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Native and non-native plant species differentially affect arthropod community dynamics with consequences for crop production in Lower Rio Grande Valley

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ABSTRACT

In agricultural ecosystems, arthropods play critical roles- including biocontrol, pollination services, and as herbivores. While herbivory negatively affects crop production, the recent decline in beneficial insect numbers have created a global concern, and consequently have led into multiple lines of conservation strategies. Agroecological practices that can provide sustenance, nesting, and refuge for beneficial organisms are considered as some of them, except we lack a better understanding of how seasonal and crop specific variation can affect their community dynamics. In this study, we examined this by investigating how native and non-native plants, when incorporated into a vegetable agroecosystem in Lower Rio Grande Valley in south Texas can influence arthropod community over their life cycle. We used a combination of different trapping systems and the following species: four species native to Texas: *Ratibidia columnifera*, *Helianthus annuus L.*, *Desmanthus virgatus var.* and *Pappophorum bicolor*. We then compared these results to the non-native species *Lobularia maritima (L.) Desv.* We found that among the arthropods trapped, pests accounted for 66.3%, and were significantly more prevalent than beneficials. More specifically, we found that sampling time and feeding guild, also affected arthropods, but not plant species or their native/ invasive status. Detailed analyses also revealed that Eulophidae was the most abundant parasitoids family, and Aleyrodidae was the most abundant herbivore family. We followed the experiment by also examining whether these differences had any consequences for eggplant, the cash crop planted post cover, although we found no significant effects. Collectively, we show that arthropod community response to vegetation is variable, and a single species may not create the interactive dynamics to meet the benefits desired in food production and needs to be examined further.

Additional index words: arthropod community, plant defenses, herbivory, ecosystem services, Rio Grande valley

The foundational purpose of agriculture is to cultivate food and feed the growing population. However, efforts to improve agricultural output are also associated with considerable negative consequences, including damage to hydrologic systems, soil health, and loss of biodiversity- most notably in insects (Forister et al., 2019; Goulson 2019; Habel et al., 2019a; Habel et al., 2019b; Ortiz-Reyes and Anex, 2018; Nath and Lal 2017). Practices associated with conventional agriculture—including heavy reliance on insecticides and monoculture—have been linked to the rapid decline in the population of pollinators and other beneficial insects (Habel et al., 2019a; Habel et al., 2019b).

Arthropods play a critical role in sustaining healthy, functional ecosystems through arthropod-mediated ecosystem services (AMES), such as biological control of pests, or pollination. However, re-

cent declines in the population of these beneficial organisms have generated global concern for the AMES (García et al., 2014; Ollerton et al., 2014; Butchart et al., 2010; Genersch, 2010; Potts, 2010; Cox-Foster et al., 2007; Kluser et al., 2007; Biesmeijer et al., 2006). Populations of bees for example, and other pollinators are declining around the world. It is estimated that, bee species richness had declined by 40% in the United Kingdom and 60% in other parts of Europe, threatening the 75% of food production in Europe that depends on pollination (Wagner, 2020; Goulson et al., 2015).

Consequently, the impact of agroecological practices that encourage stability and reliability of AMES through habitat management may help forestall arthropod decline by providing adequate sustenance, nesting, and refuges for organisms

such as pollinators and other beneficial insects. (Hudewenz, 2012; Jauker et al., 2012; Kremen et al., 2004; Kremen et al., 2002). On-farm habitat management that promotes populations of beneficial insects, for example, may help limit crop damage by insect herbivores through biological control (Isaacs et al., 2009), equating to U.S. \$4.5 billion in annual savings to farmers (Nuñez, 2020; Woodcock et al., 2019; Lichtenberg et al., 2017; Hoehn et al., 2008; Schweiger et al., 2005). These same practices may also improve populations of pollinating insects that contribute to fruit yield of 70% of crops globally, and 15 - 30% of the U.S. diet estimated to be worth of U.S. \$235-577 billion (Lorenzo-Felipe et al., 2020; Lautenbach et al., 2012; Klein, 2007; Losey and Vaughn, 2006).

The Resource Concentration hypothesis implies monocultures create odor landscapes that attract high concentrations of herbivores as a result of easier host location. Additionally, the Enemies Hypothesis predicts that higher plant diversity will attract higher rates of predators and parasitoids in ecosystems. According to these hypotheses, diverse food systems can reduce herbivore pressure by complicating host locating mechanisms as well as increasing natural enemy pressure to control pest outbreaks (Blubagh 2020; Egerer 2020; Moreira et al. 2015; Letourneau 1987; Kariyat et al., 2014). Native plants, critical components of restoration efforts, also play a significant role supporting AMES. While native plants provide nesting and refuge for beneficial insects, in addition to being a major food source for them (Schell et al. 2010), non-native plants can disrupt these services (Rai and Singh, 2020; Martinez et al., 2020; Litt et al., 2014, and references within), although they can also be beneficial. While the role of non-native plants in agroecosystems is gaining attention recently, there is only a limited number of studies examining the ability of plant species, commonly considered as weeds, in providing these services similar to native plants. A recent, detailed meta-analysis suggested the need for local and targeted studies on AMES (Litt et al., 2014), mainly to do comparative studies to understand the interplay of native and non-native plants, and their functional consequences on AMES.

To examine this, in this study we investigated how native and non-native plants incorporated into vegetable production system influence arthropod community dynamics, specifically the pests and beneficial insects' populations in the Lower Rio Grande Valley (LRGV) in south Texas. In our trials, we also examined herbivore damage to the cash crops to explore the implications of companion planting with native species as an agroecological practice.

For this study, we used four species native to Texas: *Ratibidia columnifera* (Mexican hat), *Helianthus annuus* L. (common sunflower), *Desmanthus virgatus* var *depressus* (prostrate bundleflower), and *Pappophorum bicolor* (pink pappusgrass). We then compared these results to the non-native species

Lobularia maritima (L.) Desv. (Sweet alysum) commonly used in insectary strips to attract beneficial insects (Chen et al., 2020; Tiwari et al., 2020; Brennan, 2016; Brennan, 2013). Through the study, we tested the hypotheses that the flowering forbs (*R. columnifera* and *H. annuus*) will support higher densities of parasitoids and pollinators due to their asynchronous nectar offerings and local adaptation supporting longer bloom periods (Berndt and Wratten, 2003; Johanowitz and Mitchell, 2000). We also hypothesized that the *P. bicolor* will attract more predaceous arthropods, since the species is a bunchgrass with tussock growth typical of graminoid species that have successfully provided habitat for predators (Collins et al., 2002; Thomas et al., 2002; Macleod et al., 2004). For the non-native *L. maritima*, we predicted that they would have a shorter bloom period in response to the long, hot summers in the subtropical climate, and will consequently have a lower density of beneficial and herbivorous arthropods.

METHODS

Study Site

The experiment was performed from January until the middle of August at a 5-acre farm in Edinburg, TX (26°8'78" N -98°12'406" W) in LRGV in 2020. Located in a working farm, this experiment was nested among other production crops within a 150-m² block that had been fallowed for 5-year prior to planting. In preparation, the block was tilled three times to reduce the persistence of bermudagrass (*Synn dactylon*). Soil properties of our study site were as follows: soil pH was around 8, OM <1%, texture was sandy clay loam, and had total nitrogen <0.1%.

Species Selection and Experimental Design

Details on native and non-native plant species included in this study are listed in Table 1. Eggplant (var. black beauty) was chosen based on commercial availability and recommendation from seasonal planting schedules in this region. Seedlings of eggplant used in this study were purchased from a local nursery. Using a 6 X 5 randomized block transect design (Hoshmand, 2006), 30 1-m² plots were created by separating with 1-m wide borders covered with black plastic mulch (Kinney Bonded Warehouse, Donna TX USA) under a layer of wood chips to prevent the invasion of bermudagrass and to establish clear boundaries between treatments.

Each of the six treatments (including control) were replicated 5 times (6 X 5 block design). Seeds of the five treatments were hand broadcast in respective plots and harrowed in late January 2020. Control treatments were left unplanted. We installed sprinklers (Orbit Irrigation Products, Inc, FL, USA) with 1-m² reach in the center of the plot and irrigated twice daily for 30-minutes to ensure optimal growth. In March, when the native and non-native plants were well estab-

Table 1. Tabular summary of study species, their origin, plant type, and seeding rate of pure live seed (PLS).

Treatment	Common Name	Origin	Plant Type	Seeding Rate (lb/#)
Control	Sunflower + Bermuda grass	Native + non-native	Aster, Grass	—
<i>Desmanthus virgatus var. depressus</i>	Bundleflower	Native	Legume Flowering	5 PLS
<i>Lobularia maritima</i>	Sweet Alyssum	Non-native	Brassica	2.5
Native Mix		Native	Aster, Grass, Legume	0.33 + 1 + 1.5
<i>Pappophorum bicolor</i>	Pappusgrass	Native	Grass	3 PLS
<i>Ratibida columnifera</i>	Mexican Hat	Native	Aster	2 PLS

lished, eggplant seedlings were planted in the four corners of each block. Due to logistical constraints, 3 blocks within each treatment were randomly selected for data collection.

Sampling Methods

We utilized a comprehensive insect trapping method, modified from Kariyat et al., 2018 to collect community level data on arthropods. A 1-m tall chicken wire cage was enclosed in a section of the plant of interest (for each plant treatments). Trap was equipped with a single aluminum pie pan (9" diameter) filled 3/4ths with water and a couple drops of odorless detergent (Cole-Parmer Instrument Company, LLC, Vernon Hills, IL, USA) to break surface tension, as well as two unbaited sticky traps (Pherocon® AM Yellow; Trece, Inc., Adair, OK, USA) secured to the northeast and southwest sides of the cage. Two pit fall traps (8oz plastic cups 3/4ths full of water with a couple drops of detergent) were embedded into the ground nearby. Traps set for 48-hrs on days with predicted clear weather where average temperatures ranged from 27°C – 29°C. Pit fall and pan traps were transferred into 50-mL falcon tubes (Fisher Scientific Waltham, MA, USA) and preserved in 80% ethanol (Fisher Scientific Waltham, MA, USA), and sticky traps stored 4°C for observation. For details of trap design and sampling see (Kariyat et al., 2012; 2018; Kaur and Kariyat 2020).

To collect insects on the eggplant (whole plant) we used a clear plastic bag (8" X 10"). The bag was sealed at the base trapping any arthropods present, cut at the stem, secured, and stored in a refrigerator at 4°C for at least 24-hrs. Arthropods were extracted from all plant parts and stored in glass bottles in 80% ethanol. In addition, three eggplant leaves were randomly selected to analyze plant metrics such as surface area and damage through the ImageJ computer software (NIH, Rockville, MD, USA).

All arthropods collected in this study has been stored as a reference collection at the University of Texas Rio Grande Valley. Most specimens were identified to the family under a stereoscopic microscope (Leica, EZ4HD, Wetzlar, Germany). Arthropods were identified to their family through

three primary resources: the Peterson Insect Field Guide (Borror and White, 1970), A Field Guide to Common Texas Insects (Drees and Jackman, 1998), and through online references (BugGuide.com). From this data, arthropods were categorized into six feeding guilds (sucking herbivores, chewing herbivores, predators, parasitoids, pollinators, and decomposers), and then functionally pooled into their ecosystem roles as pests or beneficials (Martinez et al., 2020; Kaur and Kariyat 2020).

Statistical Analysis

Unidentifiable arthropods (n=114) and decomposers (n= 416) composed small portions of our total collection (<1%, and <2% respectively) and were omitted from analysis. Due to the non-normal nature and the presence of over-dispersed count outcome variables, we conducted generalized linear regression (GLR) with negative binomial distribution, followed by post-hoc Tukey Kramer HSD. We used JMP statistical software (JMP, Version 15, SAS Institute Inc., NC, USA) for the analyses, and figure graphics were developed using GraphPad Prism (GraphPad Software, CA, USA). Our data analysis includes all organisms collected from pan, pit, and sticky traps collectively to better understand diversity dynamics. We examined total arthropod abundance as the response based on functional guilds across all six treatments and four collection dates, considered as factors in our models.

Statistical models

We ran ten models for the complete pooled arthropod collection. The first compares pest and beneficial arthropod abundance as the response variable with role, treatment, role x treatment, and sampling time (month) as explanatory variables. The second compares pest guild abundance as the response and factored by guild, treatment, guild x treatment, and month. The third compares beneficial guilds as the response with guild, treatment, guild x treatment, and month as factored variables. The fourth model analysed the top four pest families where abundance is the response and family, treatment, family x treatment, and month are all factors. The fifth model explores beneficial families with abundance as the response

variable and family, treatment, family x treatment, and month are factored. And, for the cash crop analyses, we ran an analysis with the number of eggplant leaves, eggplant weight, and eggplant total leaf surface area as individual response variables by treatment, month, and treatment x month as factors. In addition, for arthropod community we conducted diversity estimations using the following equations:

Species diversity

We calculated both Simpson’s index and Shannon Wiener diversity index.

Simpson’s index was calculated as:

$$D = \sum p_i^2$$

Where p_i is the proportion of the total number of individuals in the family i .

Shannon Wiener diversity index was calculated as:

$$H = -\sum p_i \ln p_i$$

Where p_i is the proportion of total abundance documented by i^{th} family, \ln is the natural logarithm. n_i is the number of organisms recorded in family i , and i is the total number of families in the sample.

RESULTS

At a very broad scale, arthropods identified as pests accounted for 66.3% of the total insects found. Sucking and piercing pests comprised 66.31% and chewing and biting herbivores were minimal at 1.1%. Beneficial arthropods constituted the remaining 32.5% with 5.4% parasitoids, 11.5% predators, and 15.7 % pollinators.

Pests and Beneficial Arthropods

Pest arthropods were significantly more than beneficial arthropods (GLR; $\chi^2 = 14.3$, $df = 1$, $p = 0.0002$), and of this, sucking herbivores had significantly larger populations than chewing herbivores (GLR; $\chi^2 = 315$, $df = 3$, $p = <0.0001$). There was also a significant difference between beneficial guilds (GLR; $\chi^2 = 14.3$, $df = 2$, $p = 0.0008$), and between beneficial families (GLR; $\chi^2 = 2.5$, $df = 4$, $p = 0.0004$), between treatments for beneficial and pest comparisons (GLR; $\chi^2 = 16.7$, $df = 5$, $p = 0.0052$), chewing and sucking herbivores (GLR; $\chi^2 = 26.1$, $df = 5$, $p = <0.0001$). Additional results and relevant statistics are described in Table 3. Eulophidae, a large Hymenopteran (wasp) family, was the most abundant beneficial arthropod in our study. Although there were no statistical differences between treatments, June produced significantly higher amounts of Eulophids (Tukey; $t = -8.83$, $df = 75$, $p = <0.0001$). We observed that the parasitoids populations plummeted from June to July (Tukey; $t = 7.87$, $df = 75$, $p = <0.0001$), following the trend of beneficial arthropods. Clearly, sampling time is a critical factor in estimating arthropod community in vegetable farms in south Texas.

Plant Species Comparisons

Our regression analyses showed a significantly higher pest presence in *D. virgatus* compared to control (Tukey; $t = -4.50$, $df = 15$, $p = 0.0039$) (Figure

2). We found significantly higher sucking herbivore densities on *D. virgatus* than *P. bicolor* (Tukey; $t = 3.55$, $df = 33$, $p = 0.0457$) and control (Tukey; $t = -4.87$, $df = 33$, $p = 0.0014$) (Figure 3.3). Of the sucking herbivore functional guild, the Aleyrodidae family (whitefly) resulted in significantly higher abundance in *D. virgatus* over control (Tukey; $t = -3.99$, $df = 51$, $p = 0.0206$) (Figure 4). We documented significantly higher populations of chewing herbivores on *L. maritima* than the native mix (Tukey; $t = 3.77$, $df = 33$, $p = 0.0269$) (Figure 2). No significance was found between treatments in beneficial functional guilds or families.

Table 2. Statistics examining the effects of arthropods on various factors such as collection date, arthropod classification, treatment, and combination of treatment and class. $df =$ degrees of freedom, $\chi^2 =$ Wald ChiSquare. Significance of $p = <0.05$ bolded.

Trait	df	χ^2	p-Value
Beneficial v. Pest			
Month	3	47.3	<0.0001
Arthropod Role	1	14.3	0.0002
Treatment	5	16.7	0.0052
Trt x Role	5	13	0.0234
Pest Guilds			
Month	1	73.3	<0.0001
Guild	1	315	<0.0001
Treatment	5	26.1	<0.0001
Trt x Guild	5	11.6	0.0415
Beneficial Guilds			
Month	3	120.7	<0.0001
Guild	2	14.3	0.0008
Treatment	5	14.7	0.0119
Trt x Guild	10	17.9	0.0559
Most Abundant Pest Families			
Month	3	61.2	0.1319
Family	4	78.5	0.0813
Treatment	5	0.72	0.9223
Trt x Family	20	30.1	0.9998
Most Abundant Beneficial Families			
Month	3	58.7	<0.0001
Family	4	2.5	0.0004
Treatment	5	2.7	0.4806
Trt x Family	20	24.4	0.8782

Cash crop (Eggplant) Fitness and Health

The analysis of arthropod community and plant traits on eggplant yielded interesting, rather surprising, results (Figure 5). We found that none of the models showed statistical significance among treatments for beneficial and pest abundance. In addition, multiple

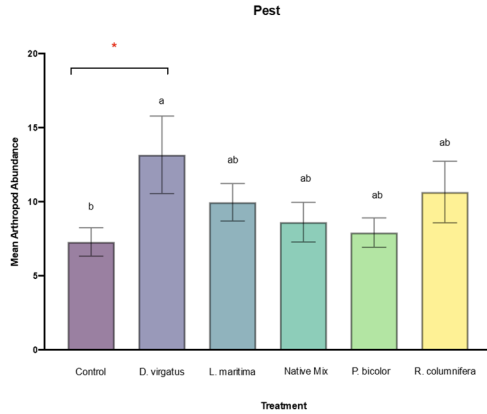


Figure 1. Mean pest arthropod abundance by treatment. *D. virgatus* shows significantly higher densities than the control (Tukey; $t = -4.5$, $df = 33$, $p = 0.0199$) ($n = 14,558$). Significance differences of $p < 0.05$ denoted by differing letters.

comparisons on pest, predator, parasitoids, and pollinators among different treatments also showed no significant differences.

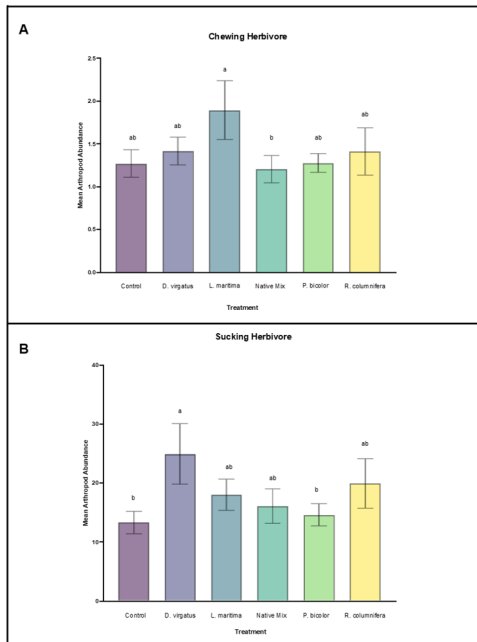


Figure 2. Mean arthropod abundance of pests by guild by treatment. **A.** Chewing herbivore pests were significantly higher in *L. maritima* than the control (Tukey; $t =$, $df =$, $p =$) and the native mix (Tukey; $t = 3.77$, $df = 33$, $p = 0.0269$) ($n=246$). **B.** Sucking herbivore pests show significantly higher densities in *D. virgatus* than the control (Tukey; $t = -4.87$, $df = 33$, $p = 0.0014$) and *P. bicolor* (Tukey; $t = 3.55$, $df = 33$, $p = 0.0457$) ($n = 14,312$). Significance of $p < 0.05$ denoted by differing letters.

Table 3. Details of statistical analyses examining effect of eggplant health and fitness on relative traits including treatment, month, and appropriate guild. Eggplant leaf damage (%) reported significant differences between months (Figure 3.8) However, all other traits analyzed showed no significance in post-hoc tests. $df =$ degrees of freedom, $\chi^2 =$ Wald ChiSquare. Significance of $p < 0.05$ bolded.

Trait	<i>df</i>	χ^2	<i>p</i>
Eggplant Fruit			
Treatment	5	0.47	0.993
Month	3	0.02	0.995
Trt x Month	15	1.66	1
Pollinator Abundance	1	0	0.98
Trt x Pollinator	5	75	0.98
Pest Abundance	1	0.02	0.937
Trt x Pest	5	1.98	0.852
Pest x Pollinator	1	<0.00	0.992
Eggplant Leaf Damage (% missing)			
Treatment	5	3.04	0.69
Month	3	16.2	< 0.000
Trt x Month	15	12.32	0.655
Pest Abundance	1	<0.00	0.952
Trt x Pest	5	0.54	0.99
Month x Pest	3	0.36	0.949
Parasitoid Abundance	1	0.01	0.932
Trt x Parasitoid	5	0.3	0.998
Month x Parasitoid	3	0.09	0.994
Predator Abundance	1	0.03	0.857
Trt x Predator	5	1.15	0.95
Month x Predator	3	0.88	0.831
Parasitoid x Pest x Predator	1	0.05	0.827
Eggplant Leaf Surface Area			
Treatment	5	0.55	0.9900
Month	3	0.55	0.99
Trt x Month	15	2.13	1.000
Number of Eggplant Leaves			
Treatment	5	6.99	0.543
Month	3	9.91	0.019
Trt x Month	15	13.78	0.543
Eggplant Weight			
Treatment	15	13.4	0.02
Month	3	18.3	0.0004
Trt x Month	15	96.7	<0.0001

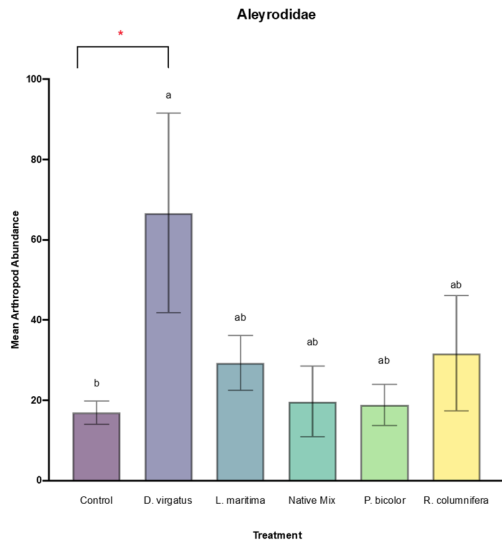


Figure 3. Mean abundance of the sucking pest *Bemisia tabaci* (Aleyrodidae) by treatment. *D. virgatus* contained significantly higher densities of whitefly than the control (Tukey; $t = -3.99$, $df = 51$, $p = 0.0206$). Significance of $p < 0.05$ is displayed with different letters.

However, comparing leaf damage (% leaf area missing) to collection dates showed differences with July experiencing greatest damage (Tukey; $F = 16.2$, $p < 0.0001$).

Table 4. Summary table on diversity indicators including the number of families and number of orders to represent richness. Shannon-Weiner and Simpson's diversity results are also calculated with the four temporal replicates. The Tukey HSD analysis reported significant difference between *P. bicolor* and *D. virgatus* in the Shannon-Wiener test. Significance of $p < 0.05$ are in bold with different letters.

Treatment	Families	Orders	H
Control	72	11	2.77 ab
<i>D. virgatus</i>	57	10	2.17 b
Lm	66	12	2.46 ab
M	64	12	2.47 ab
<i>P. bicolor</i>	65	11	2.51 a
Rc	67	9	2.49 ab

Insect community analysis

The results of diversity indicators for all six treatments including family and order richness, and Shannon Wiener and Simpson's Diversity Index showed significant results. Our analysis showed that *P. bicolor* had significantly higher diversity than *D. virgatus* (Tukey; $q = 3.18$, $p = 0.0088$), while

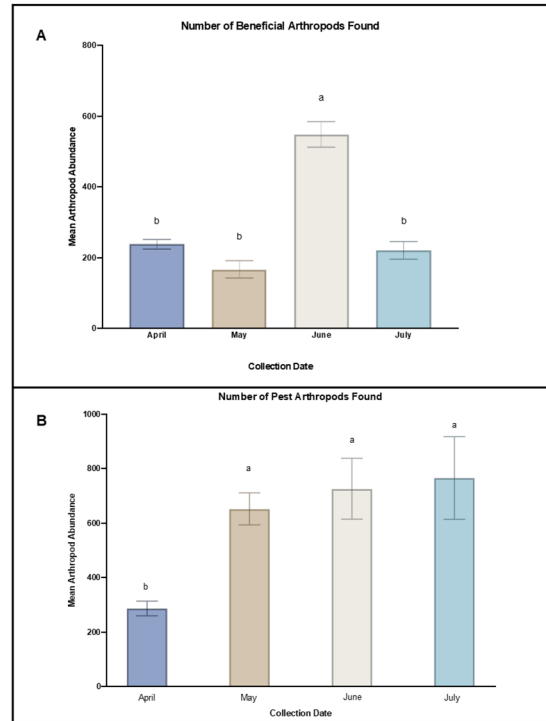


Figure 4.A. Mean beneficial arthropods found by month with June supporting significantly larger densities (Tukey; $t = -9.06$, $df = 40$, $p < 0.0001$). B. Mean pest arthropod abundance factored by collection date with April reporting significantly lower pest abundance (Tukey; $t = 11.81$, $df = 40$, $p < 0.0001$). Significance of $p < 0.05$ differing letters.

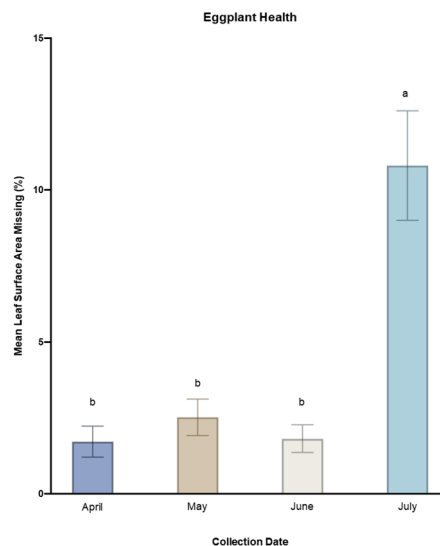


Figure 5. Eggplant leaf surface area missing by collection date. July crop damage is significantly higher than the other months (Tukey; $t = 16.2$, $df = 3$, $p < 0.0001$). Significance of $p < 0.05$ indicated by differing letters.

the Simpson's index reported no significance between the treatments.

DISCUSSION

Our treatments comparing native, non-native, and volunteer plant species showed similar results for most variables of interest. However, we recorded the highest pest populations with native legume *D. virgatus* and the lowest pest populations in our control treatment. We speculate that the crowded research plots potentially affected the growth of the eggplant alongside *H. annuus* in the control, but the creeping nature of the legume *D. virgatus* did support healthy eggplants, fruit yield, although it was not statistically significant. Regardless, our data does show a trend where these leguminous species could potentially enhance cash crop yield through niche partitioning and improvements to soil fertility, but this deserves more detailed exploration at a farm-scale.

The significance of sampling time (month) was interesting, although unsurprising. Eggplant health was significantly affected by time, estimated through percent leaf area missing, aligned with the presence of the highest densities of arthropods of all classes- during the month of June, a peak flowering period. Through our field observation, we also speculate that the slow growth rate of *D. virgatus* reduced competition for space and sunlight with eggplant, which consequently favored a visibly healthy establishment of eggplant, although not statistically significant. More importantly, in the context of arthropod community, this may have also influenced the increased presence of whiteflies, the major herbivore species found. These observations clearly warrant additional examination of whitefly - *D. virgatus* interactions. Although eggplant has been utilized as a trap crop for whitefly (Smith and McSorley 2000), the value of eggplant as a cash crop itself calls for adapted cultural approaches, i.e. trap cropping with native plants (Kalloo, 1993). Our findings suggest that *D. virgatus* could be an effective pull-crop, attracting whiteflies away from eggplant.

Examining our raw data in June, we found that the control plot, dominated by *H. annuus*, had the highest abundance of Eulophidae parasitoid populations (27%), followed by *R. columnifera* (20%). These two native flowering forbs offer necessary nectar, which has been well documented to enhance the overall fitness of these parasitoids (Zehnder et al., 2007; Wäckers 2003; Berndt and Wratten 2001; Wratten 2001; Johanowitz and Mithcell 2000). *D. virgatus* contained the highest abundance of Aleyrodidae (whitefly), a host for parasitoid Eulophids and a major pest in several crops. Our findings also suggest that nectar rewards may be preferred for this parasitoid family in our region, especially during the hottest month of June (Rasplus et al., 2020; Lahey and Polaszek 2016; Hernández-Suárez et al., 2003). Hosts are critical for synovigenic parasitoids

dependent on the nourishment for fecundity success, a key factor for biocontrol (Ye et al. 2018; Wang et al. 2014; Zhang et al. 2011; Kidd and Jervis 1989). It should also be noted that less than 1% of Eulophidae were found on eggplants, which have a very high trichome density (Kariyat et al., 2018; Kaur and Kariyat, 2020; Watts and Kariyat 2021). Trichomes are known to disrupt parasitoid productivity (Kennedy 2003; Bottrell and Gould 1998). Due to this morphological defense that has been evolved to protect against herbivores (Kaur and Kariyat 2020), enhancing agroecosystems with non-crop, but native species such as *D. virgatus* and *H. annuus* (i.e. trap crops and insectary strips), may increase the efficiency of AMES offerings from parasitoids to control pests such as whiteflies.

Dipteran insects are largely generalist pollinators, which are often underrepresented and poorly studied but contribute as the second most important insect order to animal-pollination worldwide (Larson et al. 2001). Piophilidae was the most important pollinator family in our traps. Although anthophilic flies aren't designed as efficient pollen collectors, they still add greatly to biodiversity in ecosystems and in sustaining food production with their copious floral visitation (Ssymank et al. 2008). Surprisingly, we found no significant differences among treatments or within the pollinator functional guild. This may be partially explained through the various mechanisms of plant arthropod communication that can potentially be overwhelmed by sensory noise. Since pollinators use multimodality in host recognition, relative noise differences among color, size, and scent (Kariyat et al., 2021) could also be responsible for our results, where the crowded experimental design may have affected the pollinator ability to distinguish among treatments.

The low numbers of Hymenoptera pollinators (bees) collected in our field trials is possibly an artifact of trap efficiency. While we used a comprehensive method of host plant-based trapping without baiting (Kariyat et al., 2018; 2012), adaptive vane traps (Prendergast et al. 2020; McCravy et al., 2016) have been found to capture more ambient pollinators through trap color. When employing pan traps, blue, yellow, or white colorations are often used. The impact of reflective silver from the shallow aluminum trays utilized in our study, on bees (and more largely on arthropods), is mostly unknown. Hymenoptera color preferences have been recorded as group-specific (Moreira et al., 2016) where achromatic colored flowers are often avoided by bees suggesting potential sensitivity to silver (Lunau et al., 2011). We speculate that these visual factors could have possibly deterred bee species from our traps. There are several studies comparing trapping methods for bee species (Acharya et al., 2021; McCravy et al., 2016; Joshi et al., 2015) but, since our project aimed to collect a more inclusive population of arthropods present, we did not equip these specific strategies.

In our study *D. virgatus* had a significantly lower

diversity, *H*, compared to *P. bicolor* while there was no difference among others. This could simply be because of the stronger dominance of whitefly in *D. virgatus* compared to *P. bicolor*. However, we did not find any significant difference in the Simpson's index indicating lower evenness in species distribution and dominance of a selected species (whitefly) in all the treatments.

Another confounding factor in our study was the extreme weather event due to a tropical storm just before the final trapping date, which may have impacted the beneficial arthropod community. Interestingly, we found that the pest populations remained steady from June to July, implying resiliency in the face of extreme weather events compared to the vulner-

ability observed in parasitoid populations (Niranjana et al., 2016; Romo and Tylianakis, 2013). Pollinators can also be negatively impacted by excessive precipitation as it dilutes nectar rewards, degrades pollen, overwhelms plant-pollinator communication modalities, and increases thermoregulatory costs (Lawson and Rands, 2019). Although premature to speculate based on one weather event, the evidence presented here adds to the narrative of increased risks of climate change and associated pest outbreaks, demanding the need to create more sustainable food systems to support natural predators (Stireman et al. 2005).

During our experiment, *L. maritima* (sweet alyssum) died back from 100% flower to only 40% due to the heat stress by June. Whereas native plant species re-established in August, *L. maritima* never reestablished. These observations exemplify the risk of relying only on non-native plant species which are not equipped to offer prolonged floral resources in hot, subtropical climates. Native species in this study, with prolonged asynchronous flowering, provided continuous habitat (regrowth), food, and refuge for arthropod allies. With this comes seasonal reseeded, which can save on future costs but could potentially encroach on the cash crop and would require arthropod-appropriate management. Where *L. maritima* is already used, additional native plants will add temporal diversity and increased availability of floral resources.

Taken together, as this study corroborates, arthropod community response to vegetation is variable and a single species may not create the interactive dynamics to meet the AMES desired in food production. Structural diversity is imperative to provide an array of habitat types to support an assortment of arthropods. A general guideline we applied is to combine at least three species including a flowering forb to assure carbohydrate sources are available, a grass for shelter and biomass, and a legume to improve soil and thus terrestrial and subterranean arthropods. Although the native mix did not perform as well as we expected, the establishment of a more complex vegetative community takes longer to form where accommodation for resources is at play.

LITERATURE CITED

- Acharya, R.S., Leslie, T., Fitting, E., Burke, J., Loftin, K., Joshi, N.K. 2021. Color of pan trap influences sampling of bees in livestock pasture ecosystem. *Biology* 10(5): 445.
- Berndt, L.A., Wratten, S.D., Hassan, P.G. 2002. Effects of buckwheat flowers on leafroller (Lepidoptera: Tortricidae) parasitoids in a New Zealand vineyard. *Agric. For. Entomol.* 4(1): 39-45.
- Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J., Kunin, W.E. 2006. Parallel declines in pollinators and insect pollinated plants in Britain and the Netherlands. *Science* 313(5785): 351–354.
- Borror, D.J., White, R.E. 1970. *A field guide to insects: America north of Mexico*, New York, NY: Houghton Mifflin Co.
- Bottrell, D.G., Barbosa, P., Gould, F. 1998. Manipulating natural enemies by Plant Variety selection and modification: A realistic strategy? *Annu. Rev. Entomol.* 43(1): 347–367.
- Brennan, E.B. 2016. Agronomy of strip intercropping broccoli with alyssum for biological control of aphids. *Biol. Control* 97:109-119.
- Brennan, E.B. 2013. Agronomic aspects of strip intercropping lettuce with alyssum for biological control of aphids. *Biol. Control* 65(3): 302-311.
- Butchart, S.H., Walpole, M., Collen, B., van Strein, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., LaMarque, J.F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vié, J.C., Watson, R. 2010. Global Biodiversity: Indicators of recent declines. *Science* 328(5982): 1164–1168.
- Chen, Y., Mao, J., Renolds, O.L., Chen, W., He, W., You, M., Gurr, G.M. 2020. Alyssum (*Lobularia maritima*) selectively attracts and enhances the performance of *Cotesia vestalis*, a parasitoid of *Plutella xylostella*. *Sci. Rep.* 10: 6447.
- Collins, P.J., Daghli, G.J., Bengston, M., Lambkin, T.M., Pavic, H. 2002. Genetics of resistance to phosphine in *rhyzopertha dominica* (Coleoptera: Bostrichi dae). *J. Econ. Entomol.* 95(4): 862–869.
- Cox-Foster, D.L., Conlan, S., Holmes, E.C., Pala-

- cios, G., Evans, J.D., Moran, N.A., Quan, P.L., Briese, T., Hornig, M., Geiser, D.M., Martinson, V., Vanengelsdorp, D., Kalkstein, A.L., Drysdale, A., Hui, J., Zhai, J., Cui, L., Hutchison, S.K., Simons, J.F., Egholm, M., Pettis, J.S., Lipkin, W.I. 2007. A metagenomic survey of microbes in honey bee colony collapse disorder. *Science* 318(5848): 283–287.
- Drees, B.M., Jackman, J.A. 1998. *A field guide to common Texas insects*, Houston, TX: Gulf Publishing Company.
- Egerer, M., Liere, H., Lucatero, A., Philpott, S.M. 2020. Plant damage in urban agroecosystems varies with local and landscape factors. *Ecosphere* 11(3): 1-19.
- Forister, M.L., Pelton, E.M., Black, S.H. 2019. Declines in insect abundance and diversity: We know enough to act now. *J. Soc. Conserv. Biol.* 1(8): e80.
- Garcia, K., Zimmermann, S.D. 2014. The role of mycorrhizal associations in plant potassium nutrition. *Frontiers in Plant Science* 5: 337.
- Genersch, E. 2010. Honey Bee Pathology: Current threats to honey bees and beekeeping. *Appl. Microbiol. Biotechnol.* 87(1): 87–97.
- Goulson, D., 2019. The insect apocalypse, and why it matters. *Current Biology*, 29(19): R967-R971.
- Goulson, D., Nicholls, E., Botías, C., Rotheray, E. 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Sci* 347(6229): 1255957.
- Habel, J.C., M.J. Samways, T. Schmitt. 2019.(a) Mitigating the precipitous decline of terrestrial European insects: Requirements for a new strategy. *Biodivers. Conserv.* 28: 1343-1360.
- Habel, J.C., Ulrich, W., Biburger, N., Seibold, S., Schmitt, T. 2019. (b). Agricultural intensification drives butterfly decline. *Insect Conserv. Divers.* 12(4): 289-295.
- Hernández-Suárez, E., Carnero, A., Aguiar, A., Prinsloo, H.G., LaSalle, J., Polaszek, A. 2003. Parasitoids of whiteflies (Hymenoptera: Aphelinidae, Eulophidae, Platygasteridae; Hemiptera: Aleyrodidae) from the Macaronesian archipelagos of the Canar Islands, Madeira and the Azores. *System. Biodivers.* 1(1): 55-108.
- Hoehn, P., Tschantke, T., Tylianakis, J.M., Steffan Dewenter, I. 2008. Functional group diversity of bee pollinators increases crop yield. *Proceedings of the Royal Society B: Biological Sciences*, 275(1648): 2283–2291.
- Hoshmand, A.R. 2006. *Design of experiments for agriculture and the natural sciences*, New York, NY: Chapman & Hall/CRC.
- Hudewenz, A., Klein, A.M., Scherber, C., Stanke, L., Tschantke, T., Vogel, A., Weigelt, A., Weisser, W.W., Ebeling, A. 2012. Herbivore and pollinator responses to grassland management intensity along experimental changes in plant species richness. *Biol. Conserv.* 150(1): 42–52.
- Isaacs, R., Tuell, J., Fiedler, A., Gardiner, M., Landis, D. 2009. Maximizing arthropod-mediated ecosystem services in agricultural landscapes: The role of Native plants. *Front. Ecol. Environ.* 7 (4): 196–203.
- Jauker, F., Bondarenko, B., Becker, H.C., Steffan Dewenter, I. 2011. Pollination efficiency of wild bees and hoverflies provided to oilseed rape. *Agric. Forest Entomol.* 14(1): 81–87.
- Johanowicz, D.L., Mitchell, E.R. 2000. Effects of sweet alyssum flowers on the longevity of the parasitoid wasps *Cotesia marginiventris* (Hymenoptera: Braconidae) and *Diadegma insulare* (Hymenoptera: Ichneumonidae). *The Florida Entomologist* 83(1): 41-47.
- Joshi, N.K., Leslie, T., Rajotte, E.D., Kammerer, M.A., Otieno, M., Biddinger, D.J. 2015. Comparative tapping efficiency to characterize bee abundance, diversity, and community composition in apple orchards. *Ann. Entomol. Soc. Am.* 108(5): 785-799.
- Kalloo, G. 1993. Eggplant: *Solanum melongena* L. Genetic Improvement of Vegetable Crops: 587-604
- Kariyat, R.R., Bentley, T.G., Nihranz, C.T., Stephenson, A.G., De Moraes, C.M., Mescher, M.C. 2021. Inbreeding in *Solanum carolinense* alters floral attractants and rewards and adversely affects pollinator visitation. *Amer. J. Bot.* 108 (1): 74–82.
- Kariyat, R., Chavana, J., Kaur, J. 2018. An inexpensive and comprehensive method to examine and quantify field insect community influenced by host plant olfactory cues. *Bio Protoc.* 8(16): e2967.
- Kariyat R. R., Scanlon S. R., Moraski R. P., Stephenson A. G., Mescher M. C. and De Moraes C. M. 2014. Plant inbreeding and prior herbivory influence the attraction of caterpillars (*Manduca sexta*) to odors of the host plant *Solanum carolinense* (Solanaceae). *Amer. J. Bot.* 101(2): 376-380.
- Kariyat, R.R., Mena-Alí, J., Forry, B., Mescher, M.C., De Moraes, C.M., Stephenson, A.G. 2012. Inbreeding, herbivory, and the transcriptome of *Solanum carolinense*. *Entomologia Experimentalis et Applicata*, 144(1), pp.134–144.
- Kaur, J., Kariyat, R., 2020. Role of trichomes in plant stress biology. *Evolutionary Ecology of Plant Herbivore Interaction*, pp.15–35.
- Kennedy, G.G. 2003. Tomato, pests, parasitoids, and predators: Tritrophic interactions involving the genus *Lycopersicon*. *Annu. Rev. Entomol.* 48 (1): 51–72.
- Kidd, N.A., Jervis, M.A. 1989. The effects of host-feeding behavior on the dynamics of parasitoid-host interactions, and the implications for biological control. *Res. Popul. Ecol.* 31(2): 235–274.

- Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan Dewenter, I., Cunningham, S.A., Kremen, C., Tschamtko, T. 2006. Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences* 274(1608): 303–313.
- Kluser, S., Peduzzi, P. 2007. A Global Pollinator Decline: A Literature Review. *UNEP/GRIDEurope*.
- Kremen, C., Williams, N.M., Bugg, R.L., Fay, J.P., Thorp, R.W. 2004. The area requirements of an ecosystem service: Crop pollination by native bee communities in California. *Ecology Letters* 7(11): 1109–1119.
- Kremen, C., Williams, N.M., Thorp, R.W. 2002. Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences* 99(26): 16812–16816.
- Lahey, Z.J., Polaszek, A. 2017. *Baeoentedon balios* (Hymenoptera: Eulophidae): A parasitoid of fig whitefly, *Singhiella simplex* (Singh) (Hemiptera: Aleyrodidae), new to the United States. *Int. J. Pest. Manag.* 63(4): 349351.
- Larson, B.M.H., Kevan, P.G., Inouye, D.W. 2001. Flies and flowers: Taxonomic diversity of anthophiles and pollinators. *The Canadian Entomologist* 133(4): 439–465.
- Lautenbach, S., Seppelt, R., Liebscher, J., Dormann, C. 2012. Spatial and temporal trends of global pollination benefit. *PLoS ONE*, 7(4).
- Lawson, D.A., Rands, S.A. 2019. The effects of rainfall on plant–pollinator interactions. *Arthropod Plant Interactions* 13(4): 561–569.
- Letourneau, D.K. 1987. Enemies Hypothesis: Trophic Interactions and Vegetational Diversity in Tropical Agroecosystems. *Ecology* 68(6): 1616–1622.
- Lichtenberg, E.M., Kennedy, C., Kremen, C., Batáry, P., Berendse, F., Bommarco, R., Bosque-Pérez, N.A., Carvalheiro, L.G., Snyder, W.E., Williams, N.M., Winfree, R., Klatt, B.K., Åström, S., Benjamin, F., Brittain, C., Chaplin-Kramer, R., Clough, Y., Danforth, B., Diekötter, T., Eigenbrode, S.D., Ekroos, J., Elle, E., Freitas, B.M., Fukuda, Y., Gaines-Day, H.R., Grab, H., Gratton, C., Holzschuh, A., Issacs, R., Isaia, M., Jha, S., Jonason, D., Jones, V.P., Klein, A.M., Krauss, J., Letourneau, D.K., Macfadyen, S., Mallinger, R.E., Martin, E.A., Martinez, E. Memmott, J., Morandin, L., Neame, L., Otieno, M., Park, M.G., Pfiffner, L., Pockock, M.J.O., Ponce, C., Potts, S.G., Poveda, K., Ramos, M., Rosenheim, J.A., Rundölf, M., Sardiñas, H., Saunders, M.E., Schon, N.L., Sciligo, A.R., Sidhu, C.S., Steffan-Dewenter, I., Tschamtko, T., Vesely, M., Weisser, W.W., Wilson, J.K., Crowder, D.W. 2017. A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. *Global Change Biology* 23 (11): 4946–4957.
- Litt, A.R., Cord, E.E., Fulbright, T.E., Schuster, G.L. 2014. Effects of invasive plants on arthropods. *Conservation Biology* 28(6): 1532–1549.
- Losey, J.E., Vaughan, M. 2006. The economic value of ecological services provided by insects. *Bio Sci.* 56(4):311–323.
- Lorenzo-Felipe, I., Blanco, C.A., Corona, M. 2020. Impact of Apoidea (Hymenoptera) on the world's food production and diets. *Ann. Entomol. Soc. Am.* 113(6): 407–424.
- Lunau, K., Papiorek, S., Eltz, T., Szazima, M. 2011. Avoidance of achromatic colours by bees provides a private niche for hummingbirds. *J. Exp. Biol.* 214: 1607–1612.
- MacLeod, A., Wratten, S.D., Sotherton, N.W., Thomas, M.B. 2004. 'beetle banks' as refuges for beneficial arthropods in farmland: Long-term changes in predator communities and Habitat. *Agricultural and Forest Entomology* 6(2): 147–154.
- McCravy, K.W., Geroff, R.K., Gibbs, J. 2016. Malaise trap sampling efficiency for bees (Hymenoptera: Apoidea) in a restored tallgrass prairie. *Fla. Entomol.* 99(2): 321–323.
- Moreira, E.F., Santos, R.L da. S., Penna, U.L., Angel-Coca, C. Oliveria, F.F. de. Viana, B.F. 2016. Are pan traps colors complementary to sample community of potential pollinator insects? *J. Insect Conserv.* 20: 583–596.
- Moreira, X., Abdala-Roberta, L., Rasmann, S., Castagnayrol, B., Mooney, K.A. 2015. Plant diversity effects on insect herbivores and their natural enemies: current thinking, recent findings, and future directions. *Science Direct* 14: 1–7.
- Nath, A.J., Lal, R. 2017. Effects of tillage practices and land use management on soil aggregates and soil organic carbon in the North Appalachian region, USA. *Pedosphere* 27(1): 172–176.
- Niranjana, R.F., Devi, M., Shanika, W., Sridhar, R.P. 2015. Potential use of egg parasitoids, *Trichogramma pretiosum* Riley and *Trichogramma chilonis* Ishii against brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenée. *Trop. Agri. Res.* 27(1): 88–94.
- Núñez-Farfán, J., Valverde, P.L. 2020. *Evolutionary ecology of plant-herbivore interaction*, Cham, Switzerland: Springer.
- Ollerton, J., Erenler, H., Edwards, M., Crockett, R. 2014. Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. *Science* 346(6215): 1360–1362.
- Ortiz-Reyes, E., Anex, R.P. 2018. A life cycle impact assessment method for freshwater eutrophication due to the transport of phosphorus from agricultural production. *J. Clean. Produc.* 177: 474–482.

- Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., Kunin, W.E. 2010. Trends Ecol. Evol. 25(6): 345-353.
- Prendergast, K.S., Menz, M.H.M., Dixon, K.W., Bateman, P.W. 2020. The relative performance of sampling for native bees: An empirical test and review of the literature. *Ecosphere* 11(5): 1-22.
- Rasplus, J.-Y., Blaimer, B.B., Brady, S.G., Burks, R.A., Delvare, G., Fisher, N., Cruaud, A. 2020. A first phylogenomic hypothesis for Eulophidae (Hymenoptera: Chalcidoidea). *J. Nat. Hist.* 54(9-12): 597-609.
- Romo, C.M., Tylianakis, J.M. 2013. Elevated temperature and drought interact to reduce parasitoid effectiveness in suppressing hosts. *PLoS ONE* 8(3).
- Schell, L.M., Burnitz, K.K., Lathrop, P.W. 2010. Pollution and human biology. *Annals of Human Biology* 37(3): 347-366.
- Schweiger, O., Maelfait, J.P., van Wingerden, W., Billeter, R., Speelmans, M., Augenstein, I., Aukema, B., Aviron, S., Bailey, D., Bukacek, R., Burel, F., Diekötter, T., Dirksen, J., Frenzel, M., Herzog, F., Liira, J., Roubalova, M., Bugter, R. 2005. Quantifying the impact of environmental factors on arthropod communities in agricultural landscapes across organizational levels and spatial scales. *J. Appl. Ecol.* 42(6), pp.1129-1139.
- Smith, H.A., and McSorley, R. 2000. Potential of field corn as a barrier crop and eggplant as a trap crop for management of *Bemisia agentifolii* (Homoptera: Aleyrodidae) on common bean in north Florida. *Fla Entomol.* 83(2).
- Ssymank, A. Kearns, C.A., Pape, T., Thompson, F.C. 2008. Pollinating flies (Diptera): A major contribution to plant diversity and agricultural production. *Biodiversity* 9(1-2): 86-89.
- Stireman III, J.O., Dyer, L.A., Janzen, D.H., Singer, M.S., Lill, J.T., Marquis, R.J., Diniz, I.R. 2005. Climatic unpredictability and parasitism of caterpillars: Implication of global warming. *PNAS* 102(48): 17384-17387.
- Thomas, S.R., Goulson, D., Holland, J.M. 2002. Resource provision for farmland gamebirds: the value of beetle banks. *Ann. Appl. Biol.* 139 (1): 111-118.
- Tiwari, S., Sharma, S., Wratten, S.D. 2020. Flowering alyssum (*Lobularia maritima*) promote arthropod diversity and biological control of *Myzus persicae*. *J Asia-Pacific Entomol.* 23(3): 634-640.
- Wäckers, F.L. 2003. *Quality Control and production of biological control agents: Theory and testing procedures*, Wallingford, Oxon, UK: CABI Pub.
- Wang, C., Gibb, T. & Bennett, G.W., 2014. Evaluation of two least toxic integrated pest management programs for managing bed bugs (Heteroptera: Cimicidae) with discussion of a bed bug intercepting device. *J. Med. Entomol.* 46(3): 566-571.
- Watts, S., Kariyat, R., 2021. Picking sides: Feeding on the abaxial leaf surface is costly for caterpillars. *Planta*, 253(4).
- Woodcock, B.A., Garratt, M.P.D., Powney, G.D., Shaw, R.F., Osborne, J.L., Soroka, J., Lindström, S.A.M., Stanley, D., Ouvard, P., Edwards, M.E., Jauker, F., McCracken, M.E., Zou, Y., Potts, S.G., Rundlöf, M., Noriega, J.A., Greenop, A., Smith, H.G., Bommarco, R., van der Werf, W., Stout, J.C., Steffan-Dewenter, I., Morandin, L., Bullock, J.M., Pywell, R.F. 2019. Meta-analysis reveals that pollinator functional diversity and abundance enhance crop pollination and yield. *Nature Communications*, 10(1).
- Woodcock, B.A., Harrower, C., Redhead, J., Edwards, M., Vanbergen, A.J., Heard, M.S., Pywell, R.F. 2013. National patterns of functional diversity and redundancy in predatory ground beetles and bees associated with key UK arable crops. *J. Appl. Ecol.* 51 (1): 142-151.
- Wratten, S., Berndt, L., Gurr, G., Tylianakis, J., Fernando, P., Didham, R. 2003. Adding floral diversity to enhance parasitoid fitness and efficacy. *1st International Symposium on Biological Control of Arthropods*.
- Ye, Z.M., Jin, X.F., Inouye, D.W., Wang, Q.F., Yang, C.F. 2018. Variation in composition of two bumble bee species across communities affects nectar robbing but maintains pollinator visitation rate to an alpine plant, *Salvia przewalskii*. *Ecol. Entomol.* 43(3): 363-370.
- Zhang, Y., Li, Y., Zhang, Y., Chen, Y., Wu, K., Peng, Guo, Y. 2011. Seasonal expression of bt proteins in transgenic rice lines and the resistance against asiatic Rice Borer *Chilo suppressalis* (Walker). *Environ. Entomol.* 40(5): 1323-1330.
- Zehnder, G., Gurr, G.M., Kühne, S., Wade, M.R., Wratten, S.D., Wyss, E. 2007. Arthropod pest management in organic crops. *Annu. Rev. Entomol.* 52: 57-80.