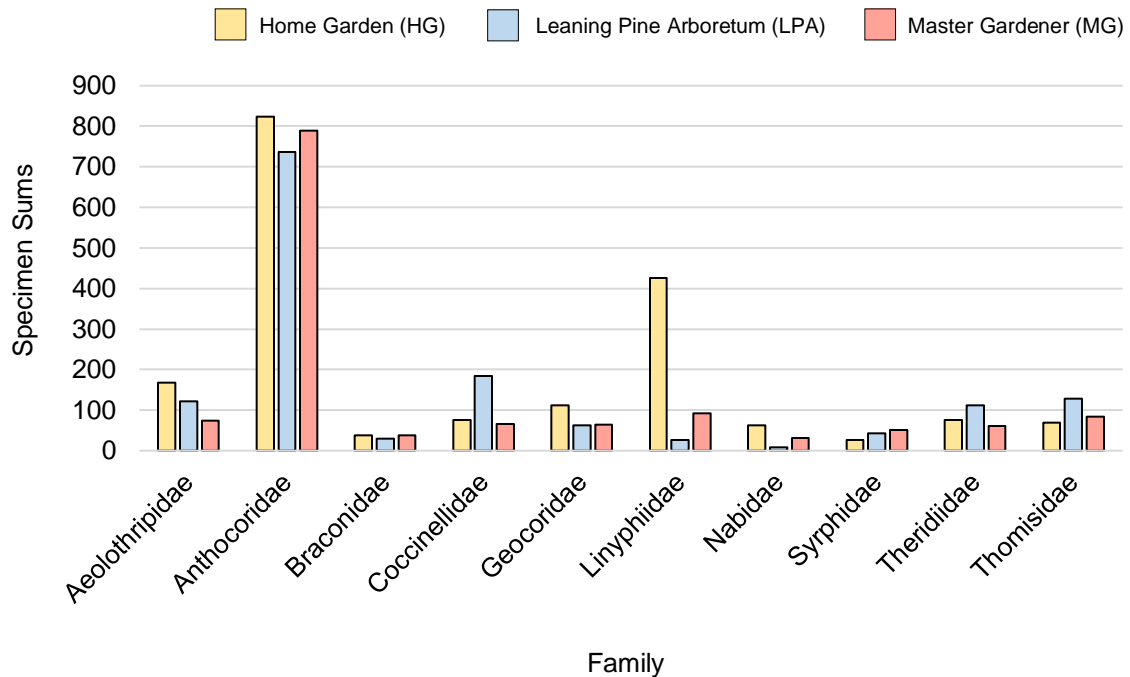


**Figure 17:** Insect specimen sums for top phytophagous Families by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).



**Table 13:** Insect specimen sums of the top natural enemy Families by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden
Family	N	N	N
Aeolothripidae	167	121	74
Anthocoridae	824	736	789
Braconidae	38	30	37
Coccinellidae	75	184	65
Geocoridae	112	63	64
Linyphiidae	426	27	92
Nabidae	63	9	32
Syrphidae	27	43	51
Theridiidae	76	111	61
Thomisidae	69	128	84



**Figure 18:** Insect specimen sums for top natural enemy Families by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

#### 4.4.3 2018 Top Agriculturally Important Families Collection Date Analyses

Peak bloom for all locations was recorded on 6/24/18, corresponding with a peak in total specimen density (N = 3061) and the second highest date for total Family diversity (N = 56, the greatest diversity was 7/8/18, N = 57). Specimen data for the top agriculturally important Families in 2018 were analyzed to determine if there were any differences in seasonal occurrence or abundance (Table 14). In contrast to total specimen density, total counts for only the top Families across all locations peaked earlier in June on 6/10/18 (N = 2058), driven by high number of Thripidae and Aphididae. All top Families were recorded from 6/3/18 through 7/8/18, reflecting their numerical dominance in the collections over a third of the study period. The last collection count for the top Families in late August (N = 463), was less than half of the peak numbers of 6/10/18. This was primarily due to a drop in Aphididae and Thripidae numbers; final collections still contained relatively high numbers of predatory Anthocoridae, Nabidae, Linyphiidae, and Theridiidae.

Total specimen density (combined counts for all locations) from the first weeks of the study (4/22/18 through 5/6/18) indicate collection numbers were driven primarily by Aphididae and Thripidae which were likely attracted to the *T. vulgaris* foliage. A comparison of total specimen sums and individual location counts for each Family indicates location also influenced specimen numbers over the collection season. Aphididae totals and LPA counts peaked on 6/3/18, but the HG plot peaked in early June (5/6/18) and the MG plot did not peak until early July (7/1/18). These differences could be influenced by the quality of the *T.*

*vulgaris* plots or by the surrounding vegetation supporting populations that spilled over to the *T. vulgaris* plots. Total thrips numbers also peaked on 6/3/18, but all three locations had different peak dates – HG on 6/24/18, MG on 6/10/18, and the LPA plot had two thrips peaks, 6/24/18 and 7/29/18 – again indicating conditions in the different habitats may have influenced the suitability of the plots for thrips. As the season progressed and the plants in the plots increased in size and bloom density, specimen density and diversity also increased. Cicadellidae became more common beginning in early June, with total numbers peaking on 6/3/18, while location peaks were more dispersed (HG on 6/3/18, LPA on 6/18/18, MG on 6/24/18). The Cicadellidae peak corresponded with the Aphididae peak, indicating the same factors may have influenced their numbers. Total Miridae as well as HG and MG counts peaked on 7/8/18, with LPA peaking on 7/22/18. Miridae were consistently collected in greater numbers in both the HG and MG plots, and earlier peaks may have been due to the surrounding vegetation providing better resources for faster development. While analysis did not find significant differences among dates for Chrysomelidae, both total and all location counts peaked on 7/8/18. Their populations may have been influenced by the availability of floral food in the surrounding vegetation in relation to the bloom status in the plots.

Populations of the top natural enemy Families generally peaked much later in the study, indicating they were responding to either prey populations or the increasing availability of food in the developing *T. vulgaris* flowers. As with phytophagous Families, differences between total specimen peak dates and

individual location peak dates indicated that surrounding habitat may have also influenced their population numbers. The predatory Aeolothripidae numbers peaked early in the study, with total and all location counts peaking on 6/10/18, which was the same date for the phytophagous thrips peak numbers. Aeolothrips were likely responding to thrips population numbers; while they are known also to feed on flowers, their populations began to decrease before peak bloom on 6/24/18. Anthocoridae totals peaked on 7/8/18 (HG on 6/24/18, LPA on 7/8/18, and MG on 6/24/18), and their populations were likely responding to thrips and aphid densities which had begun to decline in early June. Total numbers for Geocoridae peaked 7/22/18 (HG on 7/15/18, LPA on 7/29/18, and MG on 7/22/18), and Nabidae peaked on 8/12/18 (HG on 8/12/18, LPA on 7/22/18, and MG on 8/5/18). There is limited information on Geocoridae and Nabidae using floral foods; populations of these general predators may have been responding to prey densities as plot vegetation become denser. For the spider Families, Linyphiidae peaked on 7/1/18 (HG on 7/1/18, LPA on 6/18/18, and MG on 7/22/18), Theridiidae on 8/12/18 (HG on 8/12/18, LPA on 7/8/18, and MG on 7/15/18), and Thomisidae on 7/8/18 (HG on 7/1/18, LPA and MG on 7/8/18). Spiders rarely ingest pollen or nectar directly, so it is more likely these Families were also responding to an increasing prey base as the plants attracted a greater density and diversity of arthropods for food. Braconids, coccinellids and syrphids are aphidophagous predators and will be discussed further, below, in relation to aphid predator/prey relationships.

An in-depth comparison of Thripidae and its primary natural enemy Families (Anthocoridae and Aeolothripidae) indicated a predator/prey relationship in the HG and MG plot (Fig. 19). All plots attracted Thripidae in April immediately following plot establishment and they were found greater numbers than other top Families for the first seven weeks of the study. Anthocoridae and Aeolothripidae began to appear in mid to late May. Aeolothripidae numbers peaked on 6/10/18 in both plots, which was the same peak date as total Thripidae numbers. Thripidae and Anthocoridae numbers in the HG and MG locations continued to increase, and their numbers began to decline in tandem after peak bloom on 6/24/18, remaining linked with each other through the end the study. There was not a strong relationship for either predator noted in the LPA plot even though Anthocoridae numbers were also high at the plot. The LPA plot was the warmest and driest of the three plots, and it is possible environmental conditions rather predator/prey interactions were driving thrips populations in the plot.

A closer look at Aphididae and its primary natural enemy Families (Anthocoridae, Braconidae, Coccinellidae, and Syrphidae) did not suggest a predator/prey relationship for any of the three plots (Fig. 20). While all plots attracted greater numbers of Aphididae in April, Anthocoridae numbers peaked after the decline of aphid populations in the HG and LPA plots and just before the final aphid peak in the MG plot, but MG aphid numbers then fell below Anthocoridae numbers, indicating a lack of interaction or a focus on the more abundant thrips. Braconidae were present from the first collection date in April and totals peaked on 5/20/18 (HG on 5/27/18, LPA on 5/13/18, and MG on

5/20/18). The presence of mummified aphids in all plots suggested they had a minor influence on populations, but aphid numbers stayed high while braconid numbers stayed constant, indicating a lack of pressure on aphid population growth. Braconid specimens continued to be collected sporadically through early July but disappeared from all plots after 7/8/18 even though aphid populations were still high, indicating braconids were experiencing a seasonal population fluctuation. Coccinellids appeared in April in the HG plot and in mid-May in the LPA and MG plots with a total peak on 7/8/18 (HG on 8/12/18, LPA on 7/8/18, and MG on 7/15/18), but remained low in all three plots throughout the study. There was a slight peak at the LPA plot in early July corresponding to an increase in native coccinellid larvae numbers, which may have been a lag response of adults attracted to high aphid numbers in early June, but aphid populations had already begun to decline so they had little regulating effect. Syrphidae were present at all three locations, arriving in early to late May and staying through early to late August depending on the plot, with total and all location counts for Syrphidae peaking on 7/1/18. Their numbers remained low at all plots throughout the collections and likely had little impact on aphid density.

The pollinator Family Apidae also showed fluctuations over the season. Total specimen density peaked on 7/1/18, with LPA counts peaking on 6/24/18, the same date as peak bloom, and MG peaking on 7/1/18, the week following peak bloom. The HG count peaked on the final collection date of 8/19/18; this delayed peak may be a result of a late bloom in the *T. vulgaris* plots attracting Apidae from the surrounding crop which had finished blooming.

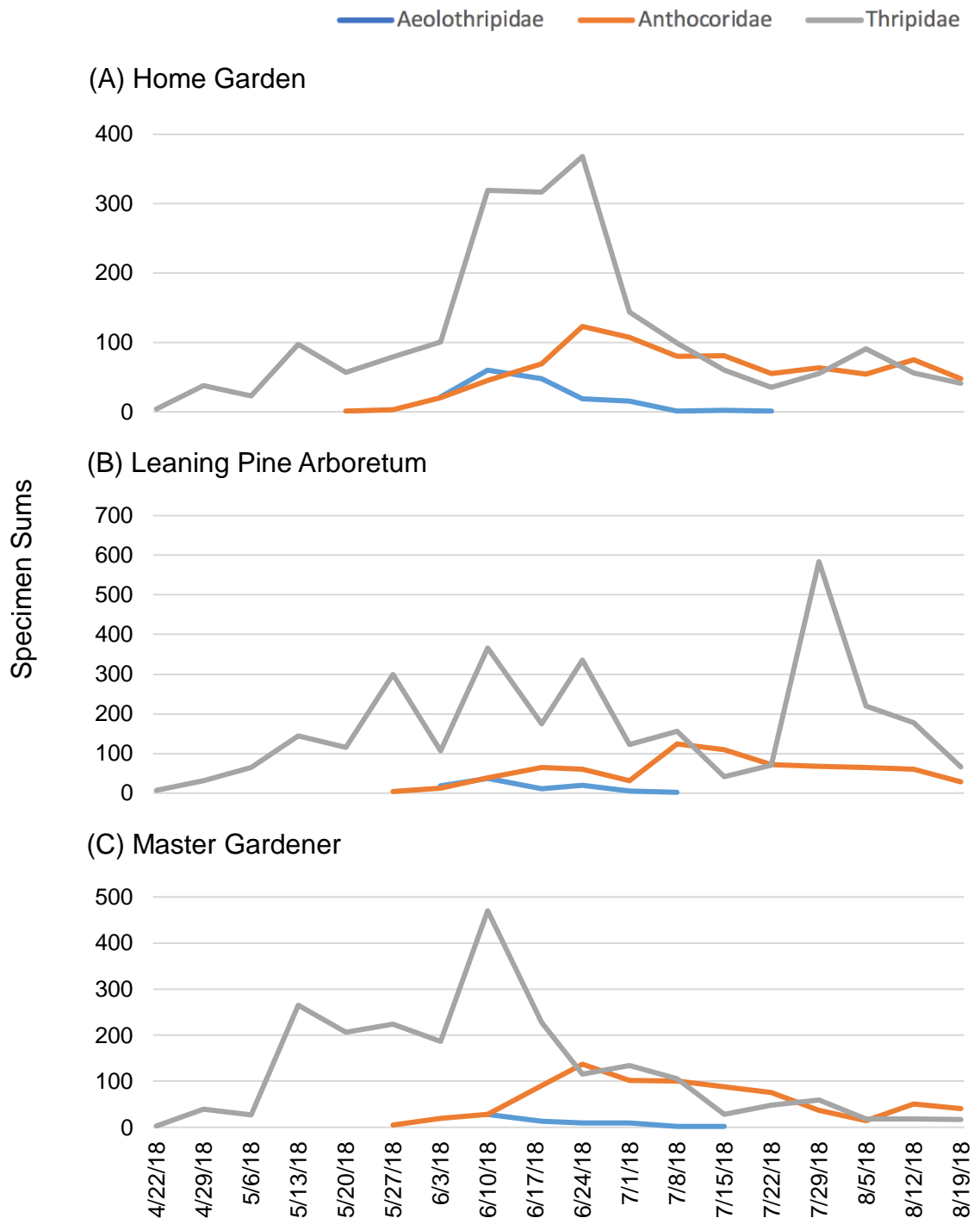
**Table 14:** Family insect specimen sums by Collection Location and Collection Date for the top agriculturally important Families collected at three San Luis Obispo, California locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 19 August 2018 (n =18). Bold numbers indicate peak collection numbers for each location, pink shading indicates peak combined counts across locations. CL = Collection Location, HG = Home Garden, LPA = Leaning Pine Arboretum, MG = Master Gardeners Demo Garden.

NATURAL ENEMY																			
FAMILY	CL	4/22	4/29	5/06	5/13	5/20	5/27	6/03	6/10	6/18	6/24	7/01	7/08	7/15	7/22	7/29	8/05	8/12	8/19
Aeolothripidae	HG	0	0	0	0	0	0	21	<b>60</b>	48	19	15	1	2	1	0	0	0	0
	LPA	0	0	0	28	0	0	18	<b>37</b>	11	20	5	2	0	0	0	0	0	0
	MG	0	0	0	10	0	0	0	<b>28</b>	13	10	9	2	2	0	0	0	0	0
Anthocoridae	HG	0	0	0	0	1	3	20	45	69	<b>123</b>	107	<b>80</b>	81	55	63	54	75	48
	LPA	0	0	0	1	0	4	12	39	64	60	31	<b>124</b>	110	72	67	64	60	28
	MG	0	0	0	1	0	5	19	28	90	<b>137</b>	102	<b>101</b>	88	75	37	15	50	41
Braconidae	HG	4	9	1	3	<b>8</b>	<b>8</b>	0	2	0	2	0	1	0	0	0	0	0	0
	LPA	2	3	6	<b>9</b>	<b>5</b>	3	0	0	1	0	1	0	0	0	0	0	0	0
	MG	1	7	5	2	<b>8</b>	2	3	3	5	1	0	0	0	0	0	0	0	0
Coccinellidae	HG	2	3	3	0	0	0	0	2	3	2	2	<b>8</b>	13	8	4	8	<b>13</b>	4
	LPA	0	0	0	4	1	0	2	17	11	26	24	<b>35</b>	17	3	17	11	9	7
	MG	0	0	0	1	2	1	3	2	8	10	7	<b>4</b>	<b>12</b>	5	7	0	2	1
Geocoridae	HG	0	0	0	0	0	0	2	1	2	11	7	19	<b>20</b>	<b>6</b>	7	13	17	7
	LPA	0	0	0	0	0	0	0	1	0	3	2	7	7	<b>8</b>	<b>12</b>	10	10	3
	MG	0	0	0	0	0	0	1	2	0	0	0	2	6	<b>34</b>	5	7	4	3
Linyphiidae	HG	0	3	4	6	1	2	21	17	45	54	<b>64</b>	33	34	12	46	31	22	31
	LPA	1	0	1	0	1	0	0	3	<b>8</b>	2	1	0	2	1	1	0	1	5
	MG	0	0	0	0	3	0	2	4	7	7	<b>4</b>	<b>4</b>	11	<b>40</b>	1	0	4	5
Nabidae	HG	0	0	0	0	0	0	1	2	0	3	0	6	8	3	6	9	<b>16</b>	9
	LPA	0	0	0	0	0	0	0	0	2	2	0	0	0	<b>2</b>	1	0	1	1
	MG	0	0	0	0	0	0	0	0	0	0	0	1	3	7	1	<b>8</b>	7	5
Syrphidae	HG	0	0	0	1	0	0	1	2	3	2	<b>9</b>	3	2	0	0	2	2	0
	LPA	0	0	2	0	4	0	3	4	8	1	<b>10</b>	2	0	5	3	1	0	0
	MG	0	0	0	0	0	5	2	1	6	6	<b>13</b>	8	6	0	0	2	1	1
Theridiidae	HG	0	0	0	0	0	0	0	2	6	0	2	6	12	10	11	3	<b>19</b>	5
	LPA	0	0	1	0	2	0	4	1	7	4	7	<b>20</b>	11	12	13	4	<b>16</b>	9
	MG	0	0	0	0	1	0	0	1	0	1	0	7	<b>15</b>	4	4	7	<b>8</b>	13

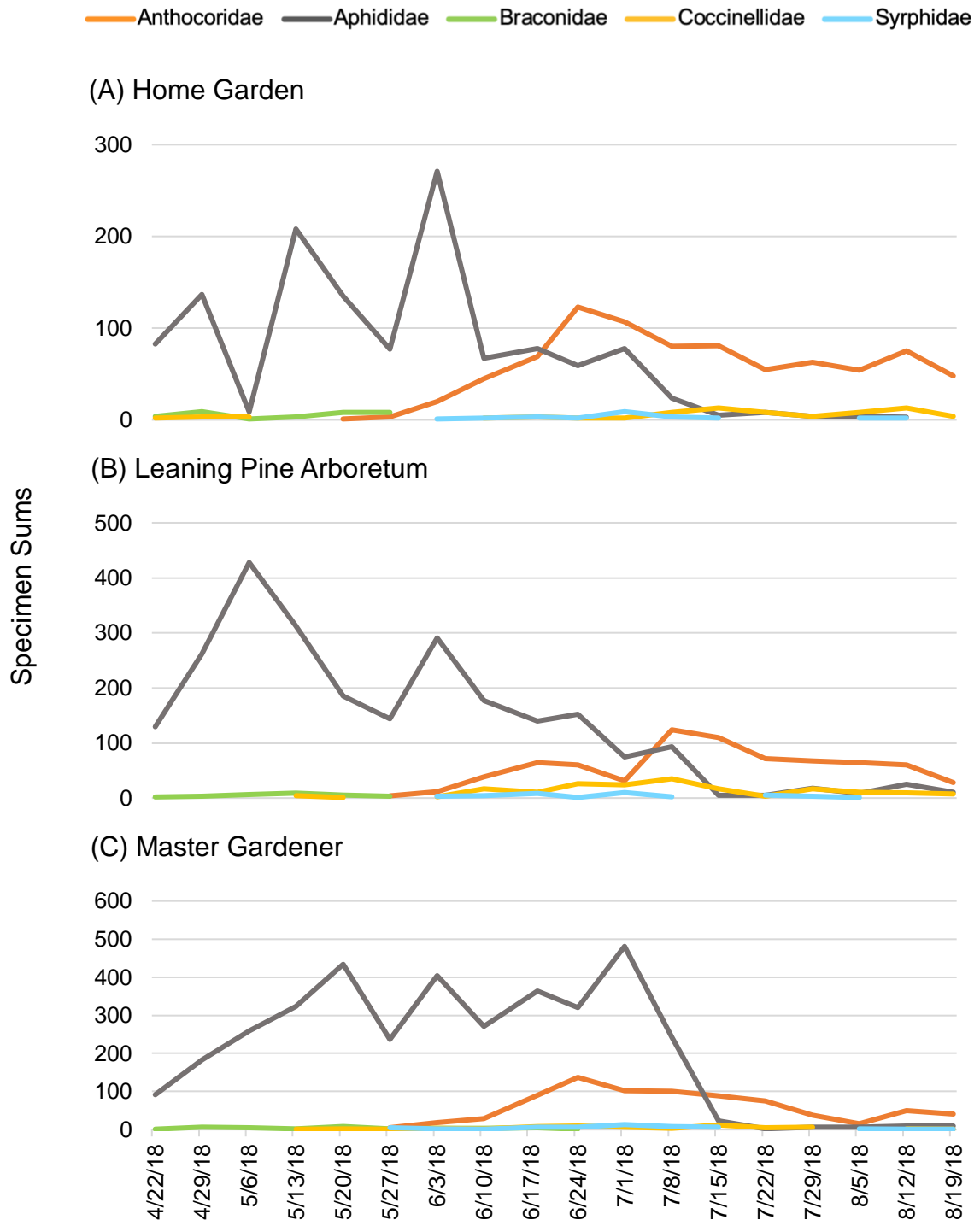
**Table 14 cont.:** Family insect specimen sums by Collection Location and Collection Date for the top agriculturally important Families collected at three San Luis Obispo, California locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 19 August 2018 (n =18). Bold numbers indicate peak collection numbers for each location, pink shading indicates peak combined counts across locations. CL = Collection Location, HG = Home Garden, LPA = Leaning Pine Arboretum, MG = Master Gardeners Demo Garden.

<b>NATURAL ENEMY cont.</b>																			
Thomisidae	HG	0	0	0	0	0	0	5	0	9	8	<b>12</b>	5	11	6	7	1	1	4
	LPA	0	0	1	0	1	0	19	9	9	13	5	<b>24</b>	19	4	6	7	10	1
	MG	0	0	0	0	1	2	8	3	9	3	8	<b>12</b>	9	6	1	5	3	14
<b>PHYTOPHAGOUS</b>																			
FAMILY	CL	4/22	4/29	5/06	5/13	5/20	5/27	6/03	6/10	6/18	6/24	7/01	7/08	7/15	7/22	7/29	8/05	8/12	8/19
Aphididae	HG	83	137	9	208	135	77	<b>271</b>	67	78	59	78	24	5	8	4	4	3	0
	LPA	130	262	<b>428</b>	313	185	144	291	177	140	152	75	93	5	5	18	8	25	11
	MG	92	183	259	323	434	236	404	271	363	320	<b>481</b>	243	22	2	7	7	10	10
Chrysomelidae	HG	1	0	0	2	6	9	6	10	7	13	15	<b>35</b>	12	5	3	4	6	4
	LPA	0	0	0	1	0	0	0	3	0	2	1	<b>3</b>	1	0	2	0	1	0
	MG	0	0	0	0	0	0	0	2	1	0	0	3	3	<b>4</b>	0	2	1	0
Cicadellidae	HG	1	1	3	9	8	10	<b>25</b>	6	8	6	7	12	5	5	4	5	10	14
	LPA	1	2	4	0	4	4	8	9	<b>22</b>	9	3	5	2	3	2	3	3	4
	MG	0	0	0	4	5	2	11	7	13	<b>13</b>	12	10	1	6	5	8	8	4
Miridae	HG	1	0	0	2	0	1	4	8	24	5	2	<b>73</b>	55	51	49	37	17	19
	LPA	0	0	0	1	0	1	0	0	1	2	1	3	11	<b>25</b>	8	4	7	7
	MG	0	0	4	5	5	3	20	15	14	8	51	<b>137</b>	82	69	27	3	7	7
Thripidae	HG	4	38	23	97	57	79	101	319	317	<b>368</b>	144	99	60	35	55	91	56	41
	LPA	7	31	64	145	115	299	106	366	175	336	123	156	41	70	<b>584</b>	219	178	66
	MG	3	39	27	265	206	224	187	<b>470</b>	228	116	134	105	28	48	59	18	18	17
<b>POLLINATOR</b>																			
FAMILY	CL	4/22	4/29	5/06	5/13	5/20	5/27	6/03	6/10	6/18	6/24	7/01	7/08	7/15	7/22	7/29	8/05	8/12	8/19
Apidae	HG	0	0	0	0	2	0	3	6	11	13	12	4	3	0	4	1	2	<b>14</b>
	LPA	0	0	1	0	3	3	2	4	10	<b>13</b>	12	1	0	0	0	6	3	0
	MG	0	1	1	1	0	5	11	2	1	8	<b>15</b>	1	0	0	0	1	1	0





**Figure 19:** Insect specimen sums by Family and Collection Date for Thripidae and its primary natural enemies Aeolothripidae and Anthocoridae collected at three San Luis Obispo, California locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 19 August 2018 (n =18). Peak bloom was on 6/24/18.



**Figure 20:** Insect specimen sums by Family and Collection Date for Aphididae and its primary natural enemies Anthocoridae, Braconidae, Coccinellidae, and Syrphidae collected at three San Luis Obispo, California locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 19 August 2018 (n =18). Peak bloom was on 6/24/18.

#### 4.5 2018 Feeding Styles Analyses

Of the seven feeding styles collected, 49.03% were phytophagous/piercing (N = 15804), 15.98% were predators (N = 5152), 4.16% were phytophagous/chewing (N = 1342), and 1.11% were parasitoids (N = 359) (Table 15). Two feeding styles, other and predator/phytophagous, were recorded but are not discussed in the results below; other represents specimens that were not phytophagous, natural enemies, or beneficials, and predator/phytophagous was represented by one species of Miridae that was treated in Family level analysis as phytophagous.

Greater numbers of phytophagous/piercing specimens were attracted across all three plots than the other feeding styles (N = 15804), which corresponds with high numbers of Thripidae, Aphididae, and Miridae (Fig. 21, Table 16). Predators were attracted in greater numbers (N = 5152) than parasitoids (N = 359) across all plots, reflecting the high numbers of specialist and generalist predatory Families attracted to the plots, although it is also possible this difference may be due to an underrepresentation of parasitoids in collections as a result of the sampling methods used.

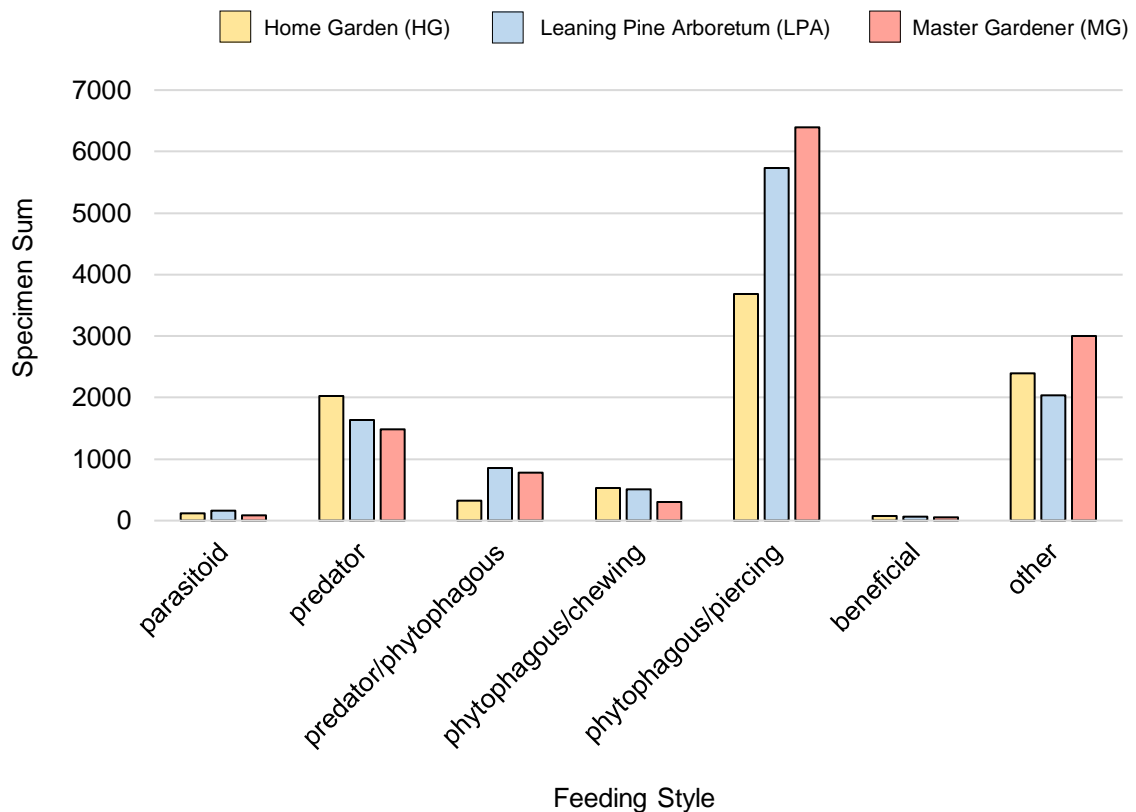
When comparing Feeding Styles among the three locations, The HG plot had the greatest number of predators (HG: N = 2030, LPA: N = 1634, MG: N = 1488), due to the high numbers of Aeolothripidae, Anthocoridae, and Linyphiidae collected in this plot. The HG plot also had the greatest number of phytophagous/chewing insects (HG: N = 530, LPA: N = 514, MG: N = 298), reflecting high Chrysomelidae numbers. The LPA plot had the greatest number of

parasitoids (LPA: N = 159, HG: N = 114, MG: N = 86), due to a high count of Encyrtidae (N = 49) found only in this plot. The MG plot had the greatest number of phytophagous/piercing (MG: N = 639, LPA: N = 5730, HG: N = 3684), reflecting high numbers of Aphididae and Thripidae in the plot. Beneficial specimens, primarily Apidae, were common in all sites but were collected in the greatest numbers in the HG plot (HG: N = 77, LPA: N = 60, MG: N = 49).

An in-depth analysis of the feeding styles of only natural enemy Families identified a combined total of 43 Families (and three classified only to Order) across all locations 2018 (Table 17), with predator numbers (N = 5152) being 14 times greater than parasitoid (N = 359) (Table 18). Predators were collected in greater numbers than parasitoids in all locations, suggesting natural enemy numbers were being driven by the availability of prey rather than hosts or that collection methods were biased towards predatory arthropods.

**Table 15:** Insect specimen sums and % of total specimens by Feeding Style at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

Feeding Style	N	% of Total
parasitoid	359	1.11
predator	5152	15.98
predator/phytophagous	1955	6.06
phytophagous/chewing	1342	4.16
phytophagous/piercing	15804	49.03
beneficial	186	0.58
other	7438	23.07



**Figure 21:** Insect specimen sums by Feeding Style and Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

**Table 16:** Insect specimen sums by Feeding Style and Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	<b>Home Garden</b>	<b>Leaning Pine Arboretum</b>	<b>Master Gardeners Demo Garden</b>
<b>Feeding Style</b>	<b>N</b>	<b>N</b>	<b>N</b>
parasitoid	114	159	86
predator	2030	1634	1488
predator/phytophagous	325	853	777
phytophagous/chewing	530	514	298
phytophagous/piercing	3684	5730	6390
beneficial	77	60	49
other	2396	2037	3005

**Table 17:** Natural enemy (parasitoid and predator) Families sums and totals by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18). Families in bold are in the top agriculturally important Families.

	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden	
<b>Parasitoid Families</b>	<b>N</b>	<b>N</b>	<b>N</b>	<b>Total</b>
Aphelinidae	18	14	16	48
Bethylidae	2	1	0	3
<b>Braconidae</b>	38	30	37	105
Chalcidoidea	2	0	0	2
Cynipoidea	0	1	2	3
Diapriidae	1	0	0	1
Encyrtidae	6	49	4	59
Eulophidae	4	20	2	26
Eurytomidae	0	0	2	2
Figitidae	1	1	4	6
Hymenoptera, unid. Family	2	1	1	4
Ichneumonidae	1	0	0	1
Megaspilidae	13	3	4	20
Mymaridae	2	11	3	16
Platygastridae	9	13	4	26
Proctotrupidae	4	9	2	15
Pteromalidae	5	3	3	11
Scelionidae	0	1	0	1
Tachinidae	4	0	1	5
Trichogrammatidae	2	2	1	5

**Table 17 cont.:** Natural enemy (parasitoid and predator) Families sums and totals by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18). Families in bold are those in the top agriculturally important Families.

	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden	
Predator Families	N	N	N	Total
<b>Aeolothripidae</b>	167	121	74	362
Anthicidae	0	1	0	1
<b>Anthocoridae</b>	824	736	789	2349
Anystidae	25	13	19	57
Araneae, unid. Family	32	36	36	104
Bdellidae	22	7	6	35
Chamaemyiidae	2	0	0	2
Chloropidae	7	0	0	7
Chrysopidae	10	5	16	31
Clubionidae	25	23	41	89
<b>Coccinellidae</b>	75	184	65	324
<b>Geocoridae</b>	112	63	64	239
<b>Linyphiidae</b>	426	27	92	545
Lycosidae	2	2	4	8
Mesostigmata, unid. Family	33	11	20	64
<b>Nabidae</b>	63	9	32	104
Oxyopidae	10	67	22	99
Philodromidae	1	32	2	35
Salticidae	6	7	5	18
Sciaridae	0	0	1	1
Staphylinidae	11	7	2	20
<b>Syrphidae</b>	27	43	51	121
Tetragnathidae	5	1	1	7
Therevidae	0	0	1	1
<b>Theridiidae</b>	76	111	61	248
<b>Thomisidae</b>	69	128	84	281



**Table 18:** Insect specimen sums for parasitoids and predators by Collection Location at three San Luis Obispo, CA locations in a repeated measures experiment on *Thymus vulgaris*. Collections were made by repeated pot tap and aspirator collections on a weekly basis from 22 April 2018 to 18 August 2018 (n =18).

	Home Garden	Leaning Pine Arboretum	Master Gardeners Demo Garden
Feeding Style	N	N	N
parasitoid	114	159	86
predator	2030	1634	1488

#### 4.6 2019 Treatment and Plot Analyses

A total of 3332 specimens from eight Orders (including the Subclass Acari) and 84 sub-groups (including 68 Families, 14 morphotypes, one Suborder, and one Superfamily) were collected in the pan traps across all treatments in 2019 (Table 19). The greatest number of specimens were collected in Half Bloom (HB) plots (N = 1202, 36.07%), followed by Full Bloom (FB) plots (N = 1138, 34.15%), and No Bloom (NB) plots (N = 992, 29.77%) (Table 20, Fig. 22).

A four factor ANOVA analysis (Treatment, Collection Date, Order, Feeding Style) using all 2019 specimen data found no significant difference in the mean number of specimens among treatments (Table 21), indicating harvest treatment was not having a significant influence on the density of specimens attracted to the plots.

**Table 19:** Family insect specimen sums by Treatment and Plot at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n =7). Treatments: FB = Full Bloom, HB = Half Bloom, NB = No Bloom. P# = plot number.

Order/Family	Full Bloom (FB)				Half Bloom (HB)				No Bloom (NB)				Total
	P1	P4	P5	FB Total	P3	P6	P9	HB Total	P2	P7	P8	NB Total	
<b>Acari</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>3</b>	<b>0</b>	<b>0</b>	<b>3</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>4</b>	<b>8</b>
Acari M1	0	0	0	0	0	0	0	0	0	1	1	2	2
Bdellidae	1	0	0	1	2	0	0	2	1	0	0	1	4
Prostigmata	0	0	0	0	1	0	0	1	0	0	0	0	1
Trombidiformes	0	0	0	0	0	0	0	0	0	0	1	1	1
<b>Araneae</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>12</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>6</b>	<b>3</b>	<b>3</b>	<b>3</b>	<b>9</b>	<b>27</b>
Araneae M1	0	1	0	1	1	0	0	1	0	0	0	0	2
Araneae M2	0	0	0	0	0	0	0	0	0	1	0	1	1
Clubionidae	0	0	0	0	0	0	0	0	0	1	0	1	1
Linyphiidae	2	2	3	7	2	0	1	3	1	1	1	3	13
Lycosidae	0	0	0	0	0	0	0	0	1	0	0	1	1
Salticidae	0	1	0	1	0	0	0	0	1	0	1	2	3
Theridiidae	2	0	0	2	0	2	0	2	0	0	1	1	5
Thomisidae	0	0	1	1	0	0	0	0	0	0	0	0	1
<b>Coleoptera</b>	<b>8</b>	<b>10</b>	<b>8</b>	<b>26</b>	<b>7</b>	<b>12</b>	<b>9</b>	<b>28</b>	<b>8</b>	<b>11</b>	<b>4</b>	<b>23</b>	<b>77</b>
Chrysomelidae	4	2	2	8	1	4	2	7	2	5	1	8	23
Coccinellidae	3	1	0	4	0	2	0	2	1	2	1	4	10
Coleoptera M1	0	0	0	0	0	0	0	0	0	1	0	1	1
Corylophidae	0	0	0	0	0	0	0	0	1	1	0	2	2
Cryptophagidae	0	0	0	0	1	1	1	3	0	1	0	1	4
Curculionidae	0	0	0	0	0	0	0	0	1	0	0	1	1
Melyridae	1	3	6	10	3	3	4	10	0	1	2	3	23
Scraptiidae	0	0	0	0	1	0	0	1	0	0	0	0	1
Staphylinidae	0	4	0	4	0	1	1	2	3	0	0	3	9
Throscidae	0	0	0	0	1	1	1	3	0	0	0	0	3
<b>Diptera</b>	<b>35</b>	<b>49</b>	<b>45</b>	<b>129</b>	<b>49</b>	<b>40</b>	<b>51</b>	<b>140</b>	<b>51</b>	<b>49</b>	<b>64</b>	<b>164</b>	<b>433</b>
Agromyzidae	7	2	6	15	2		7	9	4	3	3	10	34
Bombyliidae	0	0	0	0	1	0	0	1	0	0	0	0	1
Cecidomyiidae	2	2	1	5	1		3	4		2	4	6	15

**Table 19 cont.:** Family insect specimen sums by Treatment and Plot at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n =7). Treatments: FB = Full Bloom, HB = Half Bloom, NB = No Bloom. P# = plot number.

Order/Family	Full Bloom (FB)				Half Bloom (HB)				No Bloom (NB)				Grand Total
	P1	P4	P5	FB Total	P3	P6	P9	HB Total	P2	P7	P8	NB Total	
<b>Diptera cont.</b>													
Chloropidae	0	0	0	0	0	0	0	0	0	1	1	2	2
Conopidae	0	0	0	0	1	1	2	4	1	0	1	2	6
Diptera M1	0	0	0	0	1	0	0	1	0	0	0	0	1
Diptera M2	0	0	0	0	0	0	1	1	0	0	0	0	1
Dolichopodidae	1	2	2	5	1	1	0	2	2	2	3	7	14
Ephydroidea	0	0	0	0	1	1	0	2	0	0	1	1	3
Heleomyzidae	1	1	1	3	2	1	1	4	0	2		2	9
Hybotidae	0	1	1	2	2	1	0	3	0	3	1	4	9
Muscidae	16	22	17	55	29	19	26	74	28	28	36	92	221
Mycetophilidae	0	3	1	4	0	0	0	0	0	1	0	1	5
Phoridae	0	3	3	6	1	1	4	6	0	1	0	1	13
Psychodidae	0	1	0	1	0	0	0	0	2	0	0	2	3
Sciaridae	7	8	12	27	6	9	5	20	9	5	13	27	74
Syrphidae	0	0	0	0	0	0	0	0	1	0	0	1	1
Tachinidae	1	4	1	6	1	6	2	9	4	1	1	6	21
<b>Hemiptera</b>	<b>48</b>	<b>77</b>	<b>60</b>	<b>185</b>	<b>79</b>	<b>62</b>	<b>74</b>	<b>215</b>	<b>77</b>	<b>68</b>	<b>82</b>	<b>227</b>	<b>627</b>
Aleyroididae	1	10	4	15	2	4	2	8	8	3	3	14	37
Anthocoridae	0	1	1	2	4	1	2	7	1	0	3	4	13
Aphididae	32	48	43	123	54	37	51	142	48	52	63	163	428
Cicadellidae	12	13	9	34	13	19	15	47	14	12	9	35	116
Coreidae	0	0	0	0	1	0	0	1	0	0	0	0	1
Geocoridae	1	0	0	1	0	0	0	0	0	0	0	0	1
Kinnaridae	0	1	0	1	0	0	1	1	0	0	0	0	2
Miridae	0	2	0	2	1	0	0	1	1	1	0	2	5
Nabidae	1	0	0	1	0	0	1	1	1	0	0	1	3
Psyllidae	1	1	3	5	3	1	2	6	2	0	3	5	16
Reduviidae	0	0	0	0	0	0	0	0	1	0	0	1	1
Rhopalidae	0	1	0	1	1	0	0	1	1	0	1	2	4

**Table 19 cont.:** Family insect specimen sums by Treatment and Plot at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n =7). Treatments: FB = Full Bloom, HB = Half Bloom, NB = No Bloom. P# = plot number.

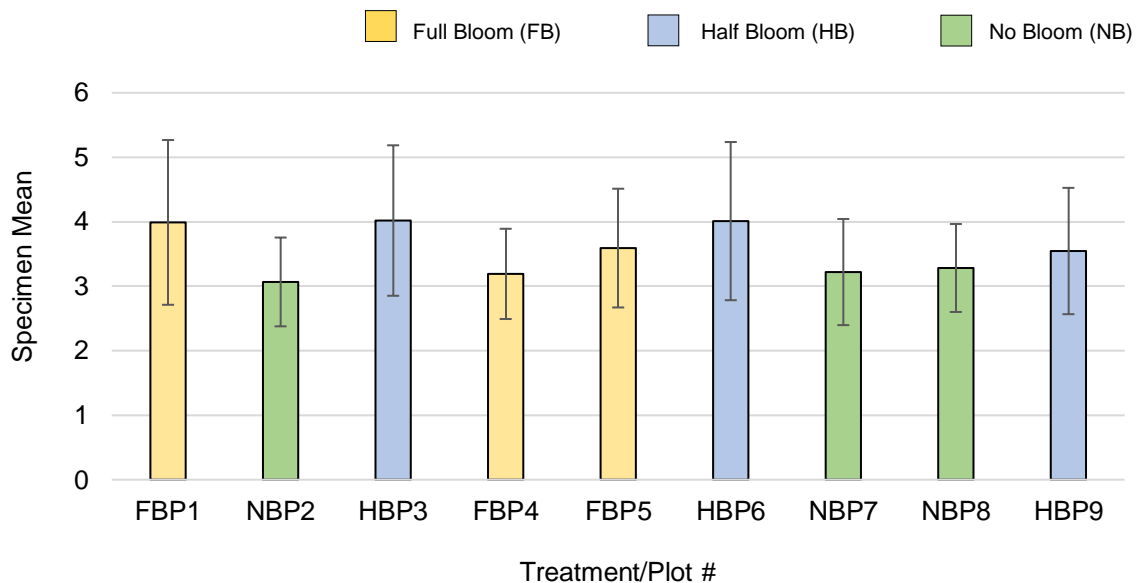
Order/Family	Full Bloom (FB)				Half Bloom (HB)				No Bloom (NB)				Grand Total
	P1	P4	P5	FB Total	P3	P6	P9	HB Total	P2	P7	P8	NB Total	
<b>Hymenoptera</b>	<b>51</b>	<b>47</b>	<b>37</b>	<b>135</b>	<b>39</b>	<b>33</b>	<b>51</b>	<b>123</b>	<b>26</b>	<b>35</b>	<b>36</b>	<b>97</b>	<b>355</b>
Aphelinidae	1	1	0	2	2	0	1	3	1	0	0	1	6
Apidae	3	8	7	18	6	5	8	19	4	7	12	23	60
Argidae	0	1	0	1	0	0	0	0	1	0	0	1	2
Bethylidae	1	3	5	9	1	1	0	2	2	2	3	7	18
Braconidae	3	1	2	6	1	1	1	3	0	0	0	0	9
Ceraphronidae	1	0	0	1	0	1	0	1	1	0	0	1	3
Cynipidae	0	0	0	0	0	0	0	0	1	0	1	2	2
Encyrtidae	7	7	4	18	9	3	5	17	3	5	4	12	47
Eulophidae	0	1	0	1	0	0	2	2	0	0	0	0	3
Eurytomidae	1	0	0	1	0	0	0	0	0	0	0	0	1
Figitidae	1	0	0	1	0	0	0	0	0	0	0	0	1
Formicidae	1	0	1	2	0	1	2	3	1	2	0	3	8
Hymenoptera M1	0	0	0	0	0	0	1	1	0	0	0	0	1
Hymenoptera M2	0	0	1	1	1	0	0	1	0	0	0	0	2
Hymenoptera M3	0	0	0	0	0	1	0	1	0	0	0	0	1
Hymenoptera M4	0	0	0	0	0	0	0	0	0	1	0	1	1
Hymenoptera M5	0	1	0	1	0	0	0	0	0	0	0	0	1
Megaspilidae	0	0	0	0	0	0	0	0	0	0	1	1	1
Mymaridae	17	6	11	34	9	12	23	44	4	11	4	19	97
Platygastridae	8	9	2	19	7	6	4	17	5	4	3	12	48
Pompilidae	0	1	0	1	0	0	0	0	0	0	0	0	1
Proctotrupoidea	0	0	0	0	0	0	0	0	0	0	2	2	2
Pteromalidae	0	1	1	2	0	0	2	2	0	0	1	1	5
Sphecidae	0	0	0	0	0	0	0	0	0	1	0	1	1
Trichogrammatidae	5	6	3	14	3	2	0	5	3	2	4	9	28
Vespidae	2	1	0	3	0	0	2	2			1	1	6

**Table 19 cont.:** Family insect specimen sums by Treatment and Plot at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n =7). Treatments: FB = Full Bloom, HB = Half Bloom, NB = No Bloom. P# = plot number.

Order/Family	Full Bloom (FB)				Half Bloom (HB)				No Bloom (NB)				Grand Total
	P1	P4	P5	FB Total	P3	P6	P9	HB Total	P2	P7	P8	NB Total	
<b>Lepidoptera</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>5</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>1</b>	<b>7</b>
Lepidoptera M1	3	0	0	3	0	0	0	0	0	0	0	0	3
Lepidoptera M2	1	0	0	1	1	0	0	1	0	0	1	0	3
Lepidoptera M3	1	0	0	1	0	0	0	0	0	0	0	0	1
<b>Thysanoptera</b>	<b>251</b>	<b>196</b>	<b>198</b>	<b>645</b>	<b>241</b>	<b>248</b>	<b>197</b>	<b>686</b>	<b>156</b>	<b>155</b>	<b>156</b>	<b>467</b>	<b>1798</b>
Aeolothripidae	4	2	1	7	7	3	5	15	4	2	1	7	29
Thripidae	247	194	197	638	234	245	192	671	152	153	155	460	1769
<b>Grand Total</b>	<b>403</b>	<b>383</b>	<b>352</b>	<b>1138</b>	<b>422</b>	<b>397</b>	<b>383</b>	<b>1202</b>	<b>322</b>	<b>322</b>	<b>348</b>	<b>992</b>	<b>3332</b>

**Table 20:** Insect specimen sums, means  $\pm$  standard errors, and % of total specimens by Treatment and Plot at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). P# = plot number. Treatments: FB = Full Bloom, HB = Half Bloom, NB = No Bloom.

Treatment/Plot #	N	Mean $\pm$ SE	% of Total
<b>ALL FB</b>	<b>1138</b>		<b>34.16</b>
FBP1	403	3.99 $\pm$ 1.28	12.10
FBP4	383	3.19 $\pm$ 0.70	11.50
FBP5	352	3.59 $\pm$ 0.92	10.57
<b>ALL HB</b>	<b>1202</b>		<b>36.09</b>
HBP3	422	4.02 $\pm$ 1.17	12.67
HBP6	397	4.01 $\pm$ 1.23	11.92
HBP9	383	3.55 $\pm$ 0.98	11.50
<b>ALL NB</b>	<b>991</b>		<b>29.75</b>
NBP2	322	3.07 $\pm$ 0.69	9.67
NBP7	322	3.22 $\pm$ 0.82	9.67
NBP8	347	3.27 $\pm$ 0.99	10.42



**Figure 22:** Overall insect specimen means  $\pm$  standard errors by Treatment/Plot at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Treatments: FB = Full Bloom, HB = Half Bloom, NB = No Bloom. P# = plot number.

**Table 21:** Four factor ANOVA analysis (Treatment, Collection Date, Order, Feeding Style) of overall insect specimens collected at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Variables in bold were significant ( $p \leq 0.05$ ). The variable Collection Date was included for the ANOVA analysis but was not interpreted.

Variable	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.0269	0.01345	0.2915	0.7472
Collection Date	6	0.9344	0.15574	3.3750	0.0027
<b>Order</b>	7	21.1154	3.01648	65.3704	<b>&lt; 0.0001</b>
<b>Feeding</b>	5	10.0946	2.01892	43.7522	<b>&lt; 0.0001</b>
Treatment*Order	14	0.2984	0.02132	0.4620	0.9525
Treatment*Feeding	10	0.2418	0.02418	0.5240	0.8739
Error	720	33.2240	0.04614		
Total	764	85.1280			

#### 4.7 2019 Order Level Analyses

Eight Orders were collected (including subclass Acari), with the greatest number of specimens from Thysanoptera (N = 1798, 53.96%), followed by Hemiptera (N = 627, 18.82%), and Diptera (N = 433, 13.00%) (Table 22).

Similar to 2018 HG collections, Thysanoptera and Hemiptera were collected in high numbers, confirming their prevalence in the site. Contrary to 2018, greater numbers of flying specimens from Diptera and Hymenoptera were collected in pan traps, indicating a possible effect of switching the collection method from active aspirator and pot taps to passive yellow pan traps.

A four factor ANOVA analysis (Treatment, Collection Date, Order, Feeding Style) using all 2019 specimen data found a significant difference in the mean number of specimens among Orders ( $F_{7,720} = 65.3704$ ,  $p < 0.0001$ ) (see Table

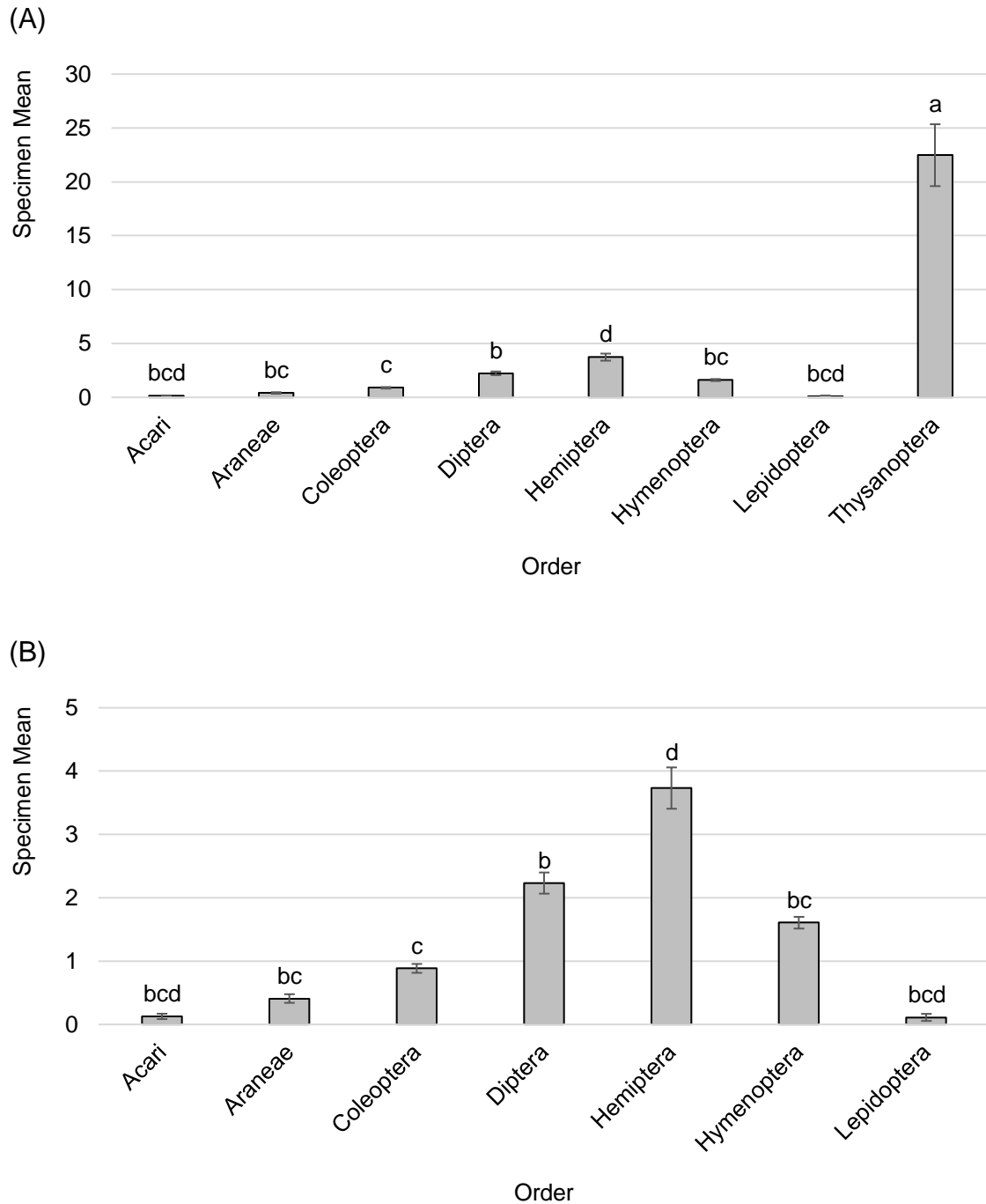
21). Multiple comparison tests (Tukey HSD) for Order (Fig. 23) found significantly greater numbers overall of Thysanoptera than all other Orders. Comparisons also found significantly greater numbers overall of Hemiptera than Araneae, Coleoptera, Diptera and Hymenoptera, and Diptera than Coleoptera.

There was no significant difference found for an interaction between Treatment and Order ( $F_{14,720} = 0.4620$ ,  $p = 0.9525$ ) (see Table 21), indicating harvest treatment was not having a significant influence on the density of specimens attracted to the plots at the Order level. The FB plots attracted the greatest numbers of Araneae (FB: N = 12, NB: N = 9, HB: N = 6), Hymenoptera (FB: N = 135, HB: N = 123, NB: N = 97), and Lepidoptera (FB: N = 5, HB: N = 1, NB: N = 1); the HB plots attracted the greatest numbers of Coleoptera (HB: N = 28, FB: N = 26, NB: N = 23) and Thysanoptera (HB: N = 686, FB: N = 635, NB: N = 467); while the NB plots attracted the greatest number of Acari (NB: N = 4, HB: N = 3, FB: N = 1), Diptera (NB: N = 164, HB: N = 140, FB: N = 129), and Hemiptera (NB: N = 227, HB: N = 215, FB: N = 185) (Table 23, Fig. 24).

**Table 22:** Insect specimen sums, means  $\pm$  standard errors, and % of total by Order at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 ( $n = 7$ ). P# = plot number. Treatments: FB = Full Bloom, HB = Half Bloom, NB = No Bloom.

Order	N	Mean $\pm$ SE	% of Total
Acari	8	0.13 $\pm$ 0.04	0.24
Araneae	27	0.41 $\pm$ 0.07	0.81
Coleoptera	77	0.89 $\pm$ 0.07	2.31
Diptera	433	2.23 $\pm$ 0.17	13.00
Hemiptera	627	3.73 $\pm$ 0.33	18.82
Hymenoptera	355	1.61 $\pm$ 0.09	10.65
Lepidoptera	6	0.11 $\pm$ 0.06	0.21
Thysanoptera	1798	22.48 $\pm$ 2.87	53.96

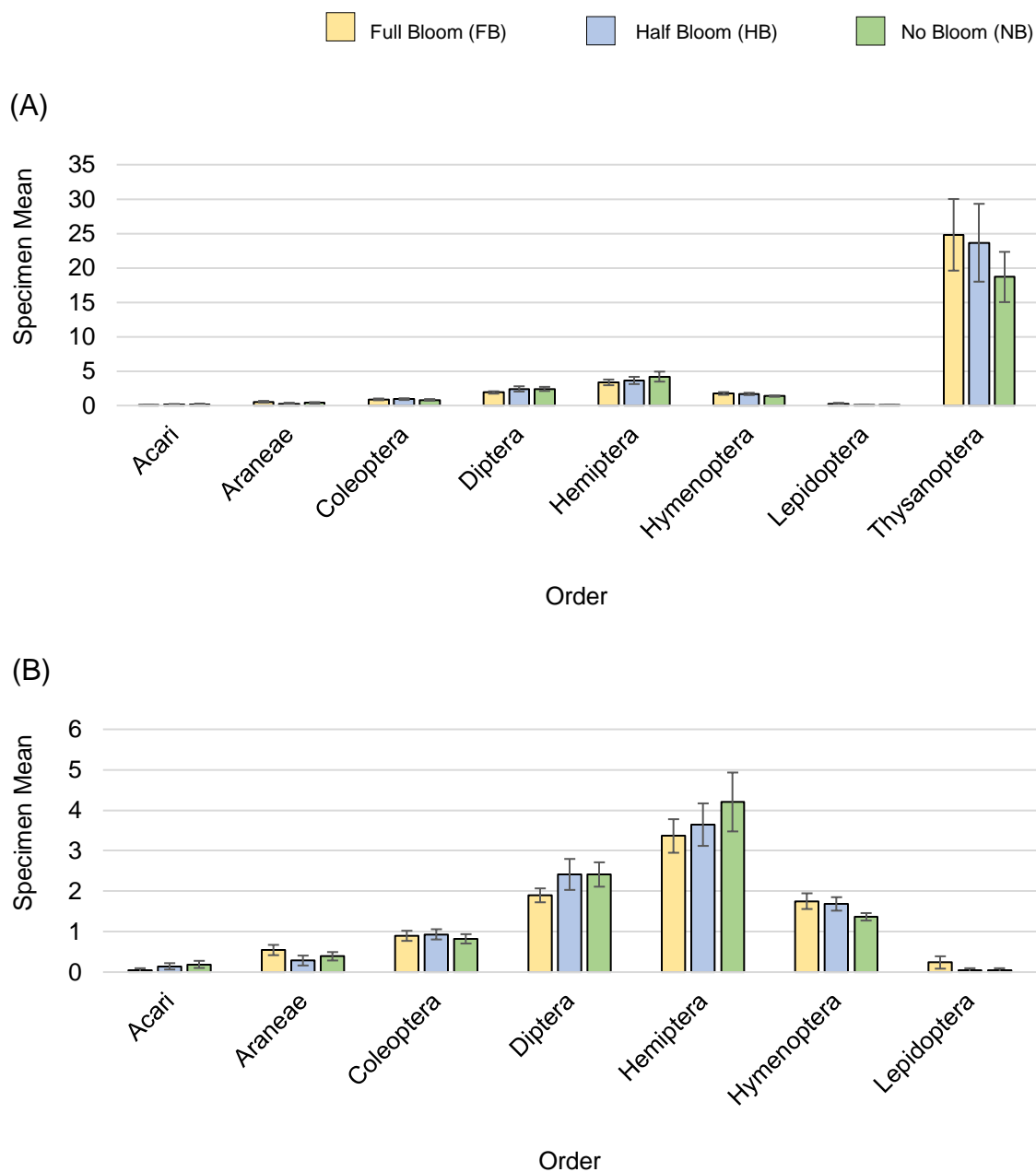




**Figure 23:** Overall insect specimen means  $\pm$  standard errors by Order at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 ( $n = 7$ ). (A) all Orders and (B) Orders without Thysanoptera. Bars with different letters are significantly different using Tukey HSD,  $p \leq 0.05$ .

**Table 23:** Insect specimen sums and means  $\pm$  standard errors by Order and Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

Order	Full Bloom		Half Bloom		No Bloom	
	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE
Acari	1	0.05 $\pm$ 0.05	3	0.14 $\pm$ 0.08	4	0.19 $\pm$ 0.09
Araneae	12	0.55 $\pm$ 0.13	6	0.29 $\pm$ 0.12	9	0.39 $\pm$ 0.10
Coleoptera	26	0.90 $\pm$ 0.13	28	0.93 $\pm$ 0.3	23	0.82 $\pm$ 0.12
Diptera	129	1.90 $\pm$ 0.17	140	2.41 $\pm$ 0.38	164	2.41 $\pm$ 0.30
Hemiptera	185	3.36 $\pm$ 0.42	215	3.64 $\pm$ 0.53	227	4.20 $\pm$ 0.73
Hymenoptera	135	1.75 $\pm$ 0.19	123	1.69 $\pm$ 0.17	97	1.37 $\pm$ 0.09
Lepidoptera	5	0.24 $\pm$ 0.15	1	0.05 $\pm$ 0.05	1	0.05 $\pm$ 0.05
Thysanoptera	645	24.81 $\pm$ 5.20	686	23.66 $\pm$ 5.66	467	18.68 $\pm$ 3.65



**Figure 24:** Overall insect specimen means  $\pm$  standard errors by Order and Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 ( $n = 7$ ). (A) all Orders and (B) Orders without Thysanoptera. No significant differences ( $p \leq 0.05$ ) were found within each Order among the three treatments.

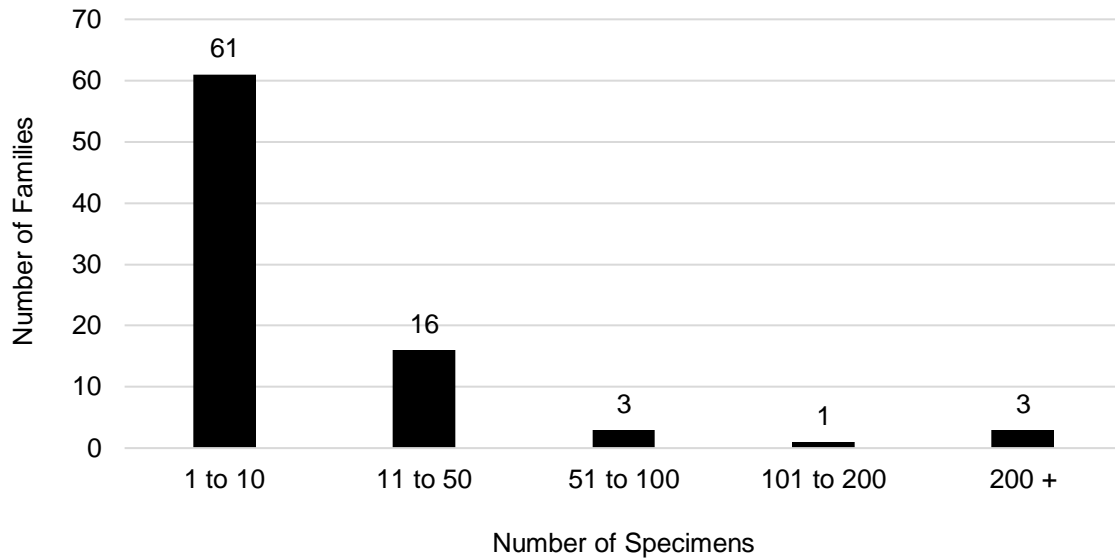
## 4.8 2019 Family Level Analyses

### 4.8.1 2019 Overall Family Categorized by Specimen Sums

Of the 84 Families collected (called “Family” here but includes 68 Families, 14 morphotypes, one Suborder, and one Superfamily), the majority (92%) had 50 or fewer specimens per Family collected across all treatments (Fig. 25). Families represented by fewer than 10 specimens were likely transitory, for example one Curculionidae weevil in the NB treatment and one Bombyliidae fly in the HB treatment. Many natural enemy Families collected in the HG plot in 2018 by aspirator and pot taps were also collected in pan traps in 2019, but in much lower numbers, for example: Anthocoridae (2018: N = 824, 2019: N = 13), Aeolothripidae (2018: N = 167, 2019: N = 29), Coccinellidae (2018: N = 75, 2018: N = 10), Geocoridae (2019: N = 112, 2018: N = 1), and Nabidae (2019: N = 63, 2018: N = 3). The lack of an adjacent crop, low vegetative growth on the *T. vulgaris* plots, and limited blooms may have reduced the attractiveness of the plots. It is also possible the lower numbers in 2019 were due to a lack of attraction of certain Families to the yellow pan traps. As noted in the Order analysis section, this may have been an effect of the pan traps which are a passive capture method and may be more effective at collecting small, fast moving specimens. Seven Families had 51 or more specimens (Table 24). As in 2018, these included several agriculturally important Families such as phytophagous Aphididae, Cicadellidae, and Thripidae, and the pollinator Apidae. In 2019 this category also included the parasitoid Mymaridae, which had been

collected in very low numbers in 2018, supporting a possible effect of the pan trap method mentioned above.

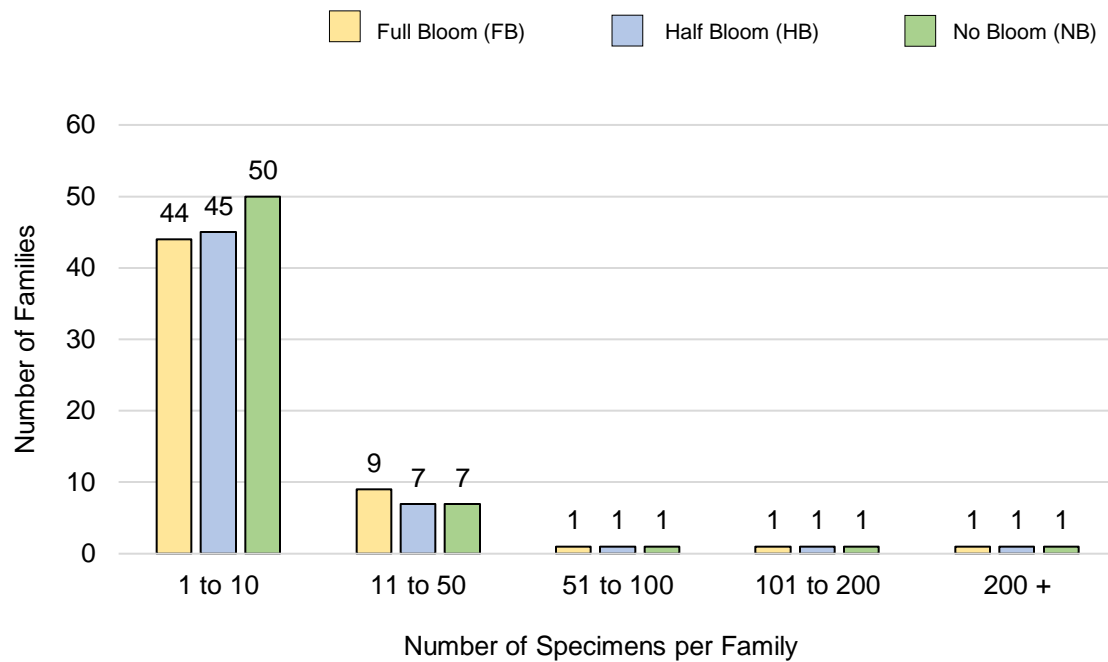
When grouped by Treatment, the greatest diversity was found in the NB treatments (N = 60), followed by the FB (N = 56) and HB (N = 55) treatments. The majority of Families had only 1 to 10 specimens collected per Family in each treatment: FB = 44 Families, HB = 45, and NB = 50 (Fig. 26), suggesting more of than 75% of the Families in each location could be considered transitory. Only ten Families had 11 to 50 specimens, with the FB treatment having the greatest diversity: FB = 9 Families, HB = 7, and NB = 7 (Table 25); six of these Families were collected in all treatments: Apidae, Cicadellidae, Encyrtidae, Mymaridae, Platygasteridae, and Sciaridae. Apidae and the three micro-hymenopteran families may have been attracted to the blossoms, while Cicadellidae and Sciaridae were likely attracted to the foliage for food. Only three Families were collected in all treatments in numbers 50+: Muscidae, Aphididae, and Thripidae. The presence of phytophagous Aphididae and Thripidae in all treatments indicate the attraction of the foliage, and perhaps floral food for the Thripidae. While Muscidae may have been attracted to the blossoms for floral foods, their high numbers in the NB plot suggest they may have been attracted by the pan traps.



**Figure 25:** Number of insect specimen Families categorized by specimen sums per Family at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

**Table 24:** Insect specimen sums and Feeding Styles for Families with 51 to 100, 101 to 200, or 201+ specimens collected at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

	Family	N	Feeding Style
<b>51 to 100</b>	Apidae	60	beneficial
	Sciaridae	74	other
	Mymaridae	97	parasitoid
<b>101 to 200</b>	Cicadellidae	116	phytophagous/piercing
<b>201 +</b>	Muscidae	221	other
	Aphididae	428	phytophagous/piercing
	Thripidae	1769	phytophagous/piercing



**Figure 26:** Insect specimen Families by Treatment and specimen sums per Family collected at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

**Table 25:** Insect specimen sums and Feeding Styles for Families with 11 to 50, 51 to 100, 101 to 200, or 200+ specimens by Treatment collected at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

	Treatment	Family	N	Feeding Style
<b>11 to 50</b>	FB	Agromyzidae	15	phytophagous/piercing
		Aleyroididae	15	predator
		Apidae	18	pollinator
		Cicadellidae	34	phytophagous/piercing
		Encrytidae	18	parasitoid
		Mymaridae	34	parasitoid
		Platygastridae	19	parasitoid
		Sciaridae	27	other
		Trichogrammatidae	14	parasitoid
	HB	Aeolothripidae	15	predator
		Apidae	19	pollinator
		Cicadellidae	47	phytophagous/piercing
		Encrytidae	17	parasitoid
		Mymaridae	44	parasitoid
		Platygastridae	17	parasitoid
		Sciaridae	20	other
	NB	Aleyroididae	14	predator
		Apidae	23	pollinator
		Cicadellidae	35	phytophagous/piercing
		Encrytidae	12	parasitoid
		Mymaridae	19	parasitoid
		Platygastridae	12	parasitoid
		Sciaridae	27	other
<b>51 to 100</b>	FB	Muscidae	55	other
	HB	Muscidae	74	other
	NB	Muscidae	92	other
<b>101 to 200</b>	FB	Aphididae	123	phytophagous/piercing
	HB	Aphididae	142	phytophagous/piercing
	NB	Aphididae	163	phytophagous/piercing
<b>200 +</b>	FB	Thripidae	638	phytophagous/piercing
	HB	Thripidae	671	phytophagous/piercing
	NB	Thripidae	460	phytophagous/piercing



#### 4.8.2 2019 Top Agriculturally Important Families Analyses

Thirteen agriculturally important Families (natural enemies, phytophagous insects, and pollinators commonly monitored in agricultural ecosystems or which have been subjects of previous biological control studies or pollination studies) with  $\geq 20$  specimens collected across all treatments during the study were selected for further analysis. This subgroup included six phytophagous Families, six natural enemy Families, and one pollinator Family (Table 26).

A three factor ANOVA analysis (Treatment, Collection Date, Family) (Table 27) using only the top six phytophagous Families found no significant difference in the mean number of specimens among treatments ( $F_{2,354} = 0.5072$ ,  $p = 0.6026$ ), indicating there was no difference in specimen numbers for these phytophagous Families among the three treatments. A significant difference was found in the mean number of specimens among Families ( $F_{5,354} = 257.7670$ ,  $p < 0.0001$ ), indicating there was a significant difference in overall specimen numbers between the six phytophagous Families. Multiple comparison tests (Tukey HSD) of Family (Fig. 27) found significantly greater numbers overall of Thripidae than the other six top phytophagous Families, and significantly greater numbers overall of Aphididae than Cicadellidae, Aleyroididae, Agromyzidae, and Chrysomelidae. As in 2018, the prevalence of Aphididae and Thripidae in all three treatments corresponds with greater numbers of Hemiptera and Thysanoptera seen in the Order analysis results, and indicates they were attracted to the plants regardless of harvest treatment. Cicadellidae also had significantly greater numbers overall than Aleyroididae, Agromyzidae, and

Chrysomelidae overall. There was no significant difference found for an interaction between Treatment and Family ( $F_{10,354} = 0.9102$ ,  $p = 0.5237$ ) (see Table 27), indicating treatment was not having a significant influence on specimen densities of the top phytophagous insects attracted to the plots at the Family level. The FB plots attracted the greatest number of Agromyzidae (FB:  $N = 15$ , NB:  $N = 10$ , HB:  $N = 9$ ) and Aleyroididae (FB:  $N = 15$ , NB:  $N = 14$ , HB:  $N = 8$ ); the HB plots attracted the greatest numbers of Cicadellidae (HB:  $N = 47$ , NB:  $N = 35$ , FB:  $N = 34$ ) and Thripidae (HB:  $N = 671$ , FB:  $N = 638$ , NB:  $N = 460$ ); and the NB plots attracted the greatest numbers of Aphididae (NB:  $N = 163$ , HB:  $N = 142$ , FB:  $N = 123$ ) (Table 28, Fig. 28). Chrysomelidae were collected in equal numbers in the FB and NB plot, followed by the HB plot (FB:  $N = 8$ , NB:  $N = 8$ , HB:  $N = 7$ ).

A three factor ANOVA analysis (Treatment, Collection Date, Family) (Table 29) using only the top natural enemy Families found no significant difference in the mean number of specimens among treatments ( $F_{2,354} = 2.1609$ ,  $p = 0.1167$ ), indicating there was no difference in specimen numbers for these natural enemy Families among the three treatments. A significant difference was found in the mean number of specimens among Families ( $F_{5,354} = 8.0062$ ,  $p < 0.0001$ ), indicating there was a significant difference in overall specimens sums between the six natural enemy Families. Multiple comparison tests (Tukey HSD) of Family (Fig. 29) found significantly greater numbers overall of Mymaridae than Aeolothripidae, Encyrtidae, Tachinidae, and Trichogrammatidae. There were also significantly greater numbers of Platygastriidae overall than Tachinidae. There

was no significant difference found for an interaction between Treatment and Family ( $F_{10,354} = 0.9693$ ,  $p = 0.4699$ ) (see Table 29), indicating treatment was not having a significant influence on specimen densities of the top natural enemy insects attracted to the plots at the Family level, but in general the flowering treatments were more attractive than the NB plots. The FB plots attracted the greatest numbers of Encyrtidae (FB: N = 18, HB: N = 17, NB: N = 12), Platygasteridae (FB: N = 19, HB: N = 17, NB: N = 12), and Trichogrammatidae (FB: N = 14, NB: N = 9, HB: N = 5), while the HB plots attracted the greatest numbers of Aeolothripidae (HB: N = 15, FB: N = 7, NB: N = 7), Mymaridae (HB: N = 44, FB: N = 34, NB: N = 19), and Tachinidae (HB: N = 9, FB: N = 6, NB: N = 6) (Table 30, Fig. 30).

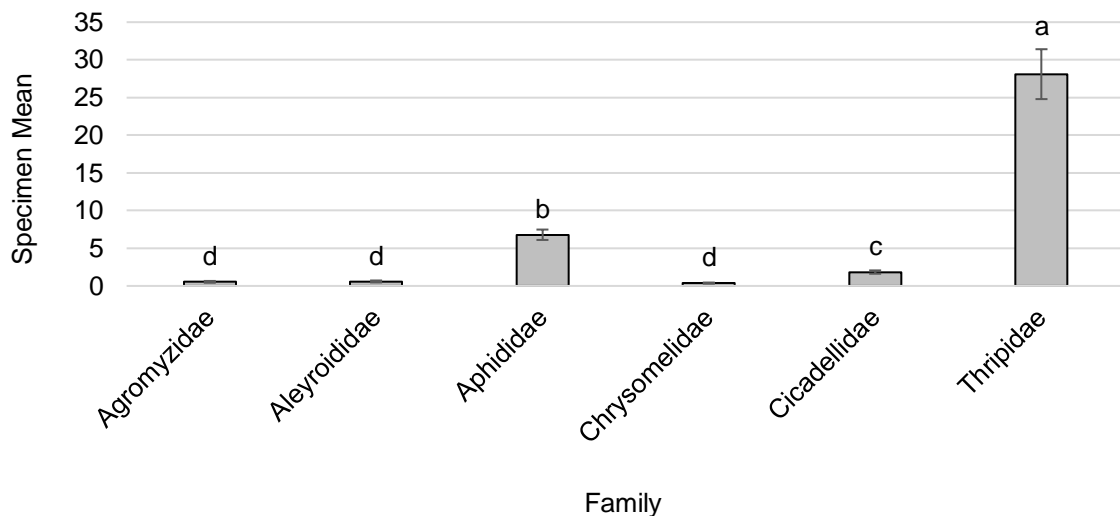
A two factor ANOVA analysis (Treatment, Collection Date) (Table 31) using only the top pollinator Family Apidae found no significant difference in the mean number of specimens among treatments ( $F_{2,354} = 0.5411$ ,  $p = 0.7221$ ), indicating there was no difference in specimen sums for Apidae among the three treatments. The greatest specimen count for Apidae was recorded in the NB plots (NB: N = 23, HB: N = 19, FB: N = 19) (Table 32), which suggests the yellow pan traps used for collections may have increased the attractiveness of the NB plots to Apidae.

**Table 26:** Insect specimen sums, means  $\pm$  standard error, % of total specimens, and Feeding Style of top agriculturally important Families collected at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Bold = top Families in both 2018 and 2019.

Family	N	Mean $\pm$ SE	% of Total	Feeding Style
<b>Apidae</b>	60	0.95 $\pm$ 0.12	1.96	pollinator
<b>Aeolothripidae</b>	29	0.46 $\pm$ 0.12	0.95	predator
Encyrtidae	47	0.75 $\pm$ 0.14	1.54	parasitoid
Mymaridae	97	1.54 $\pm$ 0.31	3.18	parasitoid
Platygastridae	48	0.76 $\pm$ 0.12	1.57	parasitoid
Tachinidae	21	0.33 $\pm$ 0.08	0.69	parasitoid
Trichogrammatidae	28	0.44 $\pm$ 0.09	0.92	parasitoid
Agromyzidae	34	0.54 $\pm$ 0.12	1.11	phytophagous/chewing
<b>Chrysomelidae</b>	23	0.37 $\pm$ 0.08	0.75	phytophagous/chewing
Aleyroididae	37	0.59 $\pm$ 0.13	1.21	phytophagous/piercing
<b>Aphididae</b>	428	6.79 $\pm$ 0.69	14.01	phytophagous/piercing
<b>Cicadellidae</b>	116	1.84 $\pm$ 0.22	3.80	phytophagous/piercing
<b>Thripidae</b>	1769	28.10 $\pm$ 3.31	57.91	phytophagous/piercing

**Table 27:** Three factor ANOVA analysis (using Treatment, Collection Date, Family) of the top six phytophagous Families collected at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Variables in bold were significant ( $p \leq 0.05$ ). The variable Collection Date was included for the ANOVA analysis but was not interpreted.

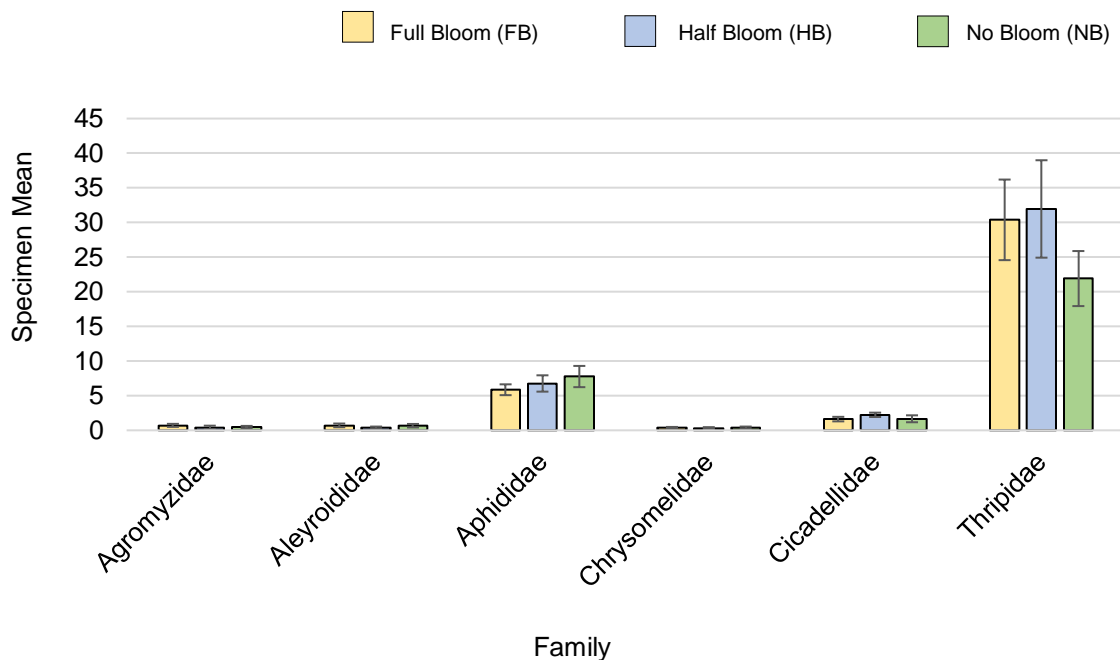
Variable	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.060	0.0302	0.5072	0.6026
Collection Date	6	2.214	0.3689	6.1911	< 0.0001
<b>Family</b>	5	76.802	15.3604	257.7670	<b>&lt; 0.0001</b>
Treatment*Family	10	0.542	0.0542	0.9102	0.5237
Error	354	21.095	0.0596		
Total	377	100.714			



**Figure 27:** Top phytophagous Family insect specimen means  $\pm$  standard errors by Family at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Bars with different letters are significantly different using Tukey HSD,  $p \leq 0.05$ .

**Table 28:** Insect specimen sums and mean  $\pm$  standard errors for the top phytophagous Families by Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

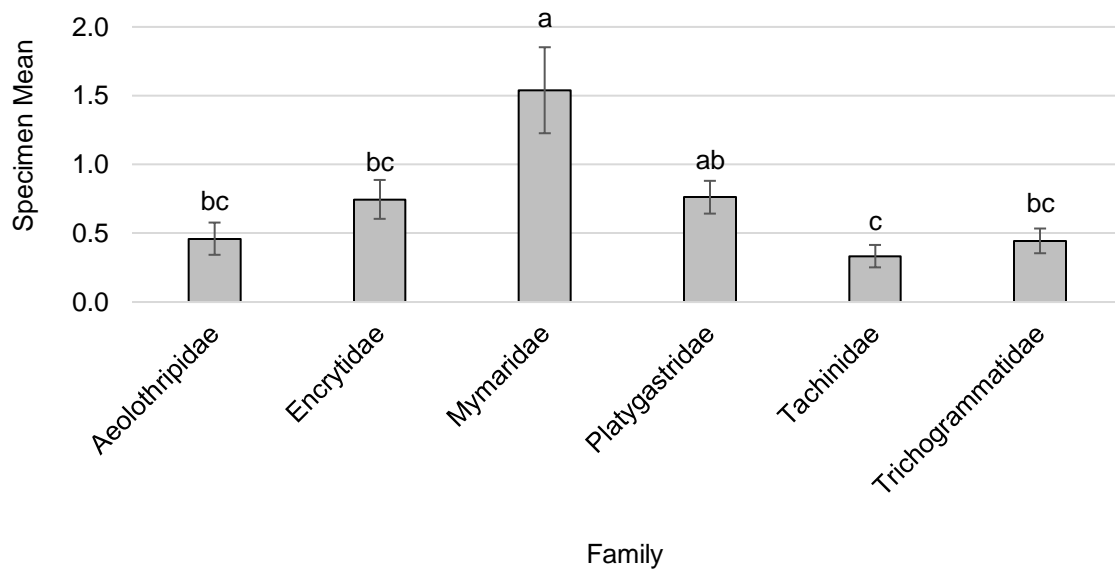
Family	Full Bloom		Half Bloom		No Bloom	
	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE
Agromyzidae	15	0.71 $\pm$ 0.22	9	0.43 $\pm$ 0.24	10	0.48 $\pm$ 0.16
Aleyroididae	15	0.71 $\pm$ 0.27	8	0.38 $\pm$ 0.16	14	0.67 $\pm$ 0.25
Aphididae	123	5.86 $\pm$ 0.78	142	6.76 $\pm$ 1.18	163	7.76 $\pm$ 1.53
Chrysomelidae	8	0.38 $\pm$ 0.11	7	0.33 $\pm$ 0.13	8	0.38 $\pm$ 0.16
Cicadellidae	34	1.62 $\pm$ 0.33	47	2.24 $\pm$ 0.32	35	1.67 $\pm$ 0.50
Thripidae	638	30.38 $\pm$ 5.82	671	31.95 $\pm$ 7.03	460	21.90 $\pm$ 3.97



**Figure 28:** Top phytophagous Family insect specimen means  $\pm$  standard errors by Family by Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). No significant differences ( $p \leq 0.05$ ) were found within each Family among the three treatments.

**Table 29:** Three factor ANOVA analysis (using Treatment, Collection Date, Family) of the top six natural enemy Families collected at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Variables in bold were significant ( $p \leq 0.05$ ). The variable Collection Date was included for the ANOVA analysis but was not interpreted.

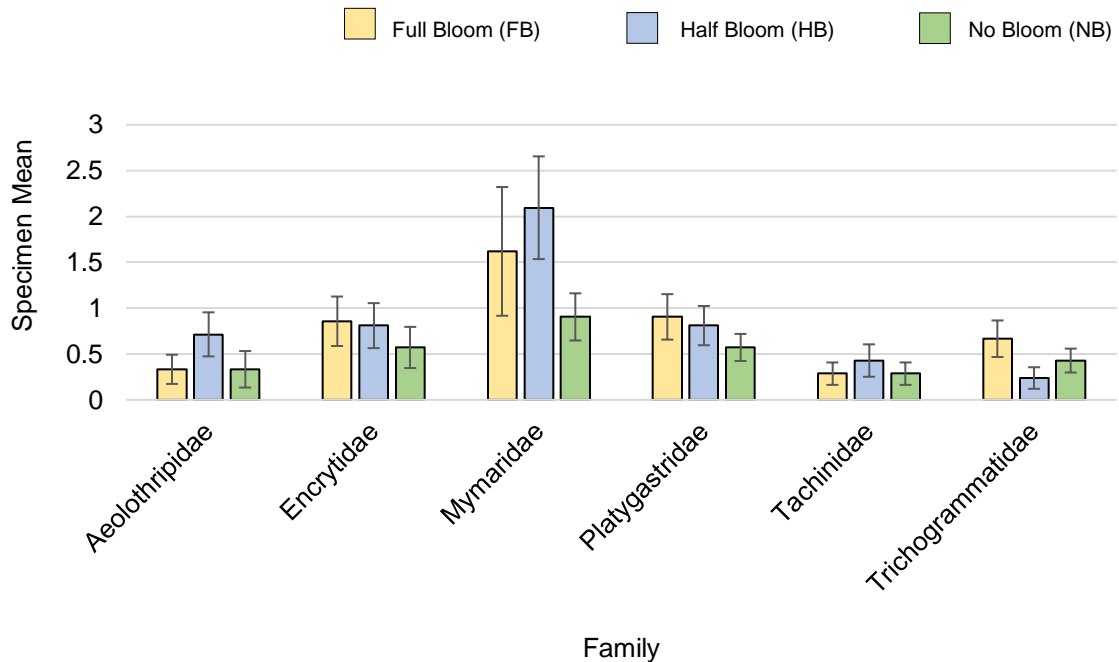
Variable	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.1643	0.08216	2.1609	0.1167
Collection Date	6	3.8685	0.64475	16.9578	< 0.0001
<b>Family</b>	5	1.5220	0.30440	8.0062	<b>&lt; 0.0001</b>
Treatment*Family	10	0.3685	0.03685	0.9693	0.4699
Error	354	13.4593	0.03802		
Total	377	19.3827			



**Figure 29:** Top natural enemy Family insect specimen means  $\pm$  standard errors by Family at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Bars with different letters are significantly different using Tukey HSD,  $p \leq 0.05$ .

**Table 30:** Insect specimen sums and mean  $\pm$  standard errors for the top natural enemy Families by Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

Family	Full Bloom		Half Bloom		No Bloom	
	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE
Aeolothripidae	7	0.33 $\pm$ 0.16	15	0.71 $\pm$ 0.24	7	0.33 $\pm$ 0.2
Encyrtidae	18	0.86 $\pm$ 0.27	17	0.81 $\pm$ 0.25	12	0.57 $\pm$ 0.22
Mymaridae	34	1.62 $\pm$ 0.7	44	2.10 $\pm$ 0.56	19	0.90 $\pm$ 0.26
Platygastridae	19	0.90 $\pm$ 0.25	17	0.81 $\pm$ 0.21	12	0.57 $\pm$ 0.15
Tachinidae	6	0.29 $\pm$ 0.12	9	0.43 $\pm$ 0.18	6	0.29 $\pm$ 0.12
Trichogrammatidae	14	0.67 $\pm$ 0.20	5	0.24 $\pm$ 0.12	9	0.43 $\pm$ 0.13



**Figure 30:** Top natural enemy Family insect specimen means  $\pm$  standard errors by Family by Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). No significant differences ( $p \leq 0.05$ ) were found within each natural enemy Family among the three treatments.



**Table 31:** Two factor ANOVA analysis (using Treatment and Collection Date) of the top pollinator Family collected at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). No significant differences ( $p \leq 0.05$ ) were found. The variable Collection Date was included for the ANOVA analysis but was not interpreted.

Variable	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.03908	0.01954	0.5411	0.5852
Collection Date	6	0.75759	0.12627	3.4966	0.0054
Error	54	1.95001	0.03611		
Total	62	2.74668			

**Table 32:** Insect specimen sums and mean  $\pm$  standard errors for the top pollinator Families by Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

Feeding Style	Full Bloom		Half Bloom		No Bloom	
	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE
Apidae	18	0.86 $\pm$ 0.23	19	0.90 $\pm$ 0.14	23	1.10 $\pm$ 0.25

#### 4.9 2019 Feeding Style Analyses

Of the six feeding styles collected, 71.25% were phytophagous/piercing (N = 2374), 9.15% were parasitoid (N = 305), and 3.57% were predators (N = 119) (Table 33). The feeding style other was used in analysis results but are not included in the discussion below. While the dominance of phytophagous/piercing specimens was similar to 2018 results, the natural enemy numbers were reversed, with greater parasitoid than predator numbers, again suggesting an effect of altering the collection method.

A four factor ANOVA analysis (Treatment, Collection Date, Order, Feeding Style) using all 2019 specimen data found a significant difference in the mean number of specimens among feeding styles ( $F_{5,720} = 43.7522$ ,  $p < 0.0001$ ) (see Table 21). Multiple comparison tests (Tukey HSD) for Feeding Style found significantly greater numbers overall of phytophagous/piercing insects than all other feeding styles (Fig. 31), which is indicative of the high numbers of Aphididae and Thripidae collected in all treatments.

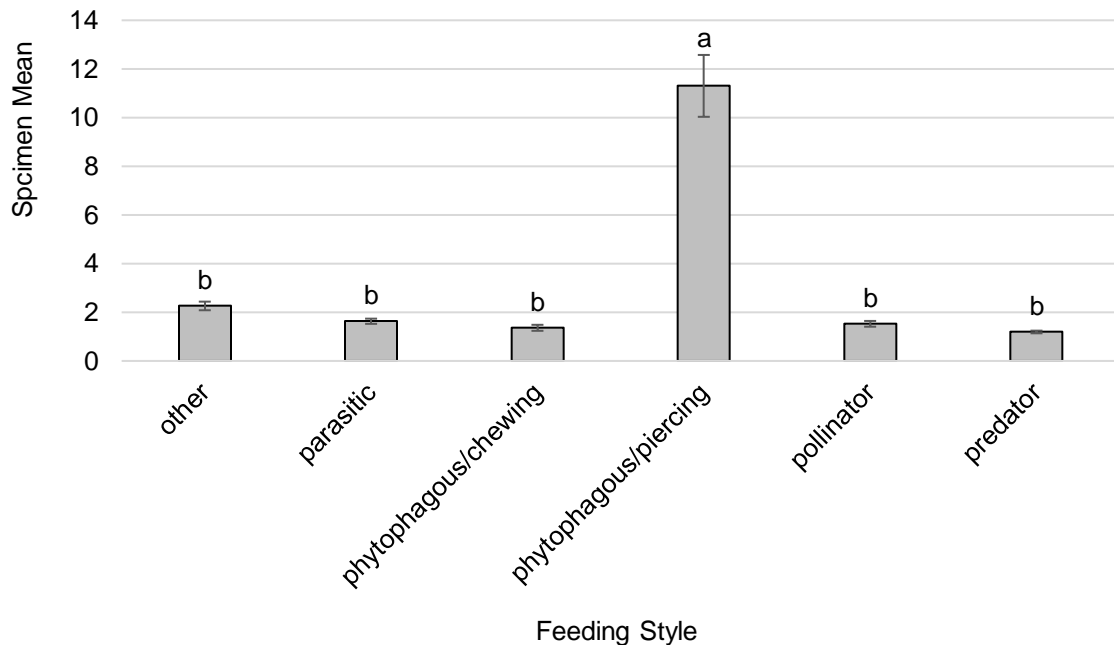
There was no significant difference found for interactions between Treatment and Feeding Style ( $F_{10,720} = 0.5240$ ,  $p = 0.8739$ ), indicating harvest treatment was not having a significant influence on the type of insects attracted to the plots (Table 34, Fig. 32). The FB plots attracted greater numbers of parasitoids (FB:  $N = 117$ , HB:  $N = 113$ , NB:  $N = 75$ ) and phytophagous chewing insects (FB:  $N = 28$ , NB:  $N = 20$ , HB:  $N = 16$ ); the HB plots attracted greater numbers of phytophagous/piercing insects (HB:  $N = 877$ , FB:  $N = 818$ , NB:  $N = 679$ ); and the NB plots attracted greater numbers of pollinators (NB:  $N = 24$ , HB:  $N = 19$ , FB:  $N = 18$ ). Predators were attracted in equal numbers to the FB and NB plots, followed by the HB plots (FB:  $N = 40$ , NB:  $N = 40$ , HB:  $N = 39$ ).

An analysis of the feeding styles for only natural enemy Families identified a combined total of 38 Families (and 7 morphotypes) across all treatments in 2019 (Table 35). While not significantly different, parasitoid numbers ( $N = 305$ ) were 2.5 times greater than predators ( $N = 119$ ) (Table 36), which is reflective of micro-hymenopterans – Mymaridae, Encyrtidae, Platygasteridae, and

Trichogrammatidae – being collected in greater numbers in all treatments over any predator Family.

**Table 33:** Insect specimen sums, means  $\pm$  standard errors, and % of total by Feeding Style at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n =7).

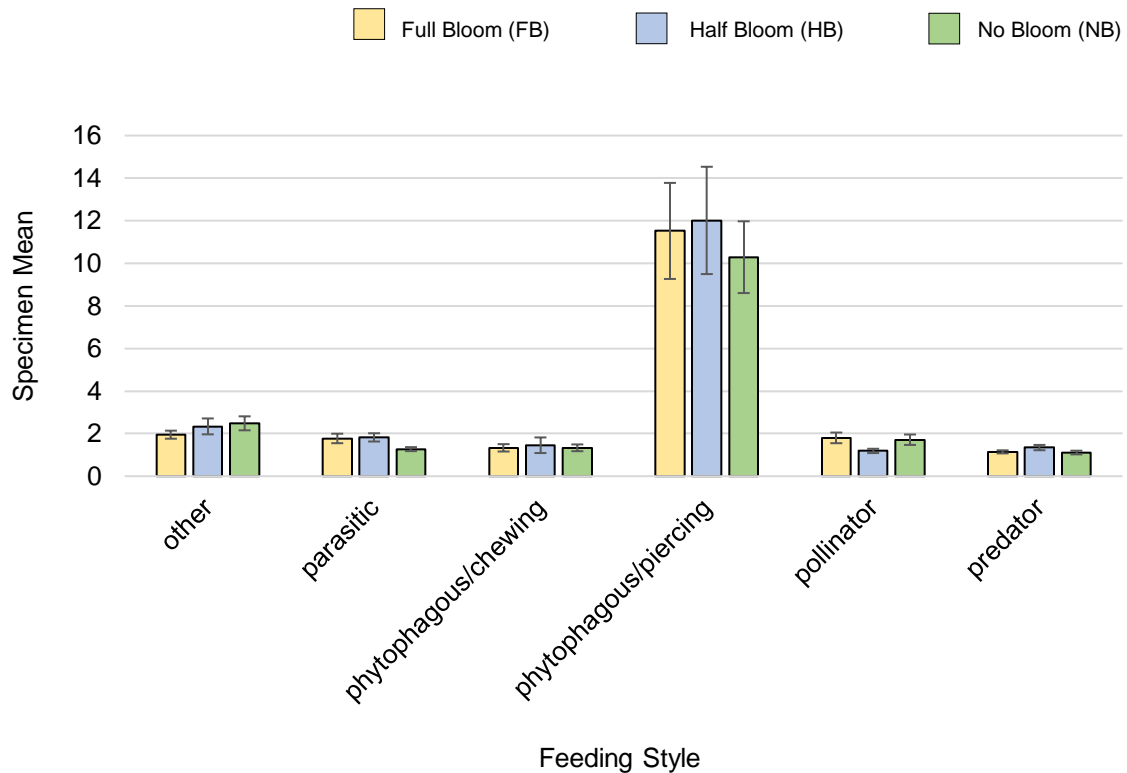
Feeding Style	Sum	Mean $\pm$ SE	% of Total
other	409	2.26 $\pm$ 0.18	12.27
parasitoid	305	1.63 $\pm$ 0.11	9.15
phytophagous/chewing	64	1.36 $\pm$ 0.12	1.92
phytophagous/piercing	2374	11.30 $\pm$ 1.27	71.25
pollinator	61	1.53 $\pm$ 0.12	1.83
predator	119	1.19 $\pm$ 0.05	3.57



**Figure 31:** Overall insect specimen means  $\pm$  standard errors by Feeding Style at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Bars with different letters are significantly different using Tukey HSD,  $p \leq 0.05$ .

**Table 34:** Insect specimen sums and mean  $\pm$  standard errors by Feeding Style and Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7).

Feeding Style	Full Bloom		Half Bloom		No Bloom	
	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE
other	117	1.95 $\pm$ 0.19	138	2.34 $\pm$ 0.37	154	2.48 $\pm$ 0.33
parasitoid	117	1.77 $\pm$ 0.22	113	1.82 $\pm$ 0.19	75	1.27 $\pm$ 0.09
phytophagous/ chewing	28	1.33 $\pm$ 0.17	16	1.45 $\pm$ 0.37	20	1.33 $\pm$ 0.16
phytophagous/ piercing	818	11.50 $\pm$ 2.26	877	12.00 $\pm$ 2.52	679	10.30 $\pm$ 1.69
pollinator	18	1.80 $\pm$ 0.25	19	1.19 $\pm$ 0.10	24	1.71 $\pm$ 0.24
predator	40	1.14 $\pm$ 0.07	39	1.34 $\pm$ 0.12	40	1.11 $\pm$ 0.09



**Figure 32:** Overall insect specimen means  $\pm$  standard errors by Feeding Style and Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). No significant differences ( $p \leq 0.05$ ) were found within each Feeding Style among the three treatments.

**Table 35:** Natural enemy (parasitoid and predator) Family sums and totals by Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n = 7). Families in bold are those in the top agriculturally important Families.

	Full Bloom	Half Bloom	No Bloom	
Parasitoid Families	Sum	Sum	Sum	Total
Aphelinidae	2	3	1	6
Apidae	0	0	1	1
Bethylidae	9	2	7	18
Bombyliidae	0	1	0	1
Braconidae	6	3	0	9
Ceraphronidae	1	1	1	3
Conopidae	0	4	2	6
<b>Encyrtidae</b>	18	17	12	47
Eulophidae	1	2	0	3
Eurytomidae	1	0	0	1
Figitidae	1	0	0	1
Hymenoptera Family, MT1	0	1	0	1
Hymenoptera Family, MT2	1	1	0	2
Hymenoptera Family, MT3	0	1	0	1
Hymenoptera Family, MT4	0	0	1	1
Hymenoptera Family, MT5	1	0	0	1
Megaspilidae	0	0	1	1
<b>Mymaridae</b>	34	44	19	97
<b>Platygastridae</b>	19	17	12	48
Pompilidae	1	0	0	1
Proctotrupoidea	0	0	2	2
Pteromalidae	2	2	1	5
Sphecidae	0	0	1	1
<b>Tachinidae</b>	6	9	6	21
<b>Trichogrammatidae</b>	14	5	9	28

**Table 35 cont.:** Natural enemy (parasitoid and predator) Family sums and totals by Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n =7). Families in bold are those in the top agriculturally important Families.

<b>Predator Families</b>	<b>Full Bloom</b>	<b>Half Bloom</b>	<b>No Bloom</b>	<b>Total</b>
	<b>Sum</b>	<b>Sum</b>	<b>Sum</b>	
<b>Aeolothripidae</b>	7	15	7	<b>29</b>
Anthocoridae	2	7	4	<b>13</b>
Araneae Family, MT1	1	1	0	<b>2</b>
Araneae Family, MT2	0	0	1	<b>1</b>
Bdellidae	1	2	1	<b>4</b>
Clubionidae	0	0	1	<b>1</b>
Coccinellidae	4	2	4	<b>10</b>
Dolichopodidae	5	2	7	<b>14</b>
Geocoridae	1	0	0	<b>1</b>
Linyphiidae	7	3	3	<b>13</b>
Lycosidae	0	0	1	<b>1</b>
Nabidae	1	1	1	<b>3</b>
Reduviidae	0	0	1	<b>1</b>
Salticidae	1	0	2	<b>3</b>
Staphylinidae	4	2	3	<b>9</b>
Syrphidae	0	0	1	<b>1</b>
Theridiidae	2	2	1	<b>5</b>
Thomisidae	1	0	0	<b>1</b>
Trombidiformes	0	0	1	<b>1</b>
Vespidae	3	2	1	<b>6</b>

**Table 36:** Insect specimen sums and means  $\pm$  standard errors values for parasitoids and predators by Treatment at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Collections were made by yellow pan trap collections every three weeks from 25 May 2019 to 20 August 2019 (n =7).

Feeding Style	Full Bloom		Half Bloom		No Bloom	
	N	Mean $\pm$ SE	N	Mean $\pm$ SE	N	Mean $\pm$ SE
parasitoid	117	1.77 $\pm$ 0.22	113	1.82 $\pm$ 0.19	75	1.27 $\pm$ 0.09
predator	40	1.14 $\pm$ 0.07	39	1.34 $\pm$ 0.12	40	1.11 $\pm$ 0.09

#### 4.10 2019 Vegetation Sampling Analyses

While specimens were noted on vegetation cuttings (Table 37), insufficient data were collected to allow for statistical analysis. The FB plots had the greatest numbers of Aeolothripidae (FB: N = 2, HB: N = 1, NB N = 0) while Anthocoridae was found in equal numbers in the FB and HB plots (FB: N = 6, HB: N = 6, NB: N = 4), but the difference in numbers was not large enough to make any inferences. The HB plots had the greatest numbers of Thripidae HB: N =15, FB: N = 10, NB: N = 8) and Cicadellidae (HB: N = 18, NB: N = 14, FB: N = 12), and the NB plots had the greatest numbers of Aphididae (NB: N = 12, FB: N = 9, HB: N = 7), suggesting an attraction to the vegetation for these phytophagous Families. Only one Syrphidae egg was found during the vegetation sampling in the HB plot (HB: N = 1, FB: N = 0, NB: N = 0).

**Table 37:** Family insect specimen sums by Treatment and vegetation sampling date at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Vegetation samples were made by cutting one branch from each *Thymus vulgaris* plant in each plot after recovering the yellow pan traps every three weeks from 27 May 2019 to 22 August 2019 (n = 7).

Treatment	Observation Date	Syrphidae (eggs)	Aphididae	Thripidae	Cicadellidae	Anthocoridae	Aeolothripidae
Full Bloom	5/27/19	0	0	0	0	0	0
	6/10/19	0	0	1	1	0	0
	6/30/19	0	2	4	1	0	0
	7/21/19	0	6	2	4	0	0
	8/13/19	0	0	0	2	1	0
	9/1/19	0	1	3	1	3	0
	9/22/19	0	0	0	3	2	2
Half Bloom	5/27/19	0	1	0	0	0	0
	6/10/19	0	2	1	0	0	0
	6/30/19	0	2	4	0	0	0
	7/21/19	0	1	6	4	0	0
	8/13/19	0	1	0	4	2	0
	9/1/19	0	0	4	3	2	0
	9/22/19	1	0	0	7	2	1
No Bloom	5/27/19	0	0	0	0	0	0
	6/10/19	0	7	1	1	0	0
	6/30/19	0	0	1	2	0	0
	7/21/19	0	2	2	2	0	0
	8/13/19	0	1	1	3	0	0
	9/1/19	0	2	3	2	3	0
	9/22/19	0	0	0	4	1	0
		1	28	33	44	16	3



#### 4.11 2019 Diversity Indices Results

ANOVA tests found no significant difference among the three treatments when considering specimen richness at the level of Order:  $F_{2,8} = 0.0769$ ,  $p = 0.9269$ , or Family:  $F_{2,8} = 0.0180$ ,  $p = 0.9822$ , indicating treatment had no significant influence on the number of specimens from each Order or Family and other variables were affecting the attractiveness of *T. vulgaris* plots. There was also no significant difference found among the three treatments for both the Shannon and Simpson indices of diversity at the level of Order:  $F_{2,8} = 4.5350$ ,  $p = 0.0631$ , and  $F_{2,8} = 3.2621$ ,  $p = 0.1100$ , Family:  $F_{2,8} = 2.6106$ ,  $p = 0.1529$ , and  $F_{2,8} = 3.0055$ ,  $p = 0.1247$ , or Feeding Style:  $F_{2,8} = 1.9071$ ,  $p = 0.2285$ , and  $F_{2,8} = 1.8990$ ,  $p = 0.2296$  (Table 38), indicating treatment also had no significant influence on the richness of the Order, Family, or Feeding Style attracted to *T. vulgaris* plots.

**Table 38:** One-way ANOVA comparisons of specimens collected in the three *Thymus vulgaris* treatments in the Home Garden were conducted for Order/Family richness and Order/Family/Feeding Style Shannon and Simpson Diversity index comparisons (n = 3). No significant differences ( $p \leq 0.05$ ) in richness or diversity were found between the treatments. Treatments: FB = Full Bloom, HB = Half Bloom, NB = No Bloom. P# = plot number.

Treatment /Plot #	ORDER Shannon Index	ORDER Simpson Index	ORDER Richness	FAMILY Shannon Index	FAMILY Simpson Index	FAMILY Richness	FEEDING Shannon Index	FEEDING Simpson Index
FBP1	1.23	0.42	9	1.82	0.38	38	0.97	0.55
NBP2	1.34	0.32	7	2.15	0.26	39	1.02	0.51
HBP3	1.26	0.38	8	1.75	0.33	42	0.92	0.56
FBP4	1.33	0.33	6	2.15	0.28	42	1.00	0.52
FBP5	1.26	0.37	6	1.89	0.33	31	0.95	0.55
HBP6	1.15	0.43	6	1.71	0.40	33	0.83	0.61
NBP7	1.38	0.31	7	2.08	0.26	36	1.03	0.51
NBP8	1.37	0.30	7	2.10	0.25	37	1.05	0.49
HBP9	1.30	0.34	6	2.04	0.28	35	1.04	0.50
<b>ANOVA Results</b>								
F	4.5350	3.2621	0.0769	2.6106	3.0055	0.0180	1.9071	1.8990
df	2, 8	2, 8	2, 8	2, 8	2, 8	2, 8	2, 8	2, 8
p	0.0631	0.1100	0.9269	0.1529	0.1247	0.9822	0.2285	0.2296

#### 4.12 2019 Observation Survey Results

Observation surveys recorded 228 individuals over ten weeks in the nine plots (Table 39), and the individuals of three Families and two Orders were recorded: Syrphidae (N = 58), Chrysomelidae (N = 46), Apidae (N = 39), Lepidoptera (N = 33), and Diptera (N = 52). The greatest number of individuals were observed in the FB plots (N = 93), followed by HB (N = 79), and NB (N = 56).

A chi-square test of independence identified a very significant relationship among flowering treatments and the insect recorded:  $\chi^2 (8, N = 228) = 29.61, p < 0.0001$ . A contingency table found several differences in observed values from the expected values (Table 39, an  $\chi^2$  value of 1.0 or greater signifies a significant difference). In the FB treatment, the largest deviation was a lower than expected number of Diptera: N = 14,  $\chi^2 = 2.45, -34.0\%$ , indicating Diptera were more attracted to HB (N = 14) and NB (N = 24) plots, and suggests they may have been more attracted to the plants for their foliage than their blooms. For the HB treatment, the largest deviation was a higher than expected number of Apidae: N = 21,  $\chi^2 = 4.15, +55.4\%$ , which along with a high count in the FB plot (N = 18) indicates an attractiveness of the flowering plots to pollinators. For the NB treatment, Apidae had the largest deviation with a complete absence from the plot: N = 0,  $\chi^2 = 9.58, -100\%$ , which contradicts trapping results which had the greatest specimen count for NB plots (NB: N = 23, HB: N = 19, FB: N = 19). Observation surveys were conducted on different days than trapping and the pan traps were not in the plots, indicating the yellow pan traps may have made the

NB plots more attractive to Apidae during sampling periods. In contrast, Diptera were observed in higher than expected values in the NB plot:  $N = 24$ ,  $\chi^2 = 9.87$ , +87.9%, which again indicates they were not attracted to the blooms.

Lepidoptera had a lower than expected deviation for the NB plot:  $N = 5$ ,  $\chi^2 = 1.19$ , -38.3%, which confirms their attractiveness to the blooms; specimens in FB ( $N = 16$ ) and HB ( $N = 12$ ) plots were usually observed feeding on the blossoms, while those in the NB plots were resting on the vegetation or passing through the plot.

Smaller deviations were observed for Syrphidae and Chrysomelidae.

Although only one Syrphidae specimen was captured during the study in the pan traps, they were observed in all three treatments (FB:  $N = 25$ , HB:  $N = 18$ , NB:  $N = 15$ ) with the FB and HB plots having the greatest counts. They were frequently recorded on the flowers, but were also noted flying around the plants, and may have been looking for aphid colonies in the vegetation. Syrphids were also observed resting and grooming in the NB plots, which may have also had aphids in the foliage. Chrysomelids were recorded in all treatments (FB:  $N = 20$ , HB:  $N = 14$ , NB:  $N = 12$ ) and were observed resting on the foliage and feeding on the flowers. While the FB plots had slightly higher counts, they may have been attracted to the HB by the flowers as well, and the NB plots for shelter in the exposed plot.

**Table 39:** Chi-square test of independence contingency table results for ten observation dates in the Home Garden by Treatment and arthropod Family/Order at the Home Garden in San Luis Obispo, CA in a replicate treatment experiment on *Thymus vulgaris*. Observation surveys consisted of five minute visual surveys at each plot every four to five days from 13 August 2019 to 22 September 2019 (n = 10). Values in bold have the largest deviations from the expected values.

<b>Full Bloom</b>						
<b>Family</b>	<b>N Observed</b>	<b>N Expected</b>	<b>% Deviation</b>	<b>Standardized Residuals</b>	<b><math>\chi^2</math></b>	
Syrphidae	25	23.66	+5.7%	+0.28	0.08	
Chrysomelidae	20	18.76	+6.6%	+0.29	0.08	
Apidae	18	15.91	+13.2%	+0.52	0.28	
Lepidoptera	16	13.46	+18.9%	+0.69	0.48	
<b>Diptera</b>	14	21.21	<b>-34.0%</b>	-1.57	2.45	

<b>Half Bloom</b>						
<b>Family</b>	<b>N Observed</b>	<b>N Expected</b>	<b>% Deviation</b>	<b>Standardized Residuals</b>	<b><math>\chi^2</math></b>	
Syrphidae	18	20.10	-10.4%	-0.47	0.22	
Chrysomelidae	14	15.94	-12.2%	-0.49	0.24	
<b>Apidae</b>	21	13.51	<b>+55.4%</b>	+2.04	4.15	
Lepidoptera	12	11.43	+4.9%	+0.17	0.03	
Diptera	14	18.02	-22.3%	-0.95	0.90	

<b>No Bloom</b>						
<b>Family</b>	<b>N Observed</b>	<b>N Expected</b>	<b>% Deviation</b>	<b>Standardized Residuals</b>	<b><math>\chi^2</math></b>	
Syrphidae	15	14.25	+5.3%	+0.20	0.04	
Chrysomelidae	12	11.30	+6.2%	+0.21	0.04	
<b>Apidae</b>	0	9.58	<b>-100%</b>	-3.09	9.58	
<b>Lepidoptera</b>	5	8.11	<b>-38.3%</b>	-1.09	1.19	
<b>Diptera</b>	24	12.77	<b>+87.9%</b>	+3.14	9.87	

#### 4.13 Comparison of results from the HG site in 2018 and 2019

A comparison of total specimen numbers collected in the Home Garden (HG) site in 2018 and 2019 (Table 40) found a greater number of specimens were collected in 2018 (N = 6981, not including Collembola and Psocodea) than 2019 (N = 3331).

At the Order level, eleven Orders were collected in the HG site over both years, with all eleven Orders collected in 2018, but only eight collected in 2019 (Collembola and Psocodea were counted only in 2018 and were not included in this analysis). For the eight Orders in common, in 2018 there was a higher percentage of Acari (2018 = 0.99%, 2019 = 0.24%), Araneae (2018 = 9.38%, 2019 = 0.81%), Coleoptera (2018 = 8.61%, 2019 = 2.31%), Hemiptera (2018 = 40.96%, 2019 = 18.82%), and Lepidoptera (2018 = 0.47%, 2019 = 0.18%). In 2019 the collections had a higher percentage Diptera (2018 = 3.76%, 2019 = 13.00%), Hymenoptera (2018 = 4.29%, 2019 = 10.65%), and Thysanoptera (2018 = 30.96%, 2019 = 53.96%).

At the Family level, a combined 101 Families were collected over both years, with 76 Families in 2018, and 75 Families in 2019. Of these, only 50 Families were collected in both years, and only six Families were collected in high enough numbers to be considered in the top agriculturally important Families for both years ( $\geq 100$  for 2018,  $\geq 20$  for 2019): predatory Aeolothripidae (2018: N = 167, 2019: N = 29); phytophagous Aphididae (2018: N = 1250, 2019: N = 428), Chrysomelidae (2018: N = 138, 2019: N = 23), Cicadellidae (2018: N =

139, 2019: N = 116), and Thripidae (2018: N = 1984, 2019: N = 1769); and pollinator Apidae (2018: N = 75, 2019: N = 60) (Table 41, Fig. 33).

At the Feeding Style level (Table 42), in 2018 there was a greater percentage of predator (2018 = 29.06%, 2019 = 3.57%) and phytophagous/chewing specimens (2018 = 7.59%, 2019 = 1.92%), while in 2019 there was a greater percentage of parasitoid (2018 = 1.63%, 2019 = 9.19%), phytophagous/piercing (2018 = 52.74%, 2019 = 71.24%), and pollinator (2018 = 1.10%, 2019 = 1.77%).

**Table 40:** Comparison of Family insect specimen sums and % of total for all Order/Families specimens collected in *Thymus vulgaris* plots in the Home Garden in San Luis Obispo, CA in 2018 (n = 18) and 2019 (n = 7). Family names in bold are top Families in both 2018 and 2019.

Order/Family	Home Garden 2018		Home Garden 2019	
	N	% of Total	N	% of Total
<b>Acari</b>	<b>102</b>	<b>0.99</b>	<b>8</b>	<b>0.24</b>
Acari, unid. Family	0	0.00	2	0.06
Anystidae	25	0.36	0	0.00
Bdellidae	22	0.32	4	0.12
Mesostigmata, unid. Family	33	0.47	0	0.00
Prostigmata	0	0.00	1	0.03
Trombidiformes, unid. Family	22	0.32	1	0.03
<b>Araneae</b>	<b>652</b>	<b>9.38</b>	<b>27</b>	<b>0.81</b>
Araneae, unid. Family	32	0.46	3	0.09
Clubionidae	25	0.36	1	0.03
Linyphiidae	426	6.13	13	0.39
Lycosidae	2	0.03	1	0.03
Oxyopidae	10	0.14	0	0.00
Philodromidae	1	0.01	0	0.00
Salticidae	6	0.09	3	0.09
Tetragnathidae	5	0.07	0	0.00
Theridiidae	76	1.09	5	0.15
Thomisidae	69	0.99	1	0.03
<b>Coleoptera</b>	<b>598</b>	<b>8.61</b>	<b>77</b>	<b>2.31</b>
Brentidae	1	0.01	0	0.00
<b>Chrysomelidae</b>	138	1.99	23	0.69
Coccinellidae	75	1.08	10	0.30
Coleoptera, unid. Family	4	0.06	1	0.03
Corylophidae	15	0.22	2	0.06
Cryptophagidae	0	0.00	4	0.12
Curculionidae	0	0.00	1	0.03
Elateridae	2	0.03	0	0.00
Latridiidae	3	0.04	0	0.00
Melyridae	14	0.20	23	0.69
Mordellidae	6	0.09	0	0.00
Scraptiidae	0	0.00	1	0.03
Staphylinidae	11	0.16	9	0.27
Tenebrionidae	319	4.59	0	0.00
Throscidae	10	0.14	3	0.09
<b>Dermaptera</b>	<b>29</b>	<b>0.42</b>	<b>0</b>	<b>0.00</b>
Forficulidae	29	0.42	0	0.00
<b>Diptera</b>	<b>261</b>	<b>3.76</b>	<b>433</b>	<b>13.00</b>
Agromyzidae	0	0.00	34	1.02
Bombyliidae	0	0.00	1	0.03
Cecidomyiidae	0	0.00	15	0.45



**Table 40 cont.:** Comparison of Family insect specimen sums and % of total for all Order/Families specimens collected in *T. vulgaris* plots in the Home Garden in San Luis Obispo, CA in 2018 (n = 18) and 2019 (n = 7). Family names in bold are top Families in both 2018 and 2019.

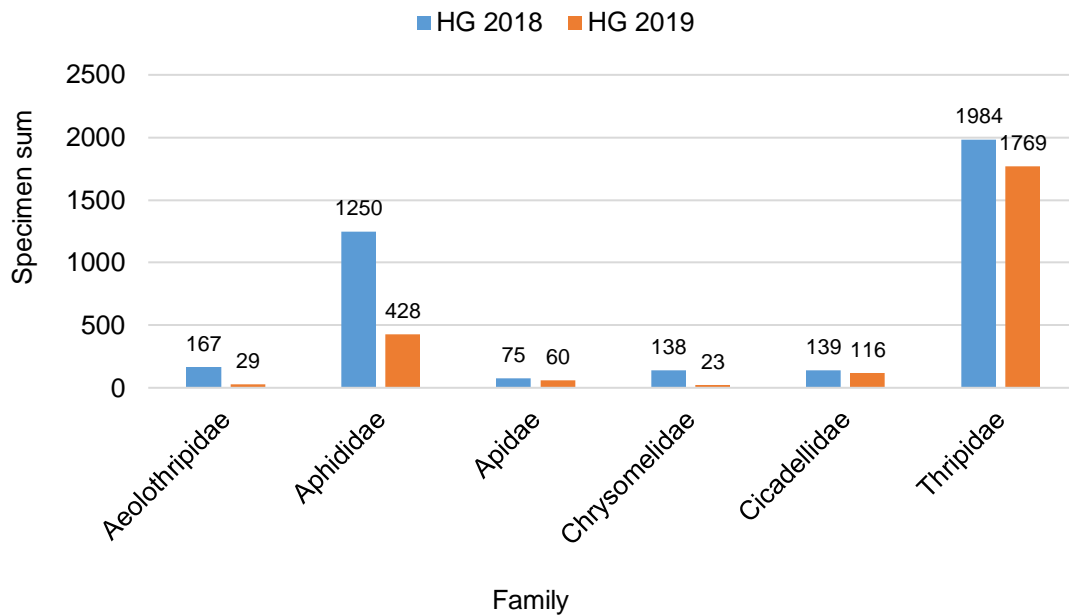
Order/Family	Home Garden 2018		Home Garden 2019	
	N	% of Total	N	% of Total
<b>Diptera cont.</b>				
Chamaemyiidae	2	0.03	2	0.06
Chloropidae	7	0.10	2	0.06
Conopidae	0	0.00	6	0.18
Diptera, unid. Family	32	0.46	5	0.15
Dolichopodidae	0	0.00	14	0.42
Ephydriidae	6	0.09	0	0.00
Heleomyzidae	0	0.00	9	0.27
Hybotidae	0	0.00	9	0.27
Muscidae	0	0.00	221	6.63
Mycetophilidae	0	0.00	5	0.15
Phoridae	1	0.01	13	0.39
Psychodidae	1	0.01	3	0.09
Sciaridae	141	2.03	74	2.22
Simuliidae	9	0.13	0	0.00
Sphaeroceridae	31	0.45	0	0.00
Syrphidae	27	0.39	1	0.03
Tachinidae	4	0.06	21	0.63
<b>Hemiptera</b>	<b>2846</b>	<b>40.96</b>	<b>627</b>	<b>18.82</b>
Aleyroididae	0	0.00	37	1.11
Anthocoridae	824	11.86	13	0.39
<b>Aphididae</b>	1250	17.99	428	12.85
<b>Cicadellidae</b>	139	2.00	116	3.48
Coreidae	1	0.01	1	0.03
Geocoridae	112	1.61	1	0.03
Hemiptera, unid. Family	81	1.17	0	0.00
Kinnaridae	5	0.07	2	0.06
Largidae	2	0.03	0	0.00
Miridae	348	5.01	5	0.15
Nabidae	63	0.91	3	0.09
Pentatomidae	11	0.16	0	0.00
Piesmatidae	1	0.01	0	0.00
Psyllidae	0	0.00	16	0.48
Reduviidae	0	0.00	1	0.03
Rhopalidae	9	0.13	4	0.12
<b>Hymenoptera</b>	<b>298</b>	<b>4.29</b>	<b>355</b>	<b>10.65</b>
Aphelinidae	18	0.26	6	0.18
<b>Apidae</b>	75	1.08	60	1.80
Argidae	0	0.00	2	0.06
Bethylidae	2	0.03	18	0.54
Braconidae	38	0.55	9	0.27

**Table 40 cont.:** Comparison of Family insect specimen sums and % of total for all Order/Families specimens collected in *T. vulgaris* plots in the Home Garden in San Luis Obispo, CA in 2018 (n = 18) and 2019 (n = 7). Family names in bold are top Families in both 2018 and 2019.

Order/Family	Home Garden 2018		Home Garden 2019	
	N	% of Total	N	% of Total
<b>Hymenoptera cont.</b>				
Ceraphronidae	0	0.00	3	0.09
Chalcidoidea	2	0.03	0	0.00
Cynipidae	0	0.00	2	0.06
Diapriidae	1	0.01	0	0.00
Encyrtidae	6	0.09	47	1.41
Eulophidae	4	0.06	3	0.09
Eurytomidae	0	0.00	1	0.03
Figitidae	1	0.01	1	0.03
Formicidae	113	1.63	8	0.24
Hymenoptera, unid. Family	2	0.03	6	0.18
Ichneumonidae	1	0.01	0	0.00
Megaspilidae	13	0.19	1	0.03
Mymaridae	2	0.03	97	2.91
Platygastridae	9	0.13	48	1.44
Pompilidae	0	0.00	1	0.03
Proctotrupidae	4	0.06	0	0.00
Proctotrupoidea	0	0.00	2	0.06
Pteromalidae	5	0.07	5	0.15
Sphecidae	0	0.00	1	0.03
Trichogrammatidae	2	0.03	28	0.84
Vespidae	0	0.00	6	0.18
<b>Lepidoptera</b>	<b>33</b>	<b>0.47</b>	<b>7</b>	<b>0.18</b>
Crambidae	1	0.01	0	0.00
Hesperiidae	1	0.01	0	0.00
Lepidoptera, unid. Family	31	0.45	7	0.18
<b>Neuroptera</b>	<b>10</b>	<b>0.14</b>	<b>0</b>	<b>0.00</b>
Chrysopidae	10	0.14	0	0.00
<b>Orthoptera</b>	<b>1</b>	<b>0.01</b>	<b>0</b>	<b>0.00</b>
Tettigoniidae	1	0.01	0	0.00
<b>Thysanoptera</b>	<b>2151</b>	<b>30.96</b>	<b>1798</b>	<b>53.96</b>
<b>Aeolothripidae</b>	167	2.40	29	0.87
<b>Thripidae</b>	1984	28.55	1769	53.09
<b>Grand Total</b>	<b>6981</b>		<b>3332</b>	

**Table 41:** Comparison of Family insect specimen sums and % of total of the top agriculturally important Families collected in *Thymus vulgaris* plots in the Home Garden in San Luis Obispo, CA in 2018 (n = 18) and 2019 (n = 7).

Family	2018 Totals		2019 Totals			Total	% of Total
	Home Garden	% of Total	Full Bloom	Half Bloom	No Bloom		
Aeolothripidae	167	2.57	7	15	7	29	0.95
Aphididae	1250	19.24	123	142	163	428	14.01
Apidae	75	1.15	18	19	23	60	1.96
Chrysomelidae	138	2.12	8	7	8	23	0.75
Cicadellidae	139	2.14	34	47	35	116	3.80
Thripidae	1984	30.54	638	671	460	1769	57.91



**Figure 33:** Comparison of Family insect specimen sums of the top agriculturally important Families collected in *Thymus vulgaris* plots in the Home Garden in San Luis Obispo, CA in 2018 (n = 18) and 2019 (n = 7). HG = Home Garden.

**Table 42:** Comparison of insect specimen sums and % of total by Feeding Styles collected in *Thymus vulgaris* plots in the Home Garden in San Luis Obispo, CA in 2018 (n = 18) and 2019 (n = 7).

Feeding Style	2018		2019	
	N	% of Total	N	% of Total
parasitoid	114	1.63	306	9.18
predator	2030	29.06	119	3.57
predator/phytophagous	325	4.65	n/a	--
phytophagous/chewing	530	7.59	64	1.92
phytophagous/piercing	3684	52.74	2374	71.25
pollinator	77	1.10	60	1.80
other	225	3.22	410	12.30
	<b>6981</b>		<b>3332</b>	

## 5 DISCUSSION

### 5.1 Attractiveness of *Thymus vulgaris*

This study was the first to consider the attractiveness of *T. vulgaris* to all arthropod visitors, with a focus on agricultural natural enemies and phytophagous insects in California. Researchers have looked at the attractiveness of other *Thymus* species to natural enemies and pollinators (Al-Doghairi & Cranshaw, 1999; Barbir et al., 2016), but only two studies have been published which specifically include *T. vulgaris*. Both were conducted in Poland and focused on the attractiveness of *T. vulgaris* to adult Syrphidae (Kelm et al., 2009; Wojciechowicz- Żytka & Jankowska, 2017). There is no published research on the attractiveness of *T. vulgaris* to other predator Families. Several studies have looked at the attractiveness of parasitoids to *Origanum vulgare* (Belz et al., 2003; Wäckers, 2004; Wanner et al., 2006; Winkler et al., 2005), a closely related species to *T. vulgaris* similar in habit and flower structure, but their results are not interchangeable with *T. vulgaris*. The current study is also the first to document the use of *T. vulgaris* vegetation by natural enemies for alternative prey and hosts. This includes considering the attractiveness of *T. vulgaris* to agricultural phytophagous insects, which would be an important factor in the potential of *T. vulgaris* to be a selective food resource for natural enemies.

Collection numbers from the current study indicate *T. vulgaris* is attractive to both natural enemies and phytophagous insects. In 2018, over 32,200 individual specimens were collected with 43 Families classified as natural enemies (parasitoid or predator) and 27 as phytophagous (piercing or chewing).

In 2019, over 3,330 specimens were collected with 38 Families classified as natural enemies and 12 as phytophagous. While it was not possible for the current study to definitively differentiate between the attractiveness of *T. vulgaris* to natural enemies for floral foods or for resources in the vegetation, inferences could be made from the feeding style analyses of the most common Families.

In 2018 the majority of natural enemies collected were predators, of which four Families have been documented using pollen or nectar resources:

Aeolothripidae, Anthocoridae, Coccinellidae, and Syrphidae; in 2019, the only predatory Family collected in substantial numbers was Aeolothripidae.

Anthocoridae, Coccinellidae, and Syrphidae are frequently used in biological control programs (Bugg et al., 2008; Wäckers & van Rijn, 2012) and have been the subject of several studies examining their response to floral resources (Bertolaccini et al., 2008; Gillespie et al., 2011; Lundgren, 2009; Pinheiro et al., 2013; Pumariño et al., 2012; Zhao et al., 2017). Anthocoridae fecundity has been shown to increase with access to pollen (Cocuzza et al., 1997), access to nectar can increase the longevity of Coccinellidae (Walton & Isaacs, 2011b) and serve as alternative food when prey is scarce (Bertolaccini et al., 2008), Syrphidae females require pollen for successful oviposition while nectar is used by both sexes (Omkar & Mishra, 2016), and pollen may play an important role in the life history of Aeolothrips (Kirk, 1997; Trdan et al., 2005). As predators it is likely these Families were also attracted to *T. vulgaris* as a source of prey.

Anthocoridae and Aeolothripidae are predators on an assortment of small insects (Triplehorn et al., 2005) and would have been attracted by the high numbers of

aphids and thrips in the plots. Coccinellid adults and larvae are predators on aphids and other soft-bodied insects (Obrycki et al., 2009), and many species of Syrphidae have aphidophagous larvae (Bugg et al., 2008; Omkar & Mishra, 2016). The distribution of adult coccinellids and syrphids is often influenced by prey densities and the presence of larval stages of both Families in 2018 confirms adults found enough prey resources for suitable oviposition conditions (Almohamad et al., 2009; Bertolaccini et al., 2008; Smith et al., 2015). Two additional hemipteran Families collected in 2018, Geocoridae and Nabidae, are considered general predators and feed on a wide range of insects. These species are not commonly used in biological control programs but are often reported in surveys of natural enemies using floral resources (Balzan et al., 2014; Gontijo et al., 2013; Nicholls et al., 2000). There is limited research indicating their use of nectar or pollen resources (Lundgren, 2009), suggesting they were attracted to *T. vulgaris* as a source of prey. Study plots also attracted Araneae, in particular high numbers of Linyphiidae, Theridiidae, and Thomisidae. Spiders are considered general predators, and while they are usually not the focus of biological control studies they may play an important role in perennial cropping systems such as orchards (Markó & Keresztes, 2014; Rodríguez-Gasol, et al., 2019). While spiders have been known to ingest nectar and pollen (Markó & Keresztes, 2014), it is much more probable they were attracted to *T. vulgaris* plants by the diverse prey available and the dense cover provided by the vegetation.

Several hymenopteran parasitoid Families were attracted to *T. vulgaris* both years, but only one, Braconidae, was collected in substantial numbers in 2018. In 2019 high numbers of four micro-hymenopteran Families were recorded: Encyrtidae, Mymaridae, Platygasteridae, and Trichogrammatidae. Statistical analysis in 2019 found Mymaridae was collected in significantly greater numbers than four other top natural enemies and Platygasteridae was collected in significantly greater numbers than Tachinidae. Encyrtidae, Mymaridae, and Trichogrammatidae are commonly used in biological control programs for a variety of pests (Flint et al., 1998) and species of some are commercially available for inundative biological control releases (Flint et al., 1998). There is extensive literature on parasitoid attraction to and the use of various floral resources (Bianchi & Wäckers, 2008; Russell, 2015; Sivinski et al., 2011; Winkler et al., 2005), including members of the Lamiaceae (Lowery et al., 2007; Wäckers, 2004). This suggests parasitoids may have been attracted to *T. vulgaris* flowers, and treatment results in 2019 did find parasitoids were attracted in greater numbers to those plots where half or all of the plants were allowed to bloom. Parasitoids may have also been attracted to *T. vulgaris* vegetation in search of oviposition sites. The presence of mummified aphids in 2018 collections confirms parasitoids were using the plants as a source of hosts (Flint et al., 1998). Parasitized aphid mummies dislodged from plants during 2018 pot tap collections were included in overall Aphididae counts, but only comprised between four and six percent of the aphid count by location. Only a small portion of the parasitized aphids may have been collected due to the nature of aphid mummies adhering to



the leaf surface (Headrick, 2016), which may have contributed to an underestimate of the actual parasitism rate. Of the parasitoids collected in 2019, Mymaridae and Trichogrammatidae are parasitoids of insect eggs, while Encyrtidae and Platygasteridae parasitize both eggs and larval stages of various species, including sternorrhynchous Hemiptera such as aphids (Triplehorn et al., 2005). Parasitized aphids were recorded only in 2018, and parasitized insect eggs were not noted in either year, consequently the attraction of *T. vulgaris* for hosts cannot be verified for 2019. Given the density and diversity of specimens collected in both years it is likely these parasitoids were also attracted to the availability of hosts within the vegetation. Parasitic Tachinidae specimens also were common in the 2019 collections. Tachinids are rarely used in biological control programs, but they can influence Lepidoptera and Coleoptera populations as well as provide pollination services (Al-Dobai et al., 2012; Flint et al., 1998). They are known to be attracted to floral nectar (Al-Dobai et al., 2012; Tooker et al., 2006), and their presence on *T. vulgaris* blooms was noted during observational surveys in 2019 (Van Wert, pers. obs.). Since tachinids usually parasitize larger prey such as caterpillars (Triplehorn et al., 2005), and no parasitized larvae were collected in either year, it is possible they were attracted to the flowers for food resources and then dispersed into the surrounding habitat in search of suitable hosts.

Several phytophagous Families were also attracted to *T. vulgaris* plots. Thripidae and Aphidae were collected in greater numbers than all other top phytophagous Families in 2018, and statistical analysis of the top phytophagous

Family data in 2019 found there were significantly greater numbers of Thripidae and Aphididae collected than other top Families, confirming their attraction to *T. vulgaris*. Cicadellidae and Chrysomelidae were also common both years, while greater numbers of Miridae were collected in 2018 and greater numbers of Agromyzidae and Aleyroididae in 2019. Aphididae, Aleyroididae, and some species of Cicadellidae are phloem feeders (Triplehorn et al., 2005) and would have been attracted to the vegetation. Thripidae feed on leaf and flower tissues, as well as pollen (Flint, 2018), and would have been attracted to both the foliage and blooms in *T. vulgaris* plots. Chrysomelidae, specifically *Diabrotica undecimpunctata* Mannerheim, and phytophagous Miridae both feed on foliage and blossoms (Flint, 2018), suggesting they may have been attracted to the flowers. Adult Agromyzidae feed on plant cell contents (Blancard, 2012), but they may have also been attracted to the foliage for oviposition sites.

## 5.2 Effect of Collection Location on *Thymus vulgaris* Attractiveness

Research has shown natural enemy populations in simple landscapes are lower than in complex ones (Bianchi et al., 2006; Chaplin-Kramer et al., 2011), and the addition of floral resources can have different attractive effects depending on the level of habitat complexity (Jonsson et al., 2015; Tschardt et al., 2005). To test the effect of habitat on the attractiveness of *T. vulgaris*, three locations were chosen in 2018 for their varying levels of complexity: the simple Home Garden (HG), the moderately complex Leaning Pine Arboretum (LPA), and the complex Master Gardeners Demo Garden site (MG). Analysis of 2018 Collection Location data found location did influence the diversity and density of

the assemblages attracted to the three *T. vulgaris* plots to varying degrees at the level of Order, Family, and Feeding Style.

Several Families were attracted in very high numbers in 2018 within all three sites, including phytophagous Aphididae and Thripidae, and predatory Anthocoridae. Aphididae and Thripidae are common in both agricultural and natural settings (Fiedler & Landis, 2007; Walton & Isaacs, 2011a), so their presence in all three sites was anticipated. The foliage and blooms of *T. vulgaris* plants may have provided resources which were limited in the habitats, especially early in the season. The high densities of Anthocoridae in all locations indicates the availability of prey was influencing their numbers more than surrounding habitat complexity (Walton & Isaacs, 2011a).

The HG plot had lowest total specimen count, but contrary to previous research regarding the effect of increasing complexity on diversity, the simple habitat had the greatest Family diversity. This may be due to several single specimen Families being found only in this plot. Many of the top Families collected in high numbers in the HG plot are known agricultural pests or natural enemies, which could be a result of years of successive organic crops in this location building resident populations (Headrick, pers. comm. 2020). The Feeding Style analysis found the HG plot had the greatest numbers of phytophagous/chewing specimens and predator numbers, reflecting greater numbers of Chrysomelidae, Anthocoridae, Geocoridae, Nabidae, and Linyphiidae. Family level analysis among locations found the HG plot attracted more Chrysomelidae than the LPA and MG plots, largely represented by the

chewing pest *D. undecimpunctata*. Adults collected in the HG plot may be a population that pupates in the soil locally and feed on the organic tomatoes, peppers, corn, summer squash, and annual flowers which are regularly planted in the field (Stoddard & DeBaise, n.d.). Individuals were seen actively feeding on the flowers (Van Wert, pers. observation) and often flew from the test plot during sampling before they could be collected, so their true numbers may be underestimated. Nabidae were also attracted to the HG plot at nine times the LPA plot and twice the MG plot. They would have been attracted to plots for access to prey, and their greater numbers in the HG plot may be a result of multiple years of crops and prey cycles compared to the less disturbed native environment of the LPA plot. While Anthocoridae were collected in the greatest numbers in the HG plot, the counts were not very different from the other locations, indicating surrounding habitat complexity had little impact on their populations. As with the Nabidae, Anthocoridae and Geocoridae numbers may be due to resident populations in the field rather than an attraction to the flowers of *T. vulgaris* plot. The general predator Linyphiidae was found in greater numbers both within the HG plot and for the HG plot among the three locations, with 4.5 times more than the MG plot and almost 16 times the LPA plot. Linyphiidae are sheet weaving spiders and the bushy structure of *T. vulgaris* may have provided suitable habitat and stable shelter in the agricultural field (Rebek et al., 2005). Linyphiidae are also small ballooning spiders; both juveniles and adults travel on air currents using a single strand of silk (Linyphiidae, n.d.), and the open environment of the HG plot may have acted as a dispersal corridor from

the surrounding habitat. In comparison, the MG and the LPA plots were more enclosed by vegetation and protected from the winds, providing better habitat for Families of hunting and tangle-web spiders.

The LPA plot had intermediate values for both total density and diversity. The location was selected to represent a native California coastal scrub habitat, but the plot was located at the edge of a large and diverse arboretum which may have influenced the diversity of specimens collected. Those specimens attracted to the LPA plot may have also been affected by the surrounding native vegetation more so than the MG and HG plots. Many of the species collected in greater numbers in the LPA plot were non-crop related native species, and some, such as the wingless encyrtid *Metanotalia maderensis* Walker, were collected only in the LPA plot. The LPA plot had the greatest numbers of Araneae, including the ambush hunters Oxyopidae and Thomisidae and tangle web weavers Theridiidae, which were attracted from the surrounding grass and native shrubs by the availability of prey within the *T. vulgaris* vegetation (Markó & Keresztes, 2014). The LPA plot also attracted the greatest number of Thripidae, but the lowest numbers of anthocorids and moderate numbers of Aeolothrips. The LPA plot was the driest and most exposed of the three plots, and while the flowering *T. vulgaris* may have provide a suitable habitat for thrips it may have been too extreme for their predators (Hoddle et al., 2000; Mendes et al., 2005). Alternatively, unlike the HG plot, the predator populations may not have been as established in the surrounding habitat and were therefore slower to respond to the increase in thrips. The LPA plot attracted greater numbers of Coccinellidae

compared to other Families. This was due to the substantial numbers of *Scymnus* and *Hyperaspis* spp. attracted to the LPA plot from the surrounding native habitat. While these smaller species may have been able to access the tubular flowers of *T. vulgaris*, the high numbers of larvae point to the attraction of available prey in the foliage. It is possible that the irrigated plants in the plot may have attracted higher concentrations of aphids than the surrounding native vegetation. In comparison, the HG plot attracted *Scymnus* sp. and various species of lady beetles including *Hippodamia convergens* Guérin-Ménéville and *Coccinella californica* Mannerheim, while the MG plot attracted the fewest coccinellids, many of which were adult or larval lady beetles of the same species in the HG plot. The lower numbers of coccinellids in the HG and MG collections may be due to a higher density of aphids in the surrounding crop and ornamental vegetation than within the plots. When comparing Feeding Styles, the LPA plot attracted the greatest numbers of parasitoids due to greater numbers of Encyrtidae and Platygasteridae. Little research has been conducted on floral resource use by these particular parasitoids (Fiedler & Landis, 2007a; Jervis et al., 1993; Pfiffner et al., 2003), so they may have been attracted from the surrounding native vegetation by either the floral resources or the potential hosts within the vegetation. One indication they were attracted by hosts is the number of parasitized aphids was the greatest in the LPA plot; some Encyrtidae are parasites of sternorrhynchous Hemiptera, including aphids, and Platygasteridae are parasites of Cecidomyiidae and Sternorrhyncha (Triplehorn et al., 2005).

The MG plot had the lowest Family diversity even though it attracted the greatest number of specimens, with 24% more than the HG plot, and 9% more than the LPA plot. This was contrary to studies which have found landscapes with higher floral density and diversity such as the MG site can attract a greater diversity of natural enemies (Ellis et al., 2005; Landis et al., 2000; Rebek et al., 2005) over simpler agricultural landscapes such as the HG site (Haenke et al., 2009; Langellotto & Denno, 2004). The MG and LPA plots both had 64 Families recorded while HG had 70 Families, suggesting a difference in Family diversity was not the reason for the higher counts in MG. A closer look at the Family level data show the difference between the MG and HG plots can be explained mainly by greater numbers of Collembola and Aphididae attracted to the MG plot. While all three plots used the same substrate mix and had the same watering regime, the MG plot was the least exposed of the three locations and the soil may have stayed damp longer, providing a suitable habitat for Collembola. The greater Aphididae numbers could be due to the higher plant diversity of the MG plot as greater plant cover can attract and harbor pests (Markó et al., 2013). The growing conditions may have also had an impact on the chemical composition of *T. vulgaris* (McGimpsey et al., 1994; Naghdi Badi et al., 2004); if the MG plants were less water-stressed they may have been more attractive to aphid colonies. In additions to Aphididae, the MG plot also attracted greater numbers of phytophagous Miridae than the LPA plot, with the Western tarnished plant bug, *Lygus hesperus* Knight, and the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), being the most common. A third mirid species collected in high

numbers at the MG and HG plots was the Western plant bug, *Rhinacloa forticornis* Reuter, which can be both a phytophagous insect and a predator but was treated as phytophagous for analysis. These three species were also collected in the LPA plot but in much lower numbers, suggesting the diverse and well-nurtured nature of the plantings at the MG plot and the crops of the HG plot were more attractive to these species than the drier LPA plot. The only Family of natural enemies collected in higher numbers at the MG plot was Syrphidae. This may be due to the complex habitat surrounding the plot, but numbers were also high in the LPA plot, suggesting flowers or prey in the plots may have had more influence than the surrounding habitat. Syrphid adults are known to require floral resources for food and reproduction (Cowgill et al., 1993; Omkar & Mishra, 2016; Nunes-Silva et al., 2010; van Rijn et al., 2013), and several were collected in plots while they were flowering. Since both aphid and syrphid larvae counts were greatest in the MG and LPA plots, it is likely syrphids were also using *T. vulgaris* for oviposition and prey resources. Both adult and juvenile numbers may be underestimated in all locations; adult syrphid flies are fast flyers and often eluded aspirator collection, and not all larvae may have been displaced by the pot tap method. The lack of natural enemies in the MG plot can be seen by comparing Feeding Style among the three locations; the MG plot had the greatest numbers of phytophagous/piercing specimens reflecting aphid and Miridae populations, and lowest numbers of both predators and parasitoids.



### 5.3 Changes in *Thymus vulgaris* Attractiveness over Collection Dates

The effectiveness of a floral resource can be dependent on the phenology of the plant species being used (Barbir et al., 2016; Bosch et al., 1997). Flowering time can affect the availability of pollen, nectar, and alternative prey for natural enemies, and can be essential to preempting pest outbreaks in an agroecosystem (Alignier et al., 2014; Landis et al., 2000; Ramsden et al., 2015). Population fluctuations over the season were seen in total numbers as well as counts within each location. Since collections took place from pre-bloom to post senescence, these fluctuations probably reflect normal population dynamics as well as Family level effects of the growth of *T. vulgaris* vegetation, the phenology of *T. vulgaris* blooms, and predator/prey cycles between natural enemies and phytophagous insects.

Each of the plots in 2018 were established with 4" non-flowering plants and as the season progressed the amount and density of the vegetation in the *T. vulgaris* plots increased. Foliage density has been found to affect both the richness and abundance of natural enemies (Markó & Keresztes, 2014; Quispe et al., 2017), due in part to denser foliage attracting phytophagous insects. In the current study aphid and thrips populations increased as the plants grew, followed by increases in Anthocoridae, Aeolothripidae, Coccinellidae, and Syrphidae. In addition to these predators the foliage provided shelter to a wide diversity of non-agriculturally important arthropods. These populations may have in turn attracted larger generalist predators such as Geocoridae, Nabidae, and the high numbers of Araneae Families recorded in all plots. At the same time, the dense vegetation

may have limited intraspecific interactions between the smaller natural enemies and the larger predatory spiders and hemipterans (Snyder, 2019). The vegetative structure of *T. vulgaris* may have also provided microclimate refuges within the sites as the season progressed and became drier, especially in the LPA plot (Gontijo, 2019). Since the vegetation in the 2018 study was not pruned, it continued to provide habitat after blooming into late summer for several Families of natural enemies, demonstrated by the high counts of Anthocoridae, Nabidae, Linyphiidae, and Theridiidae in the final collections. The use of floral resources for shelter and overwintering habitat is less studied than the provision of food or alternative prey and hosts, but research has found the availability of shelter vegetation can positively affect natural enemy abundance, diversity, and distribution (Landis et al., 2000; Griffiths et al., 2008). Although not addressed in this study, the perennial nature of *T. vulgaris* also has the potential to provide important overwintering habitat for natural enemies. Annual floral resources have often been used for enhancing natural enemies due to the management needs of most agricultural crops (Fiedler & Landis, 2007a; Tschumi et al., 2016), but these plants are not suitable for providing resources for overwintering populations. Perennial species may be preferable because they can offer secure overwintering sites for natural enemies (Buchanan et al., 2018), provide a year-round source of food and hosts (Landis et al., 2000; Pfiffner et al., 2018), and their attractiveness may even increase over the years as plants mature (Fiedler & Landis, 2007a).

Flowering stage of *T. vulgaris* plots mainly influenced population cycles of the top phytophagous Families. Phloem feeding Families such as Aphididae and Cicadellidae do not use nectar or pollen, so their populations were not directly affected by bloom status, but the flowering stage of *T. vulgaris* can have an influence on the proportions of essential oils found in the leaves. Studies have shown younger plants have higher levels of thymol while older plants have higher levels of carvacrol and camphor, chemicals which may deter feeding (Hudaib et al., 2002; Król & Kiełtyka-Dadasiewicz, 2015). Aphididae populations dropped sharply after the plants had finished blooming, suggesting as the plants matured the quality of the phloem they were feeding on may have changed, stimulating them to disperse. Thripidae, which feed on pollen as well as vegetation, responded to the reduction in floral resources after peak bloom. As *T. vulgaris* flowers senesced and pollen resources waned, thrips may have been forced to disperse from the plots into the surrounding habitat in search of food. In contrast, populations of Chrysomelidae and Miridae actually increased after peak bloom. The growth in Chrysomelidae numbers was primarily in the HG plot and for *D. undecimpunctata*, which can have multiple generations in a season. Since *T. vulgaris* blooms in the HG plot were declining by the time their numbers peaked, specimens may have been from a spillover of populations which developed within the adjacent crops, rather than the attraction of floral resources within the plot. Miridae numbers peaked two weeks after peak bloom and were consistently higher in the more complex MG site. The majority of specimens at this time were

nymphs and may have been the offspring of adults that had earlier been attracted to *T. vulgaris* blooms for nectar and pollen (Wheeler, 2001).

One of the primary goals of conservation biological control is to provide nectar and/or pollen to natural enemies when it is most needed (Colley & Luna, 2000; Jervis et al., 1993). *Thymus vulgaris* can have a long bloom season, flowering from mid spring to early summer depending on the environment (Brickell and Zuk, 1997) and may have the potential to provide floral foods over an extended time to a variety of natural enemies. Of the top Families in 2018, Anthocoridae, Aeolothripidae, Braconidae, Syrphidae, and Coccinellidae are all known to feed on floral pollen and/or nectar. Without gut analysis it is not possible to confirm if population fluctuations of these natural enemies were related to the availability of pollen or nectar within the plots, but some inferences can be made. Braconids were one of the first natural enemies recorded in the plots, arriving prior to flowering, which indicates blooms were not the primary reason they were being attracted. As plants began to bloom there was an increase in predator numbers in the plots. Pollen feeding Anthocoridae numbers decreased after peak bloom, suggesting floral resources may have influenced their populations, while pollen feeding Aeolothrips numbers began to decline before peak bloom, indicating their use of blooms was limited. Syrphidae and Coccinellidae both showed a slight increase in numbers around the peak bloom date indicating a possible attraction to floral foods. While adults of these predatory Families may have initially been attracted to the plots by the flowers, it is difficult to separate the effect of bloom status from the availability of alternate

prey or hosts also attracted to the plants. Pest and natural enemy populations often display a lag time between the establishment of prey populations and the appearance of predators or parasitoids (Headrick, 2016), and this was seen during the current study. Plots were immediately attractive to phytophagous insects, and Thripidae and Aphididae were found in greater numbers than other top Families for the first seven weeks of the study. As mentioned previously, natural enemy numbers in general increased over the study period due to increasing floral resources as well as prey numbers, but a specific predator/prey relationship was noticeable between Thripidae and Anthocoridae. Population dynamics in the HG and MG plots between the two Families indicate Anthocoridae numbers were driven more by the availability of alternative prey than floral resources and may have even had some regulating effect on thrips. In contrast, while several aphidophagous natural enemy Families were attracted to the plots, they did not seem to be linked in any specific predator/prey relationships to aphids and had little to no effect on their populations. Syrphidae and Braconidae populations were much lower than aphid numbers, while Anthocoridae and Coccinellidae numbers were out of sync with aphid population fluctuations. The remaining natural enemies in the top Families from 2018 included hemipterans Geocoridae and Nabidae, and the arachnids Linyphiidae, Thomisidae, and Theridiidae. As general predators, they were likely attracted to the increasing diversity and density of potential prey utilizing *T. vulgaris* plants over the season. While they probably did not have had a direct effect on either aphid or thrips numbers, it is possible they had an effect on intraguild predation,

which could have decreased the effectiveness of control by Anthocoridae and Aeolothripidae (Gontijo, 2019; Rusch et al., 2015; Straub et al., 2008).

#### 5.4 Effect of Treatment on *Thymus vulgaris* Attractiveness

There has been an increase in research exploring the potential of floral resources to provide additional ecosystem services beyond supporting natural enemy populations (Balzan et al., 2016; Campbell et al., 2012; Sutter et al., 2017). This involves using one floral resource planting to stack multiple services including support, regulating, cultural, and provisioning services (Fiedler et al., 2008; Westphal et al., 2015; Wratten et al., 2012). The objective of the 2019 phase of the current study was to determine whether *T. vulgaris* could be used as a dual use resource, enhancing natural enemy populations (regulating service) while also providing a marketable product (provisioning service). The timing of *T. vulgaris* vegetation harvest depends on growing conditions, phenological stage, and desired crop (Hudaib et al., 2002; Naghdi Badi et al., 2004; Özgüven & Tansi, 1998). Some studies recommend harvest be prior to bloom (Naghdi Badi et al., 2004; Salehi et al., 2014) or at full bloom (Zantar et al., 2015) to provide premium fresh vegetation or essential oils. Since pruning delays or prevents plants from flowering, harvesting before or at peak bloom could directly impact the effectiveness of *T. vulgaris* as a floral resource for natural enemies. While results from 2018 indicate *T. vulgaris* is attractive at all stages to natural enemies and phytophagous insects, the 2019 study design allowed for clarification about whether they were utilizing the plants for floral foods or alternative prey and hosts.

Statistical analysis found no significant difference in overall specimen numbers among the three treatments or when testing for interactions between Treatment and Order, Family or Feeding Style. There were also no significant differences found in Order or Family richness and diversity among the three treatments. These results suggest harvest treatment – full bloom (FB), half bloom (HB), or no-bloom (NB) – did not affect the attractiveness of the *T. vulgaris* plots to arthropods, but differences among the treatments can be seen for the top 13 agriculturally important Families.

While there was no significant difference found among treatments for any of the top natural enemy Families, all were collected in greater numbers in the flowering FB and HB plots than the NB plots, suggesting flowering treatments were more attractive to these Families. All four micro-hymenopteran Families were collected in greater numbers in either the HB or FB plots. Mymaridae numbers were greater in the HB plots followed by the FB plots. Mymaridae are egg parasitoids of several agricultural pests (Triplehorn, 2005), and some species have been shown to benefit from the nectar of floral resources (English-Loeb et al., 2003; Irvin et al., 2014; Zhu et al., 2013). Encyrtidae, Platygastriidae, and Trichogrammatidae were all collected in greater numbers in FB plots. These Families are also known to utilize floral resources (Fiedler & Landis, 2007a; Jervis et al., 1993; Witting-Bissinger et al., 2008) and may have been attracted to the blooming *T. vulgaris*. While flowers with corollas that are narrow and relatively deep, like those of *T. vulgaris*, are often inaccessible to larger parasitoids (Patt et al., 1997a; Wäckers, 2004), the tiny size of these micro-

hymenopterans may allow them to enter the flower and access the nectaries at the base of the corolla (Wäckers, 2004). It is also possible these parasitoids were attracted to hosts hidden within the plants. Vegetation sampling in 2019 found small numbers of aphids and leaf hopper nymphs, but parasitized hosts and eggs were not recorded on any of the cuttings, so the use of the plants for hosts cannot be confirmed. The two remaining natural enemies in the top agriculturally important Families – Aeolothripidae and Tachinidae – were both found in the greatest numbers in HB plots. For Aeolothripidae, this likely corresponds to the high Thripidae numbers in the HB plot although the Aeolothripidae count was too low to recognize any predator/prey relationship. As previously mentioned, Tachinidae are known to utilize nectar and pollen from floral resources, so their attraction to flowering plots would be appropriate. Still, tachinids were collected in equal numbers in the FB and NB plots, again suggesting the yellow traps may have influenced distribution in the plots.

Although not significantly different among treatments, the number of top agricultural phytophagous insects collected did vary among treatments. The only Family affected by bloom status was Thripidae whose numbers were greatest in the HB and FB treatments, indicating thrips were being attracted in part by the flowers. Agromyzidae were most frequently collected in the FB plots, but they were also common in the NB plot. Since agromyzid larvae are phytophagous leafminers, the adults may have been looking for suitable oviposition sites in the foliage rather than being attracted to the flowers. Aleyroididae, Aphididae, and Cicadellidae are phloem feeders, and bloom status should have little effect on



their distribution. Aleyroididae counts were greatest in the FB and NB plots, Aphididae in the NB and HB plots, and Cicadellidae in the HB and NB plots. Differences among counts in the three treatments were small, indicating the presence or lack of flowers was not affecting their use of *T. vulgaris*.

Chrysomelidae were represented only by *D. undecimpunctata*. As mentioned earlier, *D. undecimpunctata* is known to feed on pollen and were seen on the flowers during observation surveys, but they were collected in pan traps in equal numbers across treatments, indicating the yellow pan traps may have been influencing their distribution.

Only one pollinator Family, Apidae, was included in the top agriculturally important Families. Aphidae were collected in greater numbers in the NB plots during pan trapping than in either the HB or FB plots, while observational surveys without pan traps recorded specimens only in FB and HB plots. This indicates the results may be influenced by the pan trap color used for sampling. Yellow pan traps are commonly used for field collections of invertebrates because of their high visibility (Moreira et al., 2016; Saunders & Luck, 2013; Vrdoljak & Samways, 2012), and are known to be attractive to natural enemies including parasitoids (Bauer et al., n.d.; Epsky et al., 2008; Shweta & Rajmohana, 2018) and syrphids (Hickman et al., 2001; Laubertie et al., 2006). Pollinator studies often use a combination of yellow, white, and blue traps (Carvell et al., 2016; Hardman et al., 2016; Meyer et al., 2017), and some have shown Apidae are more attracted to blue than yellow (Campbell & Hanula, 2007; Moreira et al., 2016; Saunders & Luck, 2013). Because the focus of the current study was natural enemies and not

Apidae pollinators, yellow traps were chosen to limit incidental taking of bees. It is possible the yellow pan traps were more visible, and therefore more attractive, in the NB plots which were kept sheared to prevent blooms (Saunders & Luck, 2013), while pans in the FB and HB plots were obscured by foliage and flowers. Given that all of the top Families had relatively high counts in the NB plots, it is possible this effect was skewing collection numbers for all Families. For example, Aphididae also had higher numbers in the NB plots and Chrysomelidae had equal numbers between NB and FB plots, and yellow traps are often used to monitor both Families (Dreistadt et al., 1998; Hesler & Sutter, 1993; Ventura et al., 2005).

#### 5.5 Comparing *Thymus vulgaris* Attractiveness 2018 and 2019 in HG site

There were substantial differences in Order and Family diversity and density between 2018 and 2019 in the HG site which could impact the conclusions of this study if the data for only one year were considered. Differences in total specimen numbers between the two years could underrepresent some Orders and Families while overrepresenting others. Specifically, high numbers of predators were collected in 2018, and yet they were almost nonexistent in the 2019 collections, while parasitoids were more prevalent in 2019.

These discrepancies may be related to several variables. First, there was a difference in the weather patterns between 2018 and 2019 in San Luis Obispo which may have influenced overall arthropod survival and populations. Rainfall in 2018 was low, with less than half an inch in early April followed by dry conditions,

while in 2019 the rain continued until late May with more than three times the recorded amount in 2018. Temperatures in 2018 were also higher overall than in 2019. The warmer, drier conditions in 2018 may have provided better conditions for pupating specimens or feeding conditions for phytophagous insects and their natural enemies, leading to an increase in populations in the site. The cooler, wetter conditions in 2019 may have delayed development or even killed arthropods, which may have been reflected in the lower specimen counts. The weather differences may have also affected the *T. vulgaris* plots. The conditions in 2018 were better suited for the growth of the *T. vulgaris* plants, with well-drained substrate in the pots and the warm, dry weather leading to a dense growth of foliage and flowers. The cooler and wetter conditions in 2019, combined with the poor soil quality, may have had a negative impact on the growth and bloom density of the plants.

Second, the cropping schedule in the site was very different between the two years. In 2018 the test plot was set out on 15 April, and on 4 May a crop of organic tomatoes, peppers, corn, and summer squash was planted adjacent to the plot. As the season progressed and the crop grew denser around the plot, the number and diversity of specimens collected increased substantially as natural enemies and phytophagous insects moved between *T. vulgaris* and the crop. Conversely, in 2019 the study plots were not planted until 5 May due to a wet spring, and the crop was not planted until mid-June. This delay in the crop development likely influenced the natural enemy and prey population cycles in the field. The study plot was also separated from the crop by a distance of

several meters in 2019. Parasitoids are known to disperse at least 30m from floral resources (Lavandero et al., 2005; Scarratt et al., 2008) and syrphids can move 200m or more between food and oviposition sites (Blaauw & Isaacs, 2014; Wratten et al., 2003a), but the bare soil of the field break in 2019 may have discouraged movement between the crop and the plots (Wratten et al., 2003a).

Third, how the plants were grown, and the number of plants used, was different between years. Thyme is very sensitive to soil conditions, and while *T. vulgaris* is drought tolerant, it requires well-drained soil for optimum growth (Prasanth et al., 2014). In 2018 a peat/perlite/fir bark substrate blend was chosen to provide drainage for the potted plants, and a small amount of fertilizer was added to each container at planting time. This led to plants that were dense in both foliage and blooms and very attractive to phytophagous insects and their predators. In 2019 the plants were planted in the native soil in the HG site, which was a heavy clay. A top dressing of compost was added to the site prior to planting, but the nutrient value of this addition was unknown and may have been inaccessible due to the soil quality. This resulted in smaller plants, sparser vegetation, and fewer flowers. There was also a shift from sixteen plants in the 1m x 1m test plot in 2018 to nine plants per plot in the 2019 design, so even though there were more plots in 2019, there was a decrease in the individual plot density of foliage and flowers. Since floral area has been shown to be an important factor in the attractiveness of floral resources (Fiedler & Landis, 2007b; Miller et al., 2013; Sivinski et al., 2011), this could have impacted the

attractiveness of the plots to both natural enemies and phytophagous insects in 2019.

Finally, the sampling method and the intensity of sampling was different between the two years. The change in collection methods from the aspirator/pot taps in 2018 to the pan traps in 2019 was made primarily because planting the plots in the ground in 2019 prevented the use of the pot tap method, but it was also meant to provide a more flexible sampling protocol. This change had a direct effect on both the density and diversity of specimens collected. Specimen density decreased between 2018 and 2019. Collections in 2018 were made eighteen times and were very intensive; all individuals around or within each of the sixteen plants were sampled, resulting in just over 9100 specimens in the HG site alone. The shift to pan traps in 2019, with seven trapping dates set over 48 hours periods, was less time consuming but collected fewer specimens, slightly over 3300 specimens. The change in sampling method to pan traps also affected specimen diversity. Flying specimens in Diptera and Hymenoptera made up a greater percentage of all specimens collected in 2019, while foliage based Araneae, Coleoptera, and Hemiptera decreased. Only six Families – Thripidae, Aphididae, Cicadellidae, Chrysomelidae, Aeolothripidae, and Apidae – were in the top Families ( $\geq 20$  specimens collected) in both years. Feeding style diversity also changed. In 2018 a greater number of predators were captured than parasitoids. This suggested aspirator collections were biased towards larger, slower predators over smaller, faster parasitoids, and the switch to pan traps was in part to create an evenness in collection rates of predators and parasitoids.

While this led to higher parasitoid counts in 2019, it also decreased predator specimens, indicating the pan traps were not as effective at collecting the predators that had been present the year before. The life-stage of specimens collected was also affected by the switch to pan traps. The 2018 collections had higher counts of apterous aphids, plus more larval stages of syrphids, lepidopterans, and coccinellids, and nymphs of predators such as Anthocoridae, Nabidae and Geocoridae, which were dislodged from the vegetation during the more aggressive pot taps. In comparison, 2019 had primarily alate aphids and higher numbers of micro-hymenopteran parasitoids and flies, which would have been attracted to the traps when visiting the flowers or passing over the plots.

One natural enemy Family noticeably absent from 2019 pan trap collections was Syrphidae. Syrphid adults and larvae were recorded in the HG test plot in 2018, but adults may have been undercounted because their rapid and erratic flight patterns make them difficult to collect. The 2019 pan traps collected only one syrphid adult over seven sampling dates although many were seen in and around the plots. Why syrphids were not collected in the yellow pan traps is unclear. Researchers have reported syrphids to be attracted to the color yellow (Sutherland et al., 1999), and several studies have successfully used yellow pan traps for estimating syrphid populations (Hickman et al., 2001; Irvin et al., 1999; Laubertie et al., 2006). Some have expressed concern over traps not providing accurate estimates of populations (Moreira et al., 2016; Vrdoljak & Samways, 2012), but in the current study populations were undoubtedly underestimated. Since no syrphids were collected in the first four sampling dates,

observational surveys were started on 13 August in an attempt to better quantify syrphid visitors. Fifty-eight syrphids were recorded over 10 weeks, with almost three quarters in the FB and HB plots, indicating an attraction to the flowers. Sweep net samples taken after observation surveys collected five different species of syrphids in the study site including several specimens of *Paragus* and *Eupeodes* species, both of which have aphidophagous larvae (Bugg et al., 2008). Syrphids are known to utilize pollen and nectar resources, and in some species, males will congregate near nectar and oviposition sites to search for mates (Omkar & Mishra, 2016). Adults were observed landing on the vegetation and flowers, but feeding behavior was not recorded. Depending on the species of syrphid, the depth of the *T. vulgaris* corolla may place the nectaries out of reach (Gilbert, 1981), but the anthers extend out of the corolla lips, which should make the pollen accessible to the females (Wratten et al., 1995). Syrphid adults were also seen copulating in the plots and engaging in oviposition searching behavior in the foliage (Almohamad et al., 2009), but only one syrphid egg and no larvae were found during vegetation sampling. Syrphids move between feeding and oviposition sites (van Rijn et al., 2006), and while they may have fed on the *T. vulgaris* blossoms the scarcity of aphids in the plots in 2019 may have encouraged them to disperse into the surrounding crops to find suitable oviposition sites (Almohamad et al., 2009; Sutherland et al., 2001).

#### 5.6 Suitability of *Thymus vulgaris* as a Dual Resource

The goals of this study were to determine if *T. vulgaris* is attractive to natural enemies, and if so, can it be grown as a dual use resource, providing a

harvestable product while continuing to support pest control. To be considered a floral resource, plants must provide natural enemies with one or more of the following: nectar, pollen, alternative prey or hosts, or shelter (Landis et al., 2000). Attraction is one consideration in determining the potential of plant as a floral resource. The current study demonstrated *T. vulgaris* is attractive to a wide diversity of arthropods. This includes agriculturally important natural enemy Families such as Anthocoridae, Syrphidae, Coccinellidae, and Aeolothripidae, as well as general predators Geocoridae, Nabidae, and several Families in the Order Araneae. Parasitoid Families were also attracted, including Tachinidae and hymenopterans Braconidae, Mymaridae, Encyrtidae, Platygasteridae, and Trichogrammatidae. While several of the natural enemies collected in 2018 and 2019 are known to feed on floral foods, this study cannot conclusively state they used *T. vulgaris* as a floral resource for nectar or pollen without lab analysis of gut contents. That said, the treatment study in 2019 did find floral feeders such as Tachinidae, Syrphidae, and four micro-hymenopteran Families were more common in full or half bloom plots, suggesting they were attracted to the flowers. Data from 2018 indicated many natural enemies were attracted to *T. vulgaris* plants for alternative prey or hosts. The high numbers of Coccinellidae and Syrphidae larvae and Anthocoridae, Geocoridae, and Nabidae nymphs collected in 2018 is likely a result of the adult's attraction to suitable conditions for oviposition. The presence of parasitized aphids in 2018 establishes parasitoids such as Braconidae were using the plants for alternative hosts. The high counts of adult Araneae, Nabidae, and Geocoridae also suggests the plants also



provided a diverse mix of prey for general predators, and perhaps shelter from intraguild predation.

One of the primary issues around choosing a floral resource is its selectivity. To be a selective food a floral resource must be used only by the natural enemy of interest and not by its target prey (Baggen & Gurr, 1998). Crop pests using floral resources can be a source of alternative prey, but if a floral resource also enhances their survival and fecundity, it can compromise the plant's effectiveness for supporting natural enemy populations (Winkler et al., 2010) or even create new outbreaks that spill over into crops (Tscharntke et al., 2016). The current study found *T. vulgaris* to be attractive in both years to phytophagous Thripidae, Aphididae, Cicadellidae, Miridae, and Chrysomelidae, and to a lesser extent to Aleyrodidae and Agromyzidae in 2019. The majority of selectivity studies focus on the use of nectar or pollen by crop pests (Ambrosino et al., 2006; Lavandero et al., 2006; Irvin et al., 2006; Winkler et al., 2009), but several of the Families in the current study were primarily phloem or cell content feeders. Research has shown floral resources can be attractive to aphid, thrips, and other herbivores (Fiedler & Landis, 2007a; Markó et al., 2013; Walton & Isaacs, 2011a), but the presence of additional natural enemies may counteract the increase (Pascual-Villalobos et al., 2006). If pest populations can be kept below threshold levels, their presence in *T. vulgaris* plantings can be considered a source of alternative prey or hosts, especially if prey populations in the surrounding crop are too low to support natural enemies (Frank, 2010; Ramsden et al., 2015). A predator/prey relationship was noted in 2018 between

Anthocoridae and Thripidae, but there was not enough evidence to determine if parasitoids and predators were keeping prey populations under control. During both years there were no visible infestations of aphids or thrips on the plants. Given the chemical nature of *T. vulgaris*, it is possible the vegetation may not provide suitable nutrients for large colonies to develop, decreasing its potential as a resource. Even so, the fact that *Thymus vulgaris* is attractive to agricultural pests of concern means it cannot be considered a selective food source, and this must be considered against its potential benefit as a floral resource to natural enemies.

To be considered a dual use resource, a floral resource should offer regulating services by enhancing natural enemies as well as support an additional ecosystem service (Amoabeng et al., 2019). The second phase of this study focused on the potential of *T. vulgaris* to offer a provisioning service through the harvest of vegetation. Statistical analysis from the 2019 treatment study suggests the presence of flowers is not the primary reason most natural enemies and phytophagous insects are attracted to *T. vulgaris*. All of the top agriculturally important Families showed a non-significant difference among the three treatments, with numbers in the vegetation-only NB plots being statistically similar to blooming plots. This agrees with results from the first phase of the study, in that the attractiveness of *T. vulgaris* for many predators is related to the availability of alternative prey or hosts. If natural enemies are attracted to prey using the vegetation and not to the flowers, then the harvesting of flowers and vegetation may not have a detrimental effect on usage. It is possible these

results were an artifact of the study design or the collection method used in 2019. Each plot was only 1m square and flowering performance in 2019 was poor compared to 2018 container plants, so there was not a large floral area in the blooming plots. Floral density has been shown to affect the attractiveness of floral resources (Fiedler & Landis, 2007b; Sivinski et al., 2011) and may have decreased visitors to the FB and HB plots. In addition, the entire study site was only 15m, with 3m of distance between each plot. As discussed, natural enemies can easily disperse distances greater than 3m, and insects may have been drawn to the yellow pan traps in the NB plots after or instead of visiting flowering plots, skewing the data. Even so, actual collection counts in 2019 for the six top natural enemy Families was greatest in either the FB or HB plots, and Mymaridae was found in greater numbers in the HB plot. This indicates flowers do play a role in attraction for some Families and must be considered when evaluating the suitability of *T. vulgaris* as a dual resource. One additional consideration is the attractiveness of *T. vulgaris* plots to pollinators in the Apidae. Pollination is considered a regulating service along with pest management (Fiedler et al., 2008). While the pan traps in the treatment study had higher counts in NB plots, all Apidae recorded during observational surveys were in FB and HB plots. The majority of these specimens were native bees, which are globally in decline (Potts et al., 2010), therefore the potential of *T. vulgaris* to also support native pollinators and pollination services would increase its importance as a floral resource.

These results indicate *T. vulgaris* could be considered a floral resource for providing nectar and pollen access to some natural enemies and alternative prey to others, with the caveat pest populations may also benefit. Attraction is only one component of suitability of a floral resource. Future research should include laboratory trials to determine if floral feeding natural enemies such as Anthocoridae, Coccinellidae, Mymaridae, and Syrphidae can access nectar and pollen resources in *T. vulgaris* flowers and how it affects their longevity and fecundity. Additional studies are also needed to determine if the vegetation of *T. vulgaris* could host damaging levels of phytophagous insects such as aphids and thrips. While not considered in this study, the evergreen, perennial nature of *T. vulgaris* may make it suited to provide overwinter habitat for natural enemies, therefore a multi-year study may be required. The results from this study also suggest with proper harvesting *T. vulgaris* plants could support the dual role of regulating and provisioning. The HB plots offer an example of a compromise, allowing the harvest of material while permitting some plants to flower. Plantings of *T. vulgaris* along the margins of agroecosystems could be harvested in alternating strips, allowing the vegetation of both treatments to provide alternative prey and hosts, while the blooms of the non-harvested plants can deliver nectar and pollen to visiting natural enemies and pollinators. Future dual use research recommendations would be to incorporate larger test plots, alternative harvesting designs, and an adjacent and reliable crop to provide a broader range of specimens.

In conclusion, this study suggests *Thymus vulgaris* has potential as a drought tolerant, dual use floral resource that could be used by growers as an added tool in non-chemical approaches to pest management and to deliver pollination services, while providing income from the harvest of foliage. On a smaller scale, it also has the potential to be a beneficial, harvestable floral resource in urban gardens which can encourage the conservation of pollinators and support pest control by natural enemy populations in place of chemical pesticides.

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