

## Agroecological Hoarding and Sharing:

### The Role of Wildflower Patches in Augmenting Beneficials & Evidence of Invertebrate Flows into Crops.

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The Farmscape Ecology Program's entomological research at the Hudson Valley Farm Hub has two primary components:

**Evaluation of Wildflower Plantings.** Contributing to the entomological evaluation of the Native Meadow Test plots (NMTs) planted in early 2017. *Are the seed mixes we planted having any influence on pests, beneficials and invertebrate biodiversity in our plots? Do those mixes influence production in adjacent crops?*

**Long-term Invertebrate Monitoring and Field Edge-to-Center Changes in Invertebrate Communities.** Long-term, standardized, edge-to-center insect monitoring in three of the Hub's fields (8, 10 and 19); this was begun as a pilot in 2016. *Is there any evidence of long-term changes in invertebrate communities across years? Are there any consistent patterns of community change as one goes from field edge to field center?*

Below, we describe each of these aspects as two different 'chapters' of our report. Because a literature review was undertaken at the same time, this document attempts to meld field report with literature review. As a result, the citations can get a bit dense at times. Nonetheless, especially in relation to the second 'chapter', that literature review is hardly complete.

#### **Summary**

- This report covers the entomological aspects of our work exploring the effectiveness of two different native-plant seed mixes and a fallow control in supporting beneficial insects and their services. It also provides an update of our long-term insect monitoring across 600' transects into three fields at the Hudson Valley Farm Hub.
- Planted in 2017, the Native Meadow Test plots (NMTs) include a flower-rich, grass-poor seed mix ("Seed Mix A"); a flower-poor, grass-rich mix ("Seed Mix B"); and a Fallow Control. As detailed in the accompanying botanical report (Knab-Vispo 2020), each of these treatments has produced a unique plant community.
- Aside from continuing our standardized insect monitoring in the NMTs, in 2019 we planted butternut squash and broccoli next to each NMT plot and assessed growth, damage and harvest in these beds.
- We predicted that Seed Mix A would support more beneficial insects and higher crop production than the other treatments.
- The treatments did have distinct invertebrate communities. In the case of bees, butterflies (some-time pollinators, some-time pests) and possibly hover flies, Seed Mix A did indeed harbor a greater abundance. Parasitoid wasps, however, appeared to be most common in the Fallow Control.
- Although a more in-depth analysis will definitely be needed, the treatments also appeared to influence biodiversity, but because of potentially diverging patterns across treatments, the net conservation effects are not yet clear.
- At harvest, squash were larger and more numerous in the beds next to the Fallow Control. This was contrary to our expectations.

- We believe the harvest pattern may relate to the higher parasitoid populations in the Fallow Control, together with the observation that squash flowers may have been more attractive to bees when they were located next to NMTs with fewer showy flowers.
- This was the fourth year of our long-term standardized transect monitoring at the Farm Hub (although the first year was a pilot and certain changes were instituted between years one and two).
- There are no clear multi-year trends, other than a pronounced increase in slugs during the most recent years. Given the various sources of noise in our data, the lack of clear trends is to be expected.
- Our study of edge effects suggests that, in most cases, the majority of evident edge effects occurred within the first 300' of the transect, although, for certain taxa, continued trends seemed apparent between 300' and 600'.
- These edge-to-center trends are most evident early, and perhaps late, in the season and are more evident for some taxa (for example, ants and spiders and, during some seasons, bees and wasps) than for others (such as hover flies and lady beetles).
- Our directional malaise trap sampling supported the idea of an early-season flush of insects, although the limited diversity of our malaise captures meant that direct comparison with the transect capture data was not possible for some taxa.
- In sum, we believe that our native meadow treatments are influencing the occurrence of beneficials, however, the pattern of those effects and their relevance for crops were, in some cases, surprising.
- The NMT work, together with our transect work, emphasize the importance of understanding the extent, direction and timing of the flow of those organisms relevant to production.
- We propose continuing our current monitoring but expanding our study of crop effects, especially early in the growing season. We also propose deepening our understanding of diversity effects and agroecological connections through refined taxonomy for certain taxa and better assessments of parasitism.
- Our studies are revealing nuances of the effects of habitats on on-farm diversity and beneficial services. Some of those nuances may be primarily of interest to die-hard entomologists, but we believe some may have clear potential relevance for growers. As the literature review incorporated into this report illustrates, the effects of habitat management on biological control and pollination are often very context dependent, and their significance further depends on the particular farming system they are being incorporated into. While this may sound like a recipe for endless complications (and hence endless research!), we do believe that this work is helping us shape the creation of more farmer-relevant trials. For example, based on what we have learnt so far, were we to establish beetle banks at the Hub, we would tweak the composition of any seed mix planted on those banks and propose an interbank spacing of no more than 200-400'.

## ***Chapter 1: Can Wildflower Plantings Increase Beneficial Insect Populations, Enhance Crop Production, and Support Biodiversity Conservation?: A mid Hudson Valley Perspective***

### Introduction

Among the most widely noted correlates of industrial agriculture globally have been the reduction in wild habitats and the widespread use of synthetic pesticides and fertilizers. As a consequence, major decreases in invertebrate abundance and diversity are being reported at global and, in some cases, regional and farm scales (e.g., Wagner 2012, 2020, Hallmann et al. 2017, 2019, Bidau 2018, Sánchez-Bayo and Wyckhuys 2019, Seibold et al. 2019, Wepprich et al. 2019, Harvey et al. 2020), although trends in the Northeast are less clear. These declines may signify conservation challenges and agroecological impacts (Benton et al. 2003, Bergman et al. 2004, Bianchi et al. 2006, Gardiner and et al. 2009, Flynn et al. 2009, Bates et al. 2011, Gámez-Virués et al. 2015, Tschardt et al. 2016, Dainese et al. 2019, Feit et al. 2019); although biodiversity conservation and agroecological services may not always go hand-in-hand (Bothwell 2012). From a conservation perspective, some projections (Sánchez-Bayo and Wyckhuys 2019) suggest that 40% of insects will become extinct in the next “few decades” (but see Simmons et al. 2019). Furthermore, because of the resilience of relatively widespread generalists, homogenization of beta diversity may simultaneously be occurring (e.g., Bergman et al. 2004, Clark et al. 2007, Carré et al. 2009). From an agricultural perspective, loss of pollinators is a major challenge for some crops, be they organically or conventionally grown. In addition, large-scale decline in the diversity and abundance of ‘natural enemies’ – such as predatory insects and spiders and parasitoid wasps – makes organic production more difficult by reducing the options for and redundancy in biological control (Letourneau and Goldstein 2009, Crowder et al. 2010, Walton 2013, Feit et al. 2019). Almost by definition, pests are less likely to be negatively impacted by industrial agriculture than beneficial invertebrates, meaning that, in some ways, conventional agriculture is self-perpetuating, because its continued use will leave organic farmers with fewer and fewer tools (see Thies et al. 2003, Bianchi et al. 2006, Chaplin-Kramer et al. 2011, for the differential response of pests and beneficials to landscape complexity and composition, but see Arnold et al. 2019 for complications in this pattern; see Lavigne et al. n.d., Östman et al. 2001 regarding the effects of pesticides on pest predation). Habitat removal in the name of food safety has likewise been shown to reduce biocontrol options (Letourneau et al. 2015).

While pesticides often play a key role in shaping communities of beneficials (e.g., Monteiro et al. 2013), habitat availability is also key. Providing that habitat involves management across varying scales (Ekroos et al. 2016) and entails both maintaining natural habitats and creating farming techniques which incorporate habitat creation. In terms of farm-scale management, it has become increasingly evident that, at least in some landscapes, simply reducing pesticide applications is not sufficient for reversing insect decline. Instead, supplemental resources such as food and/or shelter need to be provided.

One approach that has been seen as especially effective is the planting of flowers (<https://www.conservationevidence.com/actions/442>, Meek et al. 2002, Powell et al. 2004, Boller et al. 2004, van Rijn et al. 2008, Hogg et al. 2011, Blaauw and Isaacs 2012, Balmer et al. 2013, Varennes 2015, Tschumi et al. 2016, Campbell et al. 2017, Hatt 2017, McCabe et al. 2017, Pfister 2017, Sutter et al. 2018, Cipkowski 2019, Pollier et al. 2019, Rodríguez-Gasol et al. 2019, but see Poveda et al. 2008 for comparison with other diversification techniques and see Phillips and Gardiner 2015 and Quinn et al. 2017 for contrasting results). Flowers themselves can provide pollen and nectar resources not only to pollinators, thereby helping to tide them over food shortages, but also to parasitoid wasps, who as adults feed upon nectar. Perennial, as opposed to annual, plantings may be especially effective (Helms et al. 2020). Many of these insects will be further helped if a perennial (vs annual) planting is created, because plant stalks can provide shelter and the freedom from plowing can support ground-dwellers. Native plants may be most effective, both for biodiversity conservation (Burghardt et al. 2009, Tallamy and Shropshire 2009, Tallamy 2017, but see Vodraska 2008, Vispo and Knab-Vispo 2016) and support of beneficials (Isaacs et al. 2009), because specialized native herbivores may find resources, and because this herbivore diversity can, in turn, translate into predator and parasitoid diversity. As a result of these benefits, the

planting of wildflower edges, strips or even patches is widely recommended and, the USDA-NRCS and the European Union provide their respective farmers with incentives for this practice.

Nevertheless, despite its widespread application, agronomic research has suggested that the effects of wildflower plantings and other semi-natural habitats on production and conservation can be inconsistent and depend largely on landscape context (Marino and Landis 1996, Bennett 2009, Carvell et al. 2011, Klein et al. 2012, Marini et al. 2012, Balzan et al. 2016, Liere et al. 2017, Grab et al. 2018, Martin et al. 2019b, Wix et al. 2019). One simplified model (Tscharntke et al. 2005, Isaacs et al. 2009, Jonsson et al. 2015, but see Dainese et al. 2015 and, more forcefully, Karp et al. 2018) is that in heavily farmed landscapes, little diversity remains that can take advantage of habitats even when they're made available. At the opposite end of the spectrum, on farms surrounded by abundant wild habitats, small-scale farm plantings have little demographic importance, relative to the abundance of resources in the surrounding landscape. Thus, it is in landscapes with medium levels of wild habitat, where beneficials might still be present but limited by resource shortages, that habitat additions such as wildflower plantings might have the most impact. Not surprisingly, landscape effects will differ across organisms, nuancing any generalities (Burel et al. 2004, Rand and Tscharntke 2007, Carré et al. 2009, Holzschuh et al. 2010, Haapakoski et al. 2013, Shackelford et al. 2013, Winfree et al. 2018). This general model has been supported by several studies, including some in the Northeastern US (Winfree et al. 2008) suggesting that, in our generally habitat-rich landscape, native bee populations are relatively unaffected by on-farm habitat management. Indeed, it is evident that most of the habitat management techniques being encouraged and governmentally supported in the Northeast derive from work done in much more intensively farmed landscapes such as the Midwest, the Central Valley of California, and Europe. The effects of semi-natural habitat on biodiversity conservation in semi-agricultural landscapes is likewise context dependent (Luppi et al. 2018). Context may even effect the physiologies and phenologies of select species, thereby shaping their ability to survive under different land use regimes (Leong et al. 2016, Lebeau et al. 2018, Grab et al. 2019b).

Taken together, these details mean that predicting the effectiveness of habitat creation in understudied environments, such as the Northeast, is difficult and so field studies are crucial (see Duru et al. 2015 on the need for place-based, system-specific research, and Karp et al. 2018 and Settele and Settle 2018 for why local management needs to be included in data gathering and model making). In light of this, we undertook to test the efficacy of wildflower plantings in promoting beneficials and biodiversity in the context of an organically managed farm set in a relatively diverse Hudson Valley landscape.

Furthermore, it is clear that "wildflower mix" can encompass a wide variety of flowers, but that the precise species composition of such mixes can determine their effectiveness (e.g., Forehand et al. 2004, Fitzgerald and Solomon 2004, Dib et al. 2012, Campbell et al. 2017, Hatt 2017). We therefore not only compared two different mixes and a fallow control (with flowering weeds), but carried out extensive floral observations in order to understand which components of our seed mixes might be most used, and hence what improvements in species composition might be advisable.

Measuring 'efficacy' requires a multi-tiered approach. Invertebrate abundance and diversity can be measured and compared across plots. Our prediction was that our flower-rich seed mix would attract more beneficial insects than the other treatments. At the same time our hope, if not an explicit prediction, was that that seed mix would not also increase pest populations dramatically (but see Winkler et al. 2010, dos Santos 2017, McCabe et al. 2017). Together with the increase in beneficials, we predicted that we would see an increase in agroecological services such as pest predation and, finally, that crops planted adjacent to our flower-rich seed mix would, if anything, have greater production. There has been a growing realization that translating from beneficial abundances to agroecological services thence to crop production is not straightforward. Each stage needs to be assessed separately, if one wants to clearly tie augmentation of a certain beneficials to economic, or at least production, gains.

## Methods

**Experimental Planting.** As detailed in the accompanying botany report (Knab-Vispo 2020), two seed mixes were selected in collaboration with Kelly Gill, a Xerces/NRCS technical service provider. Three sets of replicated native meadow test plots (“NMTs”) totaling 4.5 acres were established organically in 2017. Each set included .5 acre of a flower-rich/grass-light seed mix (“Seed Mix A”), of a flower-light/grass-rich mix (“Seed Mix B”), and of a fallow control (managed similarly to the seed plots, but without any actual seeding). In 2019, a hay control was added by sampling in three sites in the adjacent White Clover/Orchard Grass/Rye Grass hay field.

**Insect Collection.** During the growing season, invertebrate communities were described using four techniques chosen so as to capture or assess insects interacting with the test plots in different ways. Malaise traps (BugDorm, large SLAM traps) were used to catch organisms moving through the air (e.g., flying insects, ballooning spiders), although some creatures may have been caught after crawling up from the ground. A single malaise trap was set for 24 hours at each sampling point. Soapy water was used to trap creatures in the collection vial. The samples were then strained and transferred to 70% ETOH. Three pit traps were set at each site to catch organisms walking on the ground. These were made from capped, 32oz plastic yoghurt containers with a ca. 2” hole cut in their tops. No baits or drift fences were used, nor were liquids placed in the pits. Creatures were counted in the field and released. If identification was required, specimens were returned to the lab and, in the vast majority of cases, identified live and then returned to their site of capture. The pits were set for 24 hours. Sweep netting was used to collect insects that were active on and around vegetation. Twenty-five sweeps were made while walking rapidly through the sampling site at some distance from the other traps so as to avoid disturbing them. Netting was done at a level that encompassed as much of the top of the vegetation as possible. An 18” diameter net with a mesh size of about 24 x 20 squares per inch was used (except for a few sets of sweeps during 2019 when a finer mesh was accidentally used). Captures were tallied in the field and released except for a few individuals retained for microscopic identification. Finally, we photographically tallied visitors to a bait of freeze-killed Fall Armyworm eggs. We used Moultrie Wingscape game cameras, either their TimeLapseCam Pro or BirdCam Pro models. Approximately, 100 eggs were placed in front of the camera and photographs were taken every five minutes from about 8” away. Total sightings were tallied across the 24 hours during which the camera operated.

In 2018, sampling occurred in mid June, mid July, early August and late September; in 2019, sampling was done in mid June, mid July, mid August and early in the second week of September.

In 2019, one emergence trap (Bugdorm Black Soil Emergence Trap, covering ca. 484 in<sup>2</sup>) was placed in each NMT from 17 April to 13 May. The flaps along the edges of the traps were buried to discourage comings and goings. Traps were checked roughly every week.

**Experimental Crop Beds.** In 2019, a 50’ row of Waltham butternut squash was established from starts next to each of the nine initial .5 acre experimental plots on the 14<sup>th</sup> of June; a parallel row of broccoli starts were planted around 21 June. These were managed without pesticides and herbicides, although a fine fabric was placed over the squash starts for approximately the first two weeks. They received a hand scattering of poultry pellets as an initial fertilizer. Weeding and watering occurred on an ‘as-needed’ basis. Damage and growth parameters were visually assessed periodically. Insect visitors were tallied by visual surveys and then sweep netting, although the latter was limited so as to avoid damage to the plants. In most cases, the broccoli was crowded out by the squash and/or browsed by vertebrates and did not reach maturity. At harvest, the squash were counted and individually weighed.

**Invertebrate Identification.** We could not practically identify all captured invertebrates to species. Both in the field and in the lab, we did try to identify captured ants, bees, ground beetles and hover flies to species using published keys and identification materials. Parasitoid wasps were also collected for identification. Due to the difficulty in identifying these, most were only identified to family or genus. Otherwise, aside from a few distinct creatures, family or even order was the lowest level of identification used.

## Results & Interpretation

**Apparent Invertebrate Abundances.** As suggested by Fig. 1, our hypothesis is largely, but not entirely, supported by the sweep and malaise results to date. Beneficials like bees and perhaps hover flies did tend to be more common in the flower-rich Seed Mix A, while pests, such as leafhoppers, flea beetles and aphids tended to be most common elsewhere.

However, some beneficials, such as spiders and lady beetles, seemed to show no clear patterns, and moths and butterflies (whose caterpillars are potentially pests) were, if anything, more common in the Seed Mix A plots. Erin Allen's 2018 observations (Allen 2019) also suggested that butterflies were most common in that Seed Mix A. Wasps were significantly more common in Seed Mix B and the Fallow Control than in Seed Mix A.

Pit trap captures (Fig. 2) indicated almost no statistically significant differences among treatments, although inspection of the 2019 data alone (not shown) suggests that differentiation may be growing.

At least in the case of pit traps (e.g., Holland 2001) and malaise traps, it should be noted that results are best considered 'activity densities' rather than indices of absolute abundance in the landscape. This is because those capture methods intercept creatures on the move, thus their capture totals reflect not only density but also activity. One could imagine that conditions such as low food (and hence increased food searching) or breeding (with mate searching) might increase capture rates without any actual increase in densities [insert critique of pit trapping].

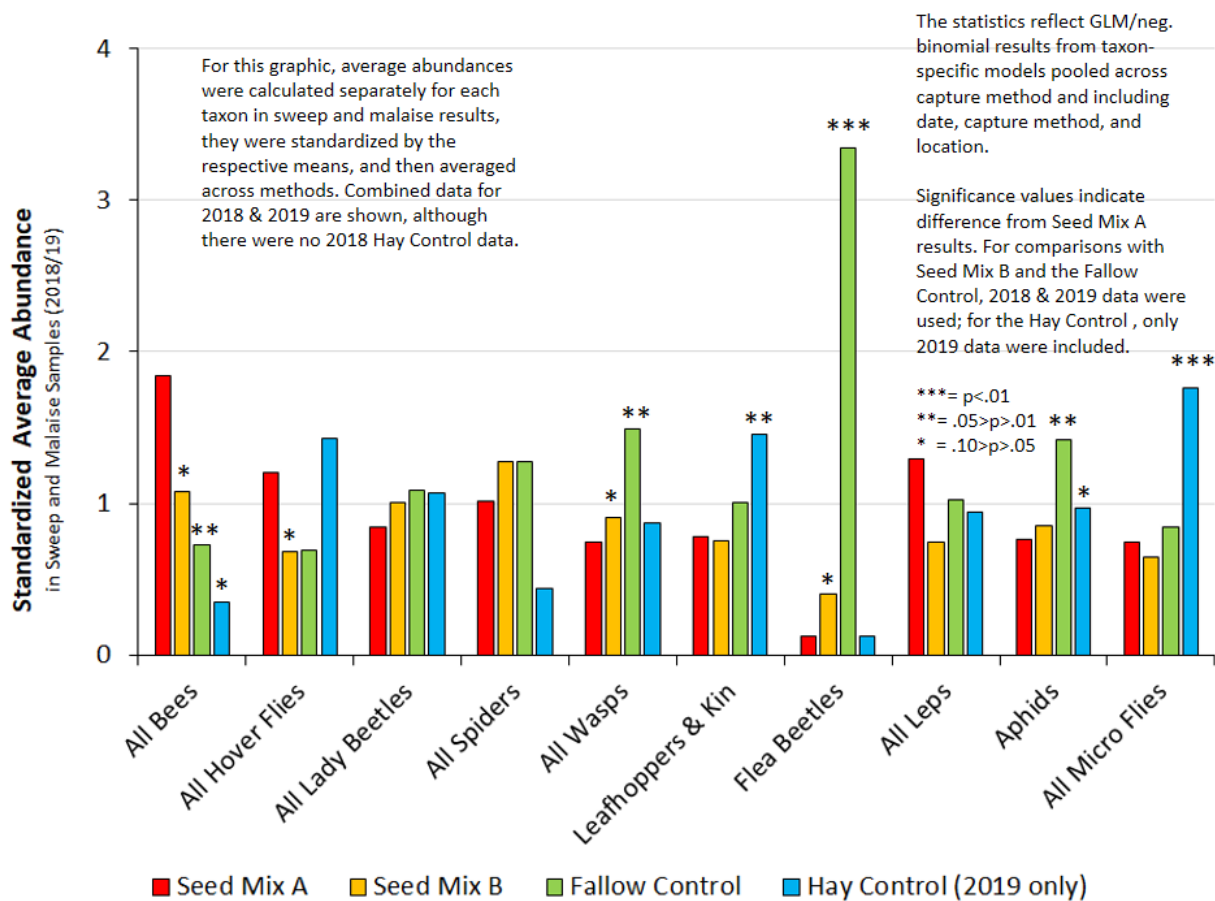


Figure 1. The standardized average abundance of select invertebrates across the experimental plots as measured by combined sweep and malaise sampling. See in-image text for details. Relative to Seed Mix B and the Fallow Control, bees and hover flies were most common in Mix A. Wasps, however, appeared to favor the Fallow Control.

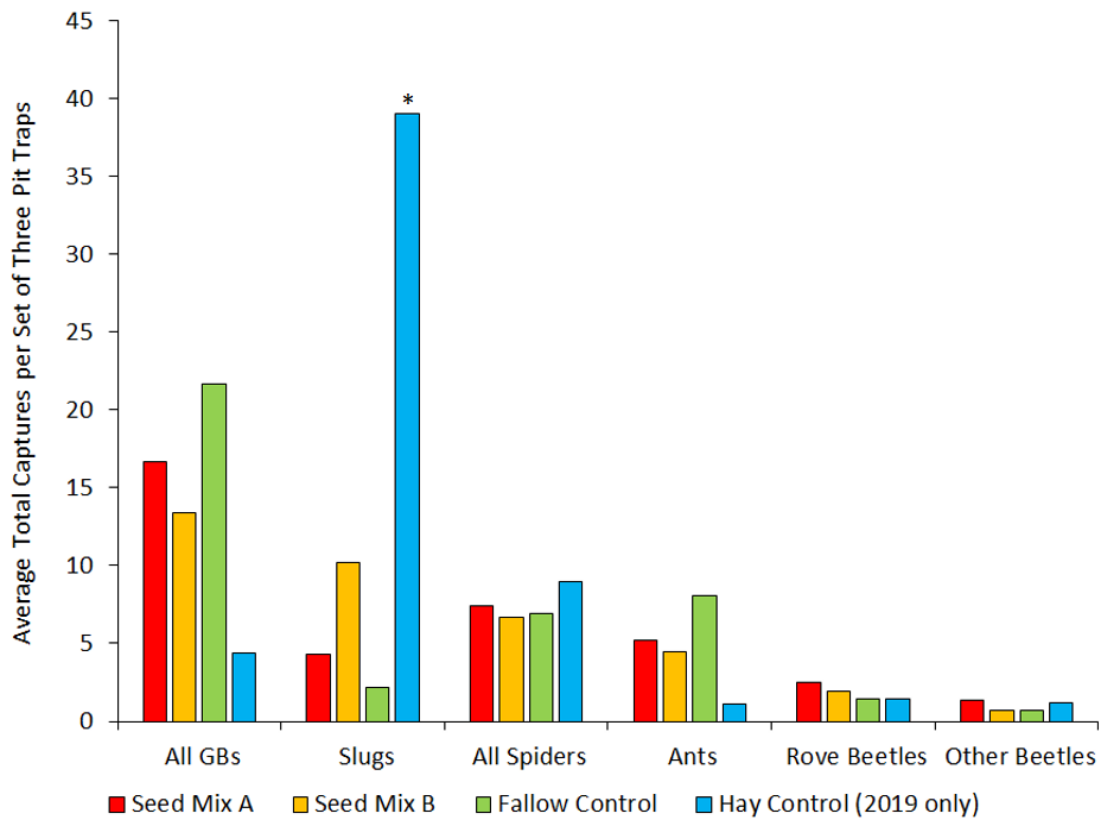


Figure 2. Pit traps captures in 2018 and 2019. Only the noted value approached statistically significance ( $p=0.06$ ) difference from the respective Seed Mix A value.

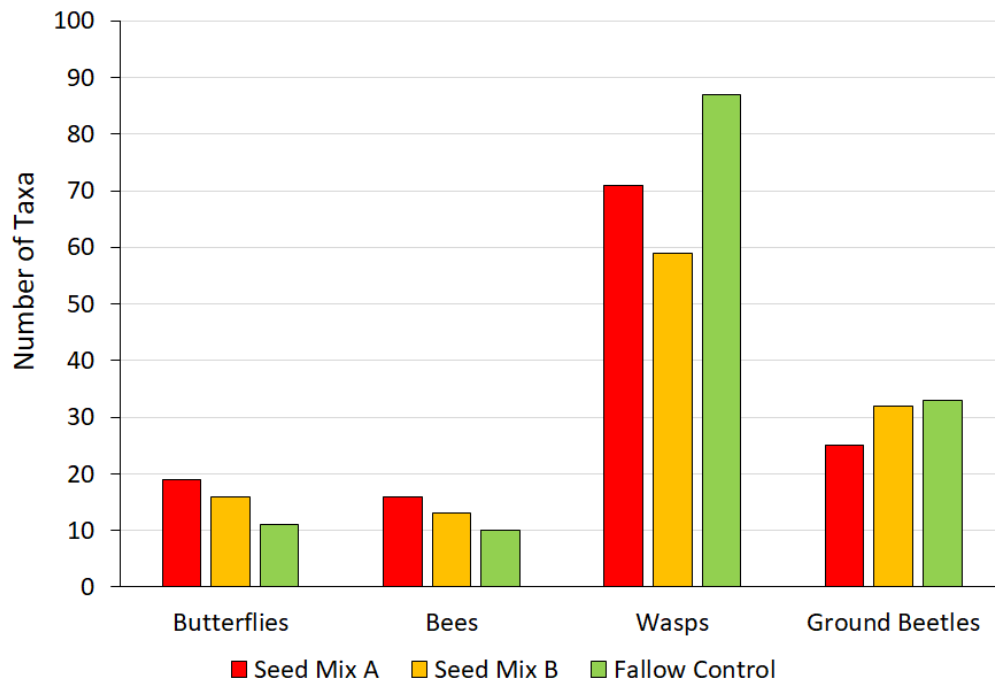


Figure 3. Number of taxa per treatment. For all but wasps, the taxa are primarily species. Because of the difficulty of species-level identification for wasps, higher taxonomic levels are represented. Butterfly data are from Allen (2019)

**Insect Biodiversity.** In terms of biodiversity conservation, the influence of the treatments on recorded species richness more or less mirrors abundance, with the total number of recorded taxa being highest in Seed Mix A for butterflies (Allen 2019 observational data) and bees, and highest in the Fallow Control for wasps and ground beetles.

Taxonomic overlap among treatments is relatively high. For example, of the approximately 13 bee species in Seed Mix B, 10 were shared with Seed Mix A. The Fallow Control shared six out of 10 species with Seed Mix A. Given our low number of identified bee captures to date (118 total), these differences may reflect incomplete sampling as much as real ecological differences, although Seed Mix A appeared to have a distinctly abundant and diverse bumblebee community. Our data on ground beetles is more complete (over 2000 captures). Of the 25 ground beetle species found in Seed Mix A, only three were unique to that treatment. On the other hand, only 18 of the 32 species found in Seed Mix B were also recorded from Seed Mix A. Amongst the wasps, Seed Mix A shared almost 60% of its taxa with Seed Mix B and with the Fallow Control, but there was substantial variation in relative abundances. For example, while Eulophidae wasps made up more than 20% of the captures in the Fallow Control, they made up only about 7% of the captures in Seed Mix A and B. A much deeper analysis of host:parasite patterns could be fruitful. A cursory inspection suggests, for instance, that aphid parasitoids may have been most common in the Fallow and Hay Control treatments, where aphids were also most common.

Taking a closer look at our results in terms of biodiversity conservation, while none of the butterflies Erin Allen recorded from our experimental plots in 2018 (Allen 2019) are currently considered rare, several appear to be declining in New York ([webutterfly.org](http://webutterfly.org)). Of these, three species (Common Ringlet, American Copper and Bronze Copper) were only observed in Seed Mix A; one species (Painted Lady) was only seen in Seed Mix B, and a third (the non-native European Skipper) was only observed in the Fallow Control. Perhaps even more importantly, three declining species (the Monarch, Silver-spotted Skipper and Pearl Crescent) were at least twice as common in Seed Mix A as in the other treatments. These data are based on butterfly flower visits and probably do not reflect the value of the treatment plots for supporting caterpillars.

The results for native bees did not indicate clear patterns: Seed Mix A and Seed Mix B each had one declining bee species among their captures (based on Bartomeus et al. 2013).

Four ground beetle species (including one exotic) were found only in Seed Mix A; seven (including two exotics) were found only in Seed Mix B, and two species were unique to the Fallow Control, and one to the Hay Control. We have not found published data on Northeastern ground beetle population trends, however among the native species unique to particular treatments, only one of those (from the Fallow Control) might be considered common and one species may, in fact, be a new state record. Clearly, the NMT plots were not responsible for attracting these rarer species to the farm – its sandy, riverine soils were likely a key factor. However, they do demonstrate that some of our management regimes can support somewhat unusual species, and, while more work is needed, it appears that the grass-rich Seed Mix B might be the most beneficial from in terms of ground beetle conservation.

**Activity at Bait Stations.** Fig. 4 graphically presents the summary data and tentative statistical significance for our time-lapse camera data (the stats will need to get redone; primarily simple GLM models, usually just Treatment + Plot models, usually negative binomial distributions but sporadic ‘failure to converge’ errors necessitated tinkering; current is best guess). Fig. 5 presents a more digestible summary of the same information.

While the total number of photographed visitors differed relatively little among the three primary treatments, the composition of those visits varied more dramatically. For example, slugs and ground beetles were recorded less than half as frequently in Seed Mix A as in Seed Mix B or the Fallow Control. Conversely, ants and true bugs were significantly *more* common in Seed Mix A. Slugs abounded in the Hay Fallow.

In 2019, we also tried to record eggs remaining after 24 hours. Average proportion of eggs consumed varied relatively little (from 91-99%) among the primary treatments, but it dropped to only 73% in the Hay Control.



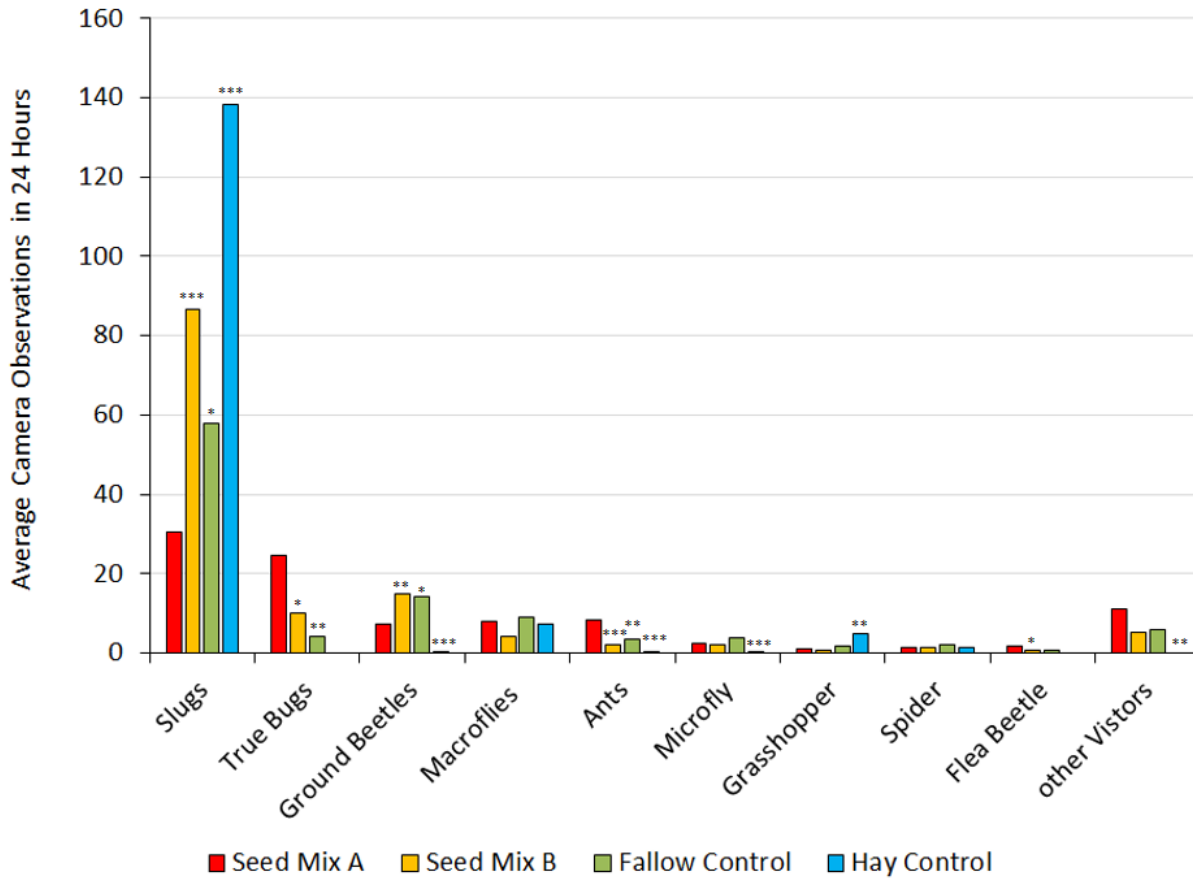


Figure 4. Organisms observed at Fall Armyworm egg bait stations by taxa and treatment. Significance levels (of GLM, primarily neg binomial distributions) as in Fig. 1. Slugs were a primary apparent predator, and they were noticeably less common in Seed Mix A; true bugs, and ants were more common in Seed Mix A.

**Crop Effects: Harvest.** In some ways, the ultimate criterion for judging the success of agroecological management is whether or not production amount and/or quality is improved. While the general consensus seems to be that conservation biological control regularly does enhance production, counter examples are common, and it is clear that results are system-specific and cannot be safely presumed (Letourneau et al. 2011, Winqvist et al. 2011, Veres et al. 2013, Begg et al. 2017; see, positive effects from NY in Connelly et al. 2015 [looking at the effect of landscape simplification]). It's worth noting that there may be an inherent bias in these results given the probably greater excitement to publish positive rather than negative results.

Table 1 summarizes the harvest results. The individual squash weights averaged significantly higher (Paired T-Test,  $p < .01$ ) next to the Fallow Control than next to Seed Mixes A and B; the average weights of squashes grown next to the two

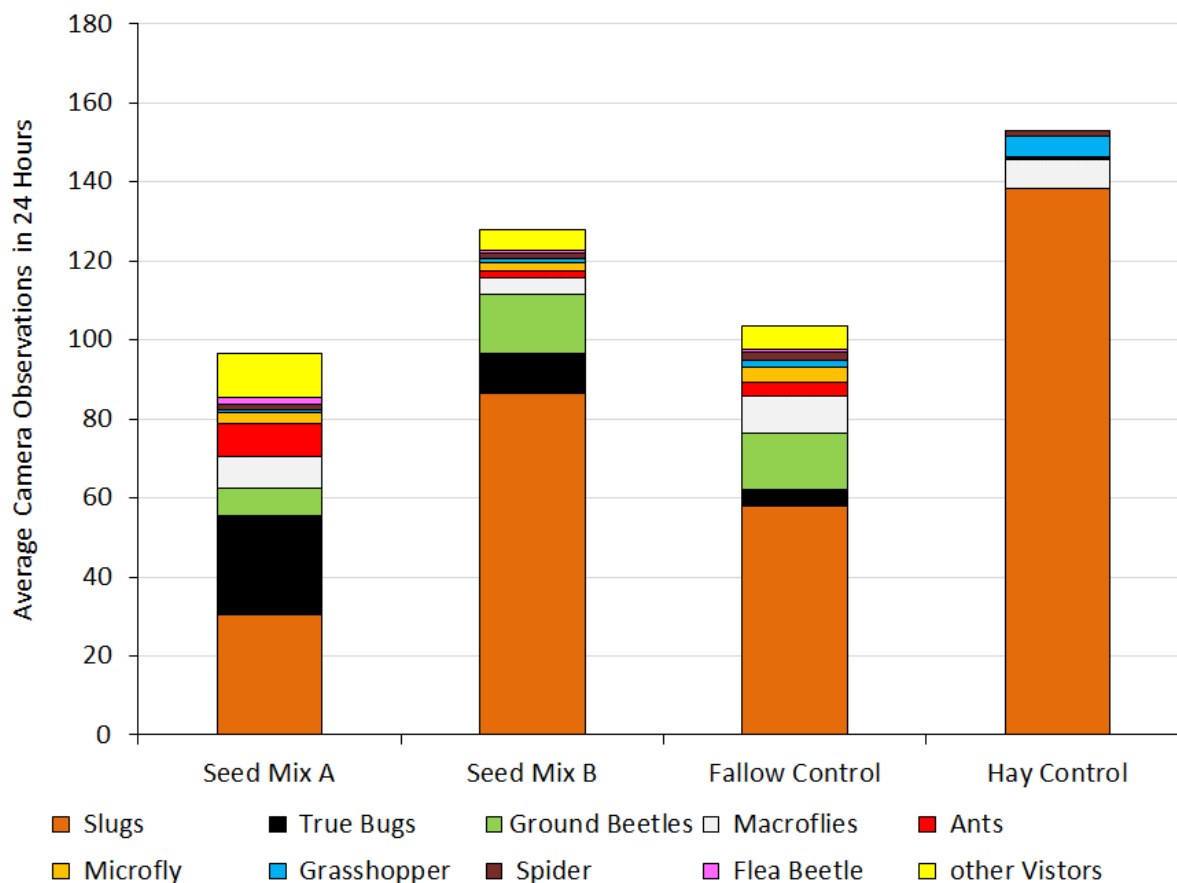


Figure 5. Stacked bar graphs of the same data showing the relative composition of visitors to each treatment. This illustrates how the composition of the apparent predators can vary more than the apparent total predation.

Table 1. Harvest statistics for butternut squash harvested from beds next to each treatment on 14 Sept. 2019. Squash were larger and more numerous next to the Fallow Control.

	Average No. of Ripe Squash per Bed	Mean Weight (lbs)	Total Weight of Harvest from Treatment (lbs)
Seed Mix A	81.7	4.0	933.8
Seed Mix B	91.3	4.1	995.4
Fallow Control	97.7	4.5	1284.2

seed mixes did not differ significantly. Total number of squash was also higher next to the Fallow Control. As a result, total squash harvest in the Fallow Control exceeded that from Seed Mixes A and B by 37% and 29% respectively. We thus got a strong signal that the adjacent vegetation was indeed influencing squash production. However, the direction of that effect was not as predicted.

**Crop Effects: Damage.** We estimated herbivore damage to squash leaves twice and to broccoli leaves three times during the season. Standardizing and averaging these assessments within crop plants and then averaging across squash and broccoli suggested that leaves adjacent to the Fallow Control experienced only about 2/3rds the herbivore damage of plants adjacent to the other plots (Fig. 6). Due to some inconsistencies in our assessment methods, we have not yet tried to test these differences statistically.

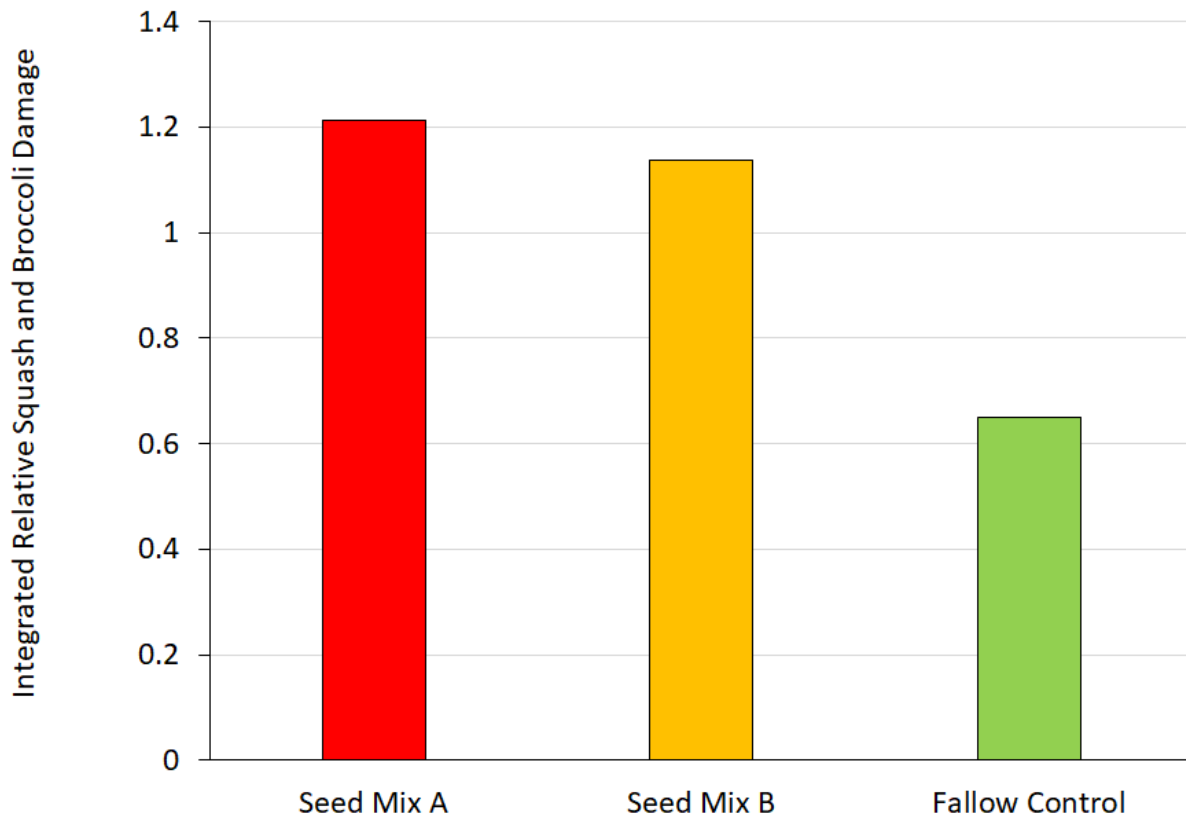


Figure 6. Relative standardized herbivore damage averaged across squash and broccoli. Such damage appeared to be lowest in the Fallow Control.

Table 2. Average squash plant dimensions as measured in mid July. By this time, the squash plants adjacent to the Fallow Control were distinctly larger.

	LxW (in <sup>2</sup> )	Leaves Behind First Tendril	Flower Buds
Seed Mix A	4293.8	61.0	45.2
Seed Mix B	3399.4	46.9	38.8
Fallow Control	5908.4	72.0	56.2

**Crop Effects: Plant Size.** During the second week of July, before the plants grew hopelessly intertwined, we collected data on plant dimensions (Table 2). By this time, the plants beside the Fallow Control were larger – they had more leaves and flower buds, and their extent was greater.

**Insects in the Crops.** Overall, our efforts to tally insects in the squash were inadequate. So as to avoid damaging young plants, we conducted visual surveys early on, but the sample sizes these produced were small. Later, we tried vacuuming, but our vacuum broke during those efforts. We did complete a full round of sweep netting in late August.

In mid-July, we conducted visual surveys of insects on the squash (Fig. 7). The sample size was small and so the results only hint at patterns. The most interesting possible tendencies were for the squash next to the Fallow Controls to have relatively low flea beetle numbers and relatively high numbers of micro wasps, a pattern only partially mirrored in the abundances of insects found in the NMTs themselves (Fig. 1).

We conducted sweep netting in the crops in late August. As Fig. 8 suggests, there were some marked differences in captures for certain insects groups, but it is unclear what, if any, significance these late season populations had for production. The generally high numbers of True Bugs, many but not all of whom are considered pests, is suggestive, but closer observation of what is causing damage and more detailed work earlier in the season will be necessary.

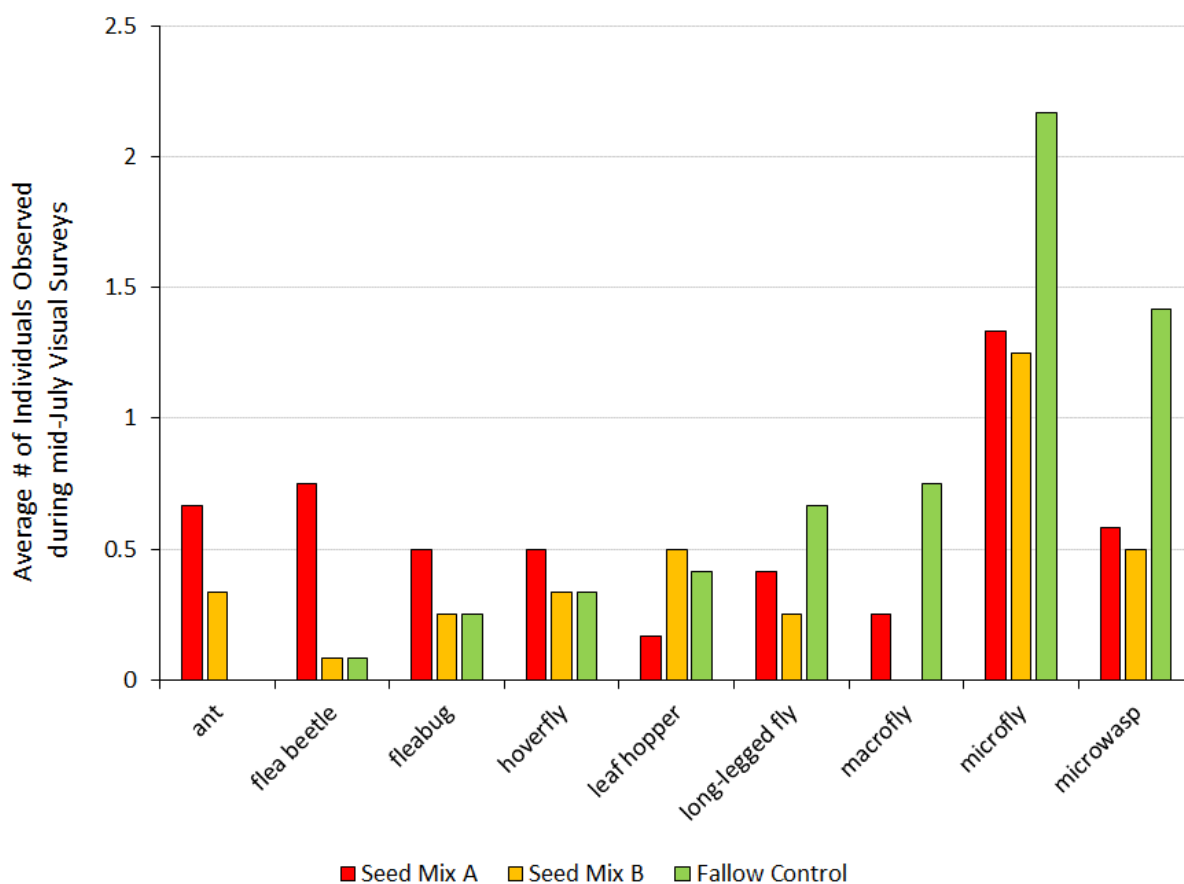


Figure 7. Insects observed on squash plants in mid July; no statistical testing was attempted. There is a hint that flea beetles were more common next to Seed Mix A and micro wasps were most common beside the Fallow Control.

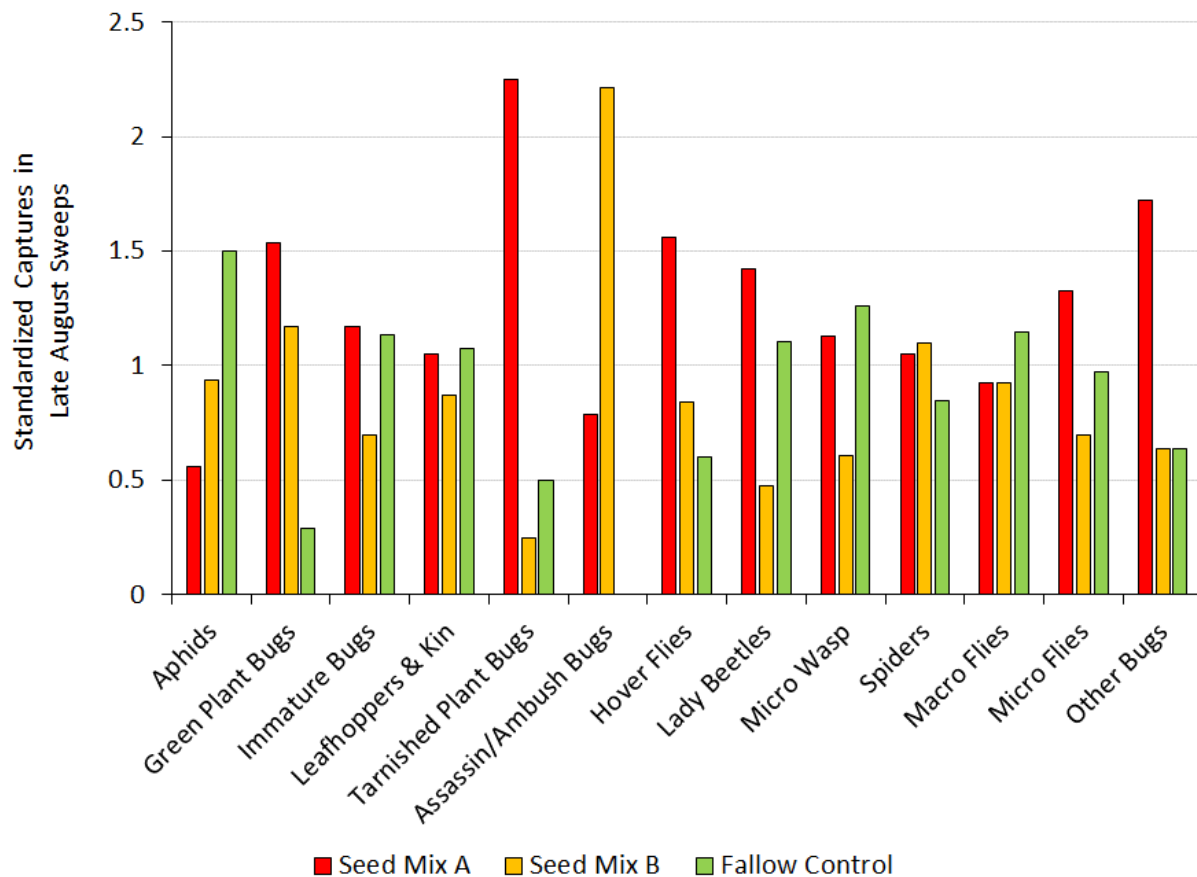


Figure 8. Standardized average captures from sweep netting conducted on squash plants next to the respective treatments in late August. No statistical testing was attempted. The abundance of Tarnished Plant Bugs in beds adjacent to Seed Mix A is evident.

In our September tallies of caterpillars feeding on the broccoli adjacent to NMT1 (the broccoli next to the other trial areas was too sparse for assessment), we found that the average number of caterpillars per plant on stalks adjacent to Seed Mix A was double that than on stalks adjacent to the Fallow Control, while the number on stalks adjacent to Seed Mix B was four times that of the Fallow Control.

**Overwintering.** Finally, our analysis so far has focused on the effects of the treatments during the height of the active season, i.e., late May – early October. However, overwintering habitat is also important for supporting wild invertebrates. Our 2019 emergence trap results (Fig. 9) suggest that, for the most part, the primary treatments differed little in the overwintering habitat they provided. A notable exception was that the Fallow Control seemed to overwinter substantially more micro flies than any other habitat. The Hay Control overwintered significantly fewer ground beetles and micro wasps, but noticeably more slugs. Only eight bees were captured in the emergent traps, but half of these were from Seed Mix A.

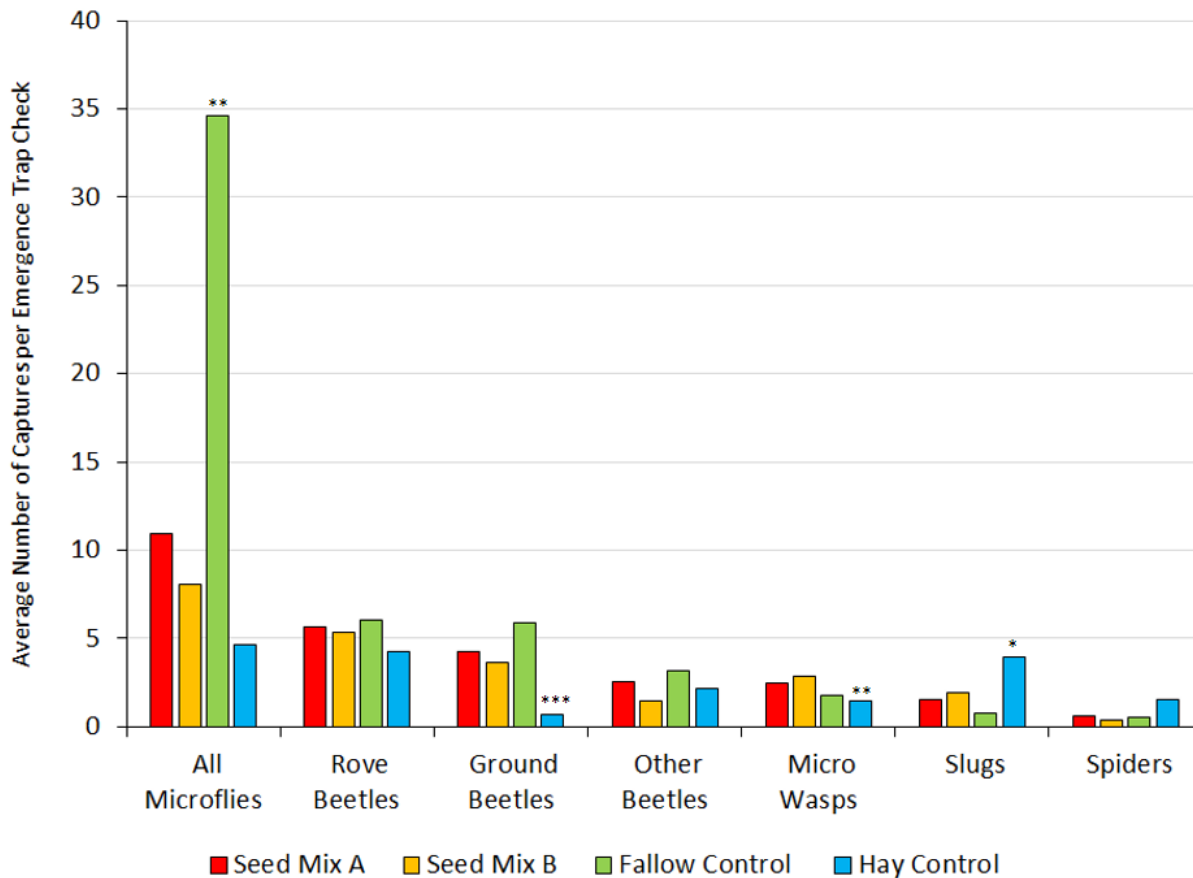


Figure 9. Average number of captures per trap check for emergence traps set from mid April to mid May 2019, and checked four times. For our three primary treatments (Seed Mixes A and B, and the Fallow Control), there was no significant differences amongst treatments.

## General Discussion

To date, the effect of the different treatments on the invertebrate community has been complex. As was predicted, butterflies (Allen 2019), bees, and hover flies appear to have been most abundant and diverse in the flower-rich Seed Mix A, whereas most pest populations were no more common than in the control plots. The notable exception amongst the beneficial creatures were the micro wasps, which were significantly more common in the Fallow Control than in the other treatments. Spiders and lady beetles did not show clear patterns. From this perspective, the flower-rich seed mix largely appeared to work, although given the potential role of parasitoid wasps in pest control, their lack of abundance in the flower-rich plots was disappointing.

Ground dwelling invertebrates showed no clear patterns in total captures, although data from 2019 suggest that patterns may be emerging. For those creatures interacting with soil as habitat, conditions may change more slowly than for those primarily interacting with above-ground vegetation (e.g., Alignier and Aviron 2017). Time will tell.

Species richness of select groups largely mirrored apparent abundance. A closer look at the species lists for each treatment and the natural history of the respective organisms may indicate whether there are discrete functional communities associated with the different treatments.

Before considering the possible agronomic consequences of these abundance patterns, it is useful to ask why they occurred. Why, for example, did bees and wasps respond to the treatments in opposite ways? Flower watches, botanical inventories, and visual-transect data from 2018 (Allen 2019) suggest that wasps favored the small, shallow flowers that

were most common in the Fallow Control (such as, the wild Annual Fleabane, Queen Anne's Lace, and Horseweed), whereas many bees and butterflies seemed to be attracted to the deeper flowers present in the Seed Mix A (for example, Monarda, Black-eyed Susan, New England Aster). In fact, in a comparison of bumblebees and wasps, the former were observed on seeded flowers 87% of the time, whereas the wasps were observed on seeded flowers only 42% of the time. The distinct flower preferences of bees and wasps have been noted by others (e.g., Wäckers and van Rijn 2012a). In our most recent plantings as part of a larger experiment elsewhere on the Hub, we have incorporated more of the wasp-favored flowers into the seed mix.

For Seed Mix A, Seed Mix B and the Fallow Control, ground-level predation intensity as indexed by photographs of presumed predator visits to Fall Armyworm eggs suggested a pattern we have seen elsewhere (Vispo et al. 2018): total predator visits can vary less between sites than the visits by specific groups. In other words, total predation intensity may be less variable than the contribution of any one group of predators. Relatively speaking, Seed Mix A, for example, seemed to abound in hungry true bugs and ants, whereas slugs and ground beetles were noticeably less active in that treatment. Our 2019 tallies of egg consumption also suggest that predation rates were relatively uniform across Seed Mix A, Seed Mix B and the Fallow Control. Interestingly, despite the markedly higher total visitation in the Hay Control, egg consumption therein seemed noticeably lower. It may be that slug presence in photos does not accurately represent their actual feeding activity. Our technique has obvious shortcomings in that it reflects predation on only a single bait presented on an unnatural surface, and, in the photographs, it can be difficult to judge for certain who is actually consuming eggs and who is just visiting.

The squash growth patterns, with more and larger squash in the beds next to the Fallow Control, were opposite to what we had predicted, i.e., that Seed Mix A would attract (and share) more beneficials than the other treatments. Either this effect was overwhelmed by an unrelated countervailing force (e.g., variation in soil conditions – although we have no evidence of consistent differences, see Knab-Vispo 2020), or the agroecological flows were different than what we had expected.

Our best guess is that two different agroecological flows may explain the observed pattern. First, the beds next to the Fallow Control had the largest plants (and hence the most flowers and fruits) and the lowest insect damage. We would hypothesize that it was the lower damage which facilitated the greater plant growth next to the Control Plot. That damage pattern may, in turn, have been attributable to higher biocontrol (because of more parasitoid wasps) next to the Fallow Control and/or greater abundance of an important pest in Seed Mix A for reasons other than reduced biocontrol (e.g., a squash pest which found an alternate food in the Seed Mix A plots). Observing the plants more closely during the early stages of their growth next season might help us understand the possible causes of growth differences and which pests (and hence beneficials) might be most relevant to squash growth. Indexing parasitism rates of key pests in each treatment might help us learn what, if any, effect the parasitoids might be having. Second, differences in the size of the squash fruits may reflect differences in the completeness of flower pollination. The fruit size of at least some cucurbits is related to the fullness of pollination (Stephenson et al. 1988). But why, if bees were most common in the Seed Mix A plots would pollination next to those plots be lower than in the vegetable beds? One answer may come from the results of trapping technique we used in 2018 – vane traps.

Fig. 10 shows 2018 abundances of 'other' wild bees (i.e., not Honey Bees, not bumble bees) as assessed by four different techniques, vane traps, malaise traps, sweep netting, and direct observation (Allen 2019). The pattern of vane trap captures seemed distinct from that of the three other techniques. To understand why this might have occurred, one needs to know how vane traps work. They are large, brightly colored, plastic 'cookie jars' topped by vanes of yellow or blue. They work because bees are attracted to the bright colors and fly into the traps; essentially, these traps use color as a bait. This method of operation sometimes results in what bee biologist Sam Droege (pers. comm.) calls the 'empty field effect', i.e., if a particular flower is the only brightly colored object in a field, then more bees are likely to visit it than if it is embedded in a showy and diverse field of wildflowers. This can be true even if there are actually more bees present in the latter field. We hypothesize that the large yellow squash flower may be more apt to receive bee visits

when located next to a relatively subdued floral display (such as in the Fallow Control) as opposed to when located next to a diverse bed of wildflowers. We have nicknamed this effect – when an abundant floral display results in reduced bee attention to adjacent flowers – the Walmart Effect, i.e., even if more customers are passing your door, if you’re a small department store located next to a mega Walmart then you are probably going to get fewer buyers than a similar store located in a ‘one horse town’.

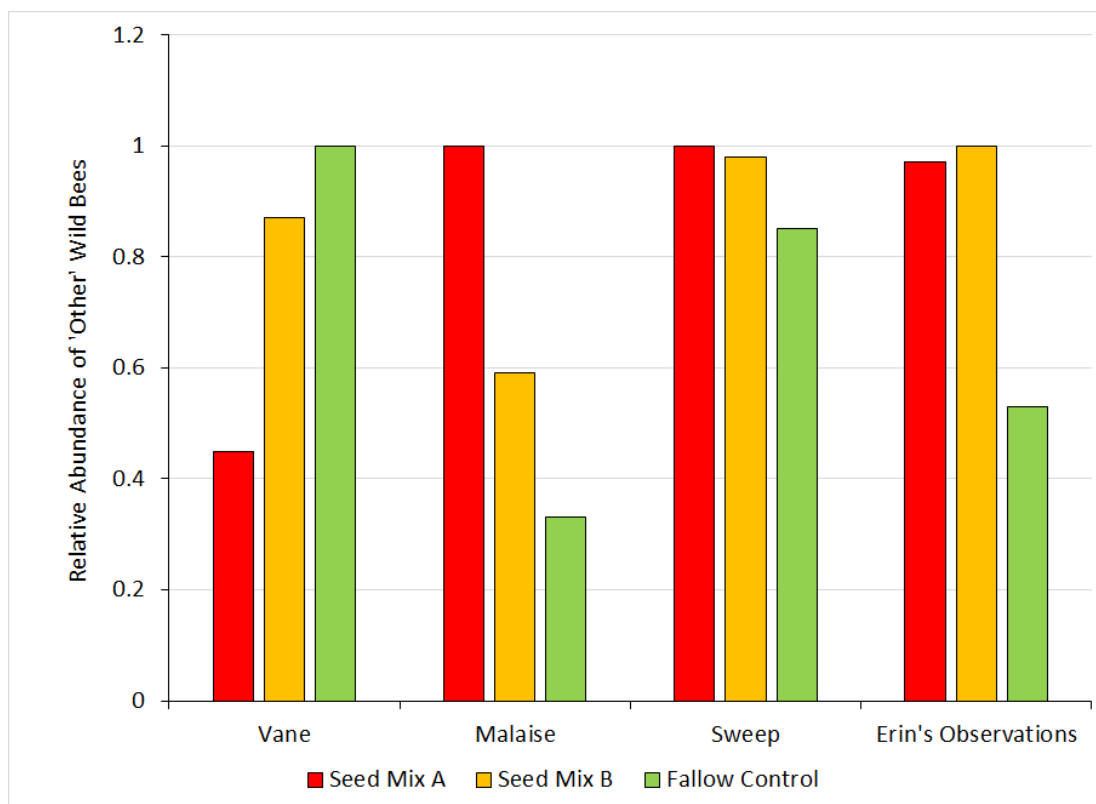


Figure 10. 2018 data showing bee occurrence as registered by four different techniques. Erin Allen’s observation come from her 2019 thesis. The patterns for the vane trap appears opposite from those of the other techniques, at least for Seed Mix A and the Fallow Control. That pattern hints that bees may be more apt to visit squash flowers located next to the relatively colorless Fallow Control rather than the more colorful Seed Mixes.

It is important to recognize that any “Walmart Effect” does not necessarily mean that wildflower plantings such as we undertook are useless or worse for growers. Rather, it indicates that one has to assess effects at different scales and manage plantings with this in mind. Specifically, standardized vane trapping of bees in the hay field adjacent to all three NMT plots suggests a 2-3 fold increase in bees from 2016 to 2018 (Fig. 11). Over the same period, another field at the Farm Hub saw no increase in bee captures since 2017, when the NMTs were planted. While given our small sample size that pattern will never be more than anecdotal, it illustrates that wildflower plantings might simultaneously enhance bee populations at the field scale, while producing localized pollination troughs in adjacent beds. Potentially, a more refined management might alleviate that trough – if there were to be a lull in wildflower blooming concurrent with the peak of crop flowering, then greater localized synergies might be expected. Such blooming control could be created through careful management of flowering phenologies or through flower clipping, although it would be important to ensure that any clipping was done in a way that minimized bee mortality. Choosing flowers which are very morphologically and/or phylogenetically distinct from the crop may also reduce crop/wildflower competition (Carvalho et al. 2014), but might also mean that the plantings support fewer effective pollinators. The flowering phenologies of cover crops and even crops themselves can play an important role in an integrated pollinator plan; for example, hemp has been touted as a valuable agroecological landscape ingredient, because its late flowering helps support pollinators during a time of lower flower availability (Flicker et al. 2019).



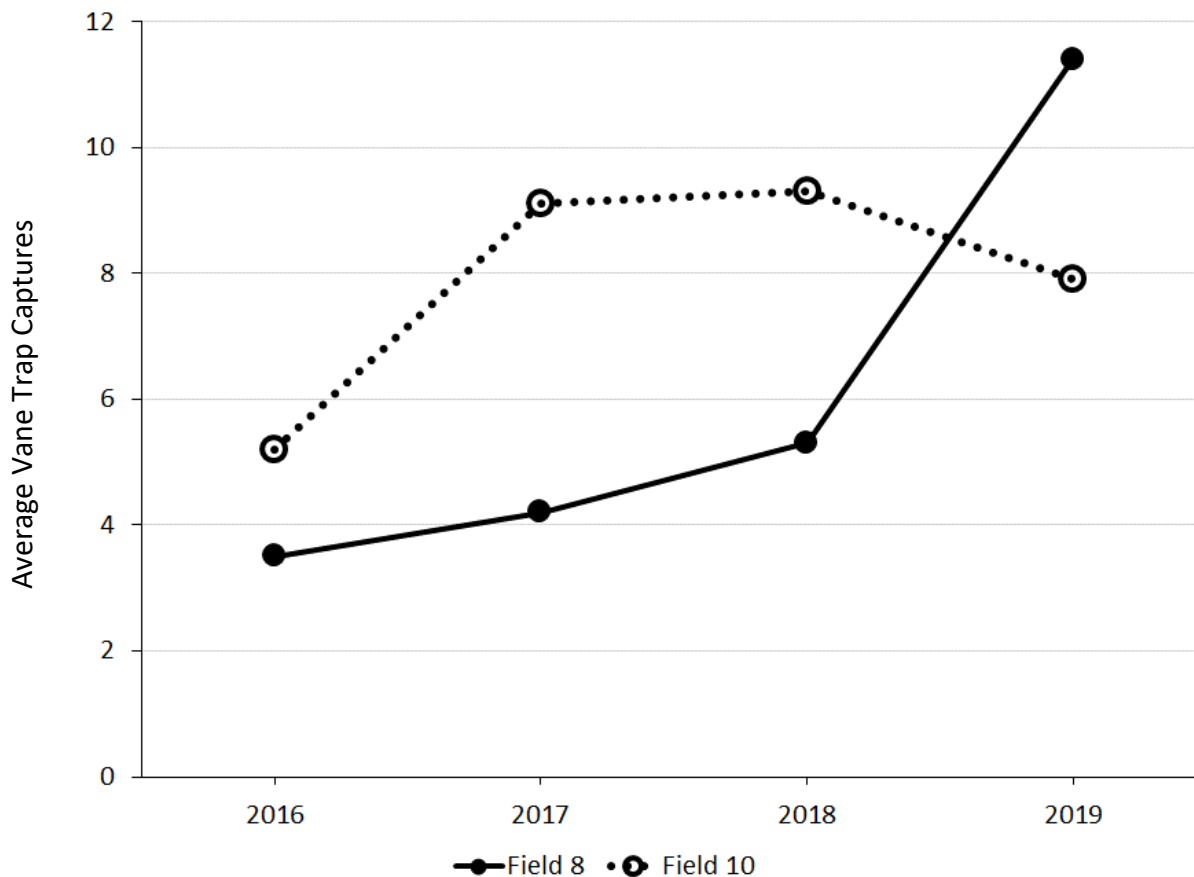


Figure 11. Total bee captures in Field 8 and Field 10 at the Farm Hub. The 2017- 2019 rise in bee captures in Field 8 may have been associated with the 2017 wildflower planting in the plots around the edge of Field 8. Field 19 data are not shown because of periodic cropping in that field.

This project has sought to answer a series of questions in the context of the mid-Hudson Valley: Could NRCS-recommended (and potentially supported) wildflower seed mixes be established organically? Would they attract/support putative beneficial invertebrates? Would those creatures actually benefit adjacent crops?

As detailed in the botany report (Knab-Vispo 2020), the answer to the first question is ‘yes’. So far, the seeded wildflower meadows have developed as hoped, and we thus have the opportunity to test their effectiveness in supporting beneficials and boosting adjacent crops. The answer to the second question is a qualified ‘yes’ – bees, especially bumblebees, seemed to respond as hoped; however, micro wasps were actually most common in our Fallow Control. Finally, the answer to the last question is a qualified ‘no’: squash were bigger and more numerous next to the Fallow Controls. However, appreciation of scale effects and tweaking of the seed mix might allow us to re-evaluate this. It is unlikely that any one ingredient of management can stand on its own; instead, we need to consider the ecological and socioeconomic landscape as a whole, and planning must occur at a variety of scales and with a variety of participants (Landis 2017).

### Future Work

Invertebrate communities fluctuate markedly from year to year for a variety of reasons including not only climatic variation, the arrival of new species, and natural periodicity, but also the natural evolution of the NMT vegetation. Furthermore, ecological lag in response to habitat change likely occurs (e.g., Alignier and Aviron 2017). For these reasons, continuing our monitoring into future years is important.

Building on what we believe we have learned about the relationship between beneficial insects and specific flowers, we have re-composed our flower-rich seed mix and planted it at a larger scale. Such tailoring of seed mix to beneficial communities is increasingly being recognized as important (e.g., Wäckers and van Rijn 2012). We will begin monitoring that planting in 2020. Blaauw and Isaacs (2012) found that the positive effects of wildflower plantings were enhanced as the size of the planting grew; this experiment should allow us to test that finding, at least in terms of beneficial abundances.

Looking at impacts on crops ‘through the eyes’ of additional vegetables can deepen our understanding of the interactions. We planted both broccoli and squash in 2019, but the broccoli was largely overwhelmed by the squash. In 2020, we hope to plant butternut squash again, together with a second crop at the opposite ends of the NMTs. We have not finalized our choice of crops, but are considering to repeat broccoli or try cauliflower or possibly sweet corn.

Squash plants next to the different treatments varied markedly in size by the time they were first measured, but we are not completely sure why. By following the early stages of crops more closely – How big are they? What damage do they have? What pests are active on them? – we hope to better understand what might explain any differing productivity of the beds. As part of this, we will probably purchase a new bug vacuum, so that we can sample insects in a way that damages young plants less than sweep netting. Continual, periodic monitoring of pest populations and their damage can be crucial for detecting the impacts of biological control, because such control might be most evident as a damper on pest increases rather than as lower pest populations in single snapshots (Chaplin-Kramer et al. 2013, Ramsden et al. 2017).

If we were correct that the abundance of micro wasps in the Fallow Control helped reduce pest pressure, then pests in those beds should have higher parasitism rates. Can we detect that? As a first pilot, perhaps we could raise the caterpillars found on the brassicas in enclosures and monitor for caterpillar mortality and parasitoid emergence. Alternatively, we could pick another common pest (e.g., Tarnished Plant Bug), collect say 10 individuals from each treatment of each plot, and then send these for DNA testing to detect and identify parasitoids. Perhaps, we should try both. In addition, if we want a broader understanding of the relevance of our work, at least in the Farm Hub context, we could gather select other important pests and likewise attempt to ID the parasitoids they host.

One of our big unanswered questions is which organisms are actually important pest predators. We could consider doing DNA stomach analysis of certain predatory organisms. Balmer et al. (2013) used molecular techniques to explore both predation and parasitism in an agroecological context. Neither the parasitoid nor the stomach analysis would prove that either parasitism or predation was controlling pest populations, but those analyses could be suggestive.

By far the most numerous single group of organisms in our captures were the so-called micro flies, yet we have little idea what ecological role these creatures may be playing. A first step towards better understanding that role might be to know which species are present and hence, by extension, what they might be doing. DNA analysis of even a few samples of micro flies might provide us with substantial insights, although, given the cost of these analyses, we could probably run no more than three samples (one pooled sample from each of the three primary treatments?).

Caterpillars are a key group of pests but also can reflect important resource use by Lepidoptera. Their presence suggests that the pickiest stage of a moth or butterfly life cycle is finding the food it needs. However, because caterpillars are only occasionally collected in sweep netting and their identification is difficult, we have very limited information regarding caterpillar diversity in our plots. More intensive collecting (e.g., with a beat sheet), perhaps coupled with refined identification (via DNA analyses or captive raising??), could produce important information for evaluating the potential of our treatments to meaningfully support both rare and pestiferous Lepidoptera. Furthermore, because we did not do any moth lighting in the plots, we have little idea of moth diversity at any life stage. A mid-summer effort to survey moths in the NMTs could be interesting.

Analyses of invertebrate behavior from the perspective of functional traits, rather than simple taxonomy has provided insights (Karp et al. 2018, Wong et al. 2019, Martin et al. 2019a) and so is being increasingly applied. This approach

requires grouping organisms according to their natural histories – when do they breed?, where do they nest?, what is their diet?, can they fly?, etc. Analyzing distribution patterns with these traits in mind can help identify the habitat drivers for different groups of beneficials (Isaia et al. 2006, Gagic et al. 2015, Wood et al. 2015, Gámez-Virués et al. 2015, Liere et al. 2017, Kremen and Merenlender 2018, Goded et al. 2019, Main et al. 2019, Odanaka and Rehan 2019, Grab et al. 2019a). Because we have a fair amount of taxonomic data on key groups, we now need to assemble functional trait databases, assign traits, and analyze our results from that perspective.

Likewise, functional trait analysis of wildflowers has helped direct the tailoring of wildflower mixes to desired beneficial communities (Sivinski et al. 2011, Bischoff et al. 2016, Campbell et al. 2017, M’Gonigle et al. 2017, Hatt et al. 2019), although flower-rich functional diversity may not always translate into a higher diversity or abundance of beneficials (Uyttenbroeck et al. 2017). Although, as a cautionary tale, see the work of Wood et al. (2016) who found, at least in the context of southern England, that the pollen loads of most solitary bees did not contain pollen from flowers sown so as to improve pollinator habitat.

Ultimately the relevance of any of this will depend upon how it is shared with farmers and other land managers. What is the take-away message and is it presented in a context that invites application? Creating researcher-farmer collaboration will be key to insuring that both the message and the research itself is seen as useful (e.g., Griffiths et al. 2008, Bridle et al. 2009, Duru et al. 2015, Landis 2017, Holland et al. 2017, Kleijn et al. 2019). Research can also help insure that, if the economic benefits of increasing semi-natural habitats do not outweigh the immediate costs but promoting such habitats supports conservation or other stakeholder interests (e.g., Gillespie and Wratten 2012, Wratten et al. 2012), then the necessary incentives are adequately estimated (Jackson et al. 2007, Kirchweyer et al. 2020). Likewise, in the case of positive but slow returns from habitat improvements, research can help estimate realistic time tables (Morandin et al. 2016).

## ***Chapter 2: Time & Flow: Spatial and Temporal Patterns of Invertebrate Abundance along 600’ Transects.***

### Introduction

For effective conservation biological control, it is necessary to understand not only which habitats support which beneficials (and pests) but also how those creatures flow out into crops and the influence of in-field management on that flow (Tscharrntke et al. 2005, Rand et al. 2006, Jauker et al. 2009, Blitzer et al. 2012, Macfadyen et al. 2015, González et al. 2016). As suggested in the previous chapter of this report, high abundances of beneficials in semi-natural habitat does not automatically translate into high abundances and benefits in the adjacent crops. When considering the arrangement of habitat patches (e.g., wildflower strips or hedgerows), knowing the distances to which creatures will regularly travel is important and so too is understanding the ‘gravitational attraction’ of particular habitat patches. Although research is relatively sparse, marked declines in the activities of select groups of beneficials over distances of from about 30 – 600’ from semi-natural habitat have been noted, (Long et al. 1998, Calabuig 2000, Collins et al. 2002, Unruh et al. 2012, Morandin et al. 2014, Vispo et al. 2015, González et al. 2016, Pollier 2016, Tschumi et al. 2016a) with about 300’ being a cited rule of thumb (Boller et al. 2004), although some found much shorter distances (e.g., Moore 2010) and some found no edge effect whatsoever (Wilson 2014, Ferrante et al. 2017). These patterns depend not only on the identity of the disperser (e.g., Morandin et al. 2014), but also the nature of the edge habitat. In the case of ground beetles, for example, it was found that abundance declined with distance (measured up to 75’) from woody edge but increased with distance from a herbaceous one (Fusser et al. 2017).

Our long-term monitoring at the Farm Hub has been designed so as to assess the distributions of spiders and insects relative to forested edges. How does the insect community vary along an edge to field-center transect, and what does that suggest about which invertebrate groups are reliant on semi-natural habitats for their persistence and about how far the agroecological influence of forested edges extends into adjacent crops?

In 2016, we established sampling transects in three fields at the Hudson Valley Farm Hub. For logistical reasons, one of those fields was switched in 2017. In each field, sampling was done within about 15' of the forest edge, at about 300' into the field from there, and at about 600' into the field using the methods outlined below (we also sampled at about 15' into the forest, but will not focus on those data here). Furthermore, we used a directional malaise trap at the edge point of each transect to describe the apparent direction of invertebrate flows.

Based on these data, in the report below we answer four questions: Were there any clear patterns in the distributions of various invertebrates across our transects? Did edge sampling with our directional traps suggest any forest-to-field insect flows? How did the results vary across the sampling season?

### Methods (this largely repeats the methods of the previous chapter)

In 2017 – 2019, sampling was conducted at the edge of and at 300' and 600' into Fields 8, 10, and 19. In 2016, Field 15 was used rather than Field 19. In 2016, sampling occurred in mid June, late July and late August; in 2017, we sampled in mid May, mid June and mid September; In 2018, sampling was in mid June, mid July, and early October; and, in 2019, it occurred in late May, late June, late July and late August. In 2017 and 2019, sampling was also done roughly 6-15' feet into the adjacent woods.

Invertebrate communities were described using five techniques chosen so as to capture or assess insects interacting with the locations in different ways. Malaise traps (BugDorm, large SLAM traps) were used to catch organisms moving through the air (e.g., flying insects, ballooning spiders), although some creatures may have been caught after crawling up from the ground. A single malaise trap was set for 24 hours at each sampling point. Soapy water was used to trap creatures in the collection vial. Three vane traps (two blue and one yellow; SpringStar) to catch insects attracted to bright, floral colors. We attempted to adjust the height of the vane trap so that the top of the vane was ca. 3' off the ground or, in the case of higher vegetation, was even with top of the vegetation. Soapy water was used to collect the organisms. The three traps were run for 24 hours at each site. After 24 hours, the samples from the malaise and vane traps were strained and transferred to 70% ETOH. Three pit traps were set at each site to catch organisms walking on the ground. These were made from capped 32oz plastic yoghurt containers with a ca. 2" hole cut in their tops. No baits or drift fences were used, nor were liquids placed in the traps. Creatures were counted in the field and released. If identification was required, specimens were returned to the lab and, in the vast majority of cases, identified live and then returned to their site of capture. The traps were set for 24 hours. Sweep netting was used to collect insects on and around vegetation. Twenty-five sweeps were made while walking rapidly through the sampling site. Netting was done so as to encompass as much of the top of the vegetation as possible. An 18" diameter net with a mesh size of about 24 x 20 squares per inch was used (except for a few sets of sweeps during 2019 when a finer mesh was accidentally used). Captures were tallied in the field and released except for a few individuals retained for microscopic identification. Finally, we photographically tallied visitors to a bait of freeze-killed Fall Armyworm eggs. We used Moultrie Wingscape game cameras, either their TimeLapseCam Pro or BirdCam Pro models. Approximately, 100 freeze-killed Fall Armyworm eggs were placed on a surface beneath the camera. Photographs were taken every five minutes and total sightings tallied across the 24 hours during which the camera operated. The traps and cameras were set up at the chosen location within approximately 30' of each other. The sweep netting occurred elsewhere in the same habitat to avoid disturbance.

### Results & Interpretation

Fig. 12 illustrates the combined captures in malaise, sweep and vane sampling. It should be noted that while the woods captures are illustrated, forest conditions probably mean that trapping efficacy differed radically from that in the field. In considering distance trends, we therefore focus on the edge-to-600' results. The woods captures can, however, give us important information on the distribution of particular taxa.

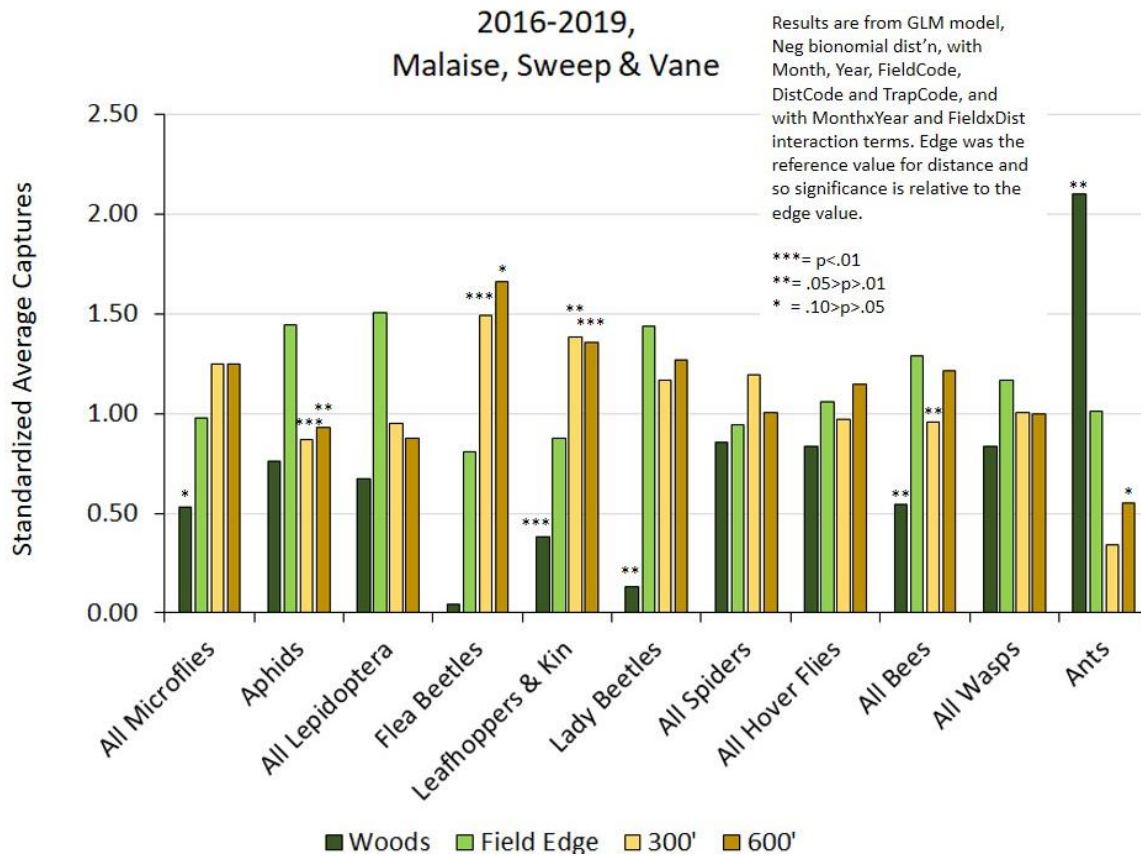


Figure 12. Standardized average captures across malaise, sweep and vane trapping for four distances along three transects extending into farm fields. Statistical significance is relative to edge captures; significance marks are as indicated in Fig. 1. Some pests (i.e., flea beetles and leafhoppers) were most common deeper into the fields. Bees and aphids were statistically more common at field edges than towards field centers.

The strongest conclusions in these data appear to be the higher number of aphids near the field edge, the higher number of flea beetles and leafhopper towards the field center and the abundance of ants in the woods. Because of their particular potential relevance for the crops, we will explore the patterns for lepidoptera, lady beetles, spiders, hover flies, bees and wasps in more detail, focusing, as noted, on the edge-to-center data.

Field observations indicate substantial insect movements and changes in distribution patterns in Spring and Autumn (e.g., Vispo and Knab-Vispo 2012), and that led us to explore seasonal patterns in the data (Fig. 13). Lepidoptera and spiders appeared to show the same patterns across the seasons, with edges supporting relatively more individuals across all seasons (see Clough 2005, who found similar edge-peaks in spider activity). For bees, wasps, macro flies (other than hover flies), micro flies, and lady beetles, it appears that edge captures were higher in Spring (and often Autumn) than in mid-Summer. This is suggestive of a possible expansion of these groups into fields as the growing season began. Hover flies (and the likes of treehoppers and flea beetles, not shown) seemed to show less distinct seasonal patterns; interestingly Jauker et al. (2009) likewise found an absence of any decline across distance for hover flies. Averages across multiple taxa (Fig. 14) suggest a clear seasonal pattern.

It is important to note that data presented in Fig. 12 and Fig. 13 are summarized in different ways, and this sometimes presents diverging apparent patterns. Note for example that the data in Fig. 12 are standardized captures averaged across trapping techniques. Each trapping technique thus receives equal weight. The results in Fig. 13 are simply straight total captures across all techniques; essentially, the results from each technique are weighted by the number of captures, and those techniques with greater captures carry proportionally greater weight. Both approaches have merit and, in many cases, show similar patterns. A notable exception is spiders, where patterns evidenced in low-capture techniques (i.e., in this case, vane and malaise sampling) ran opposite to patterns evident in the high-capture method (sweep netting).

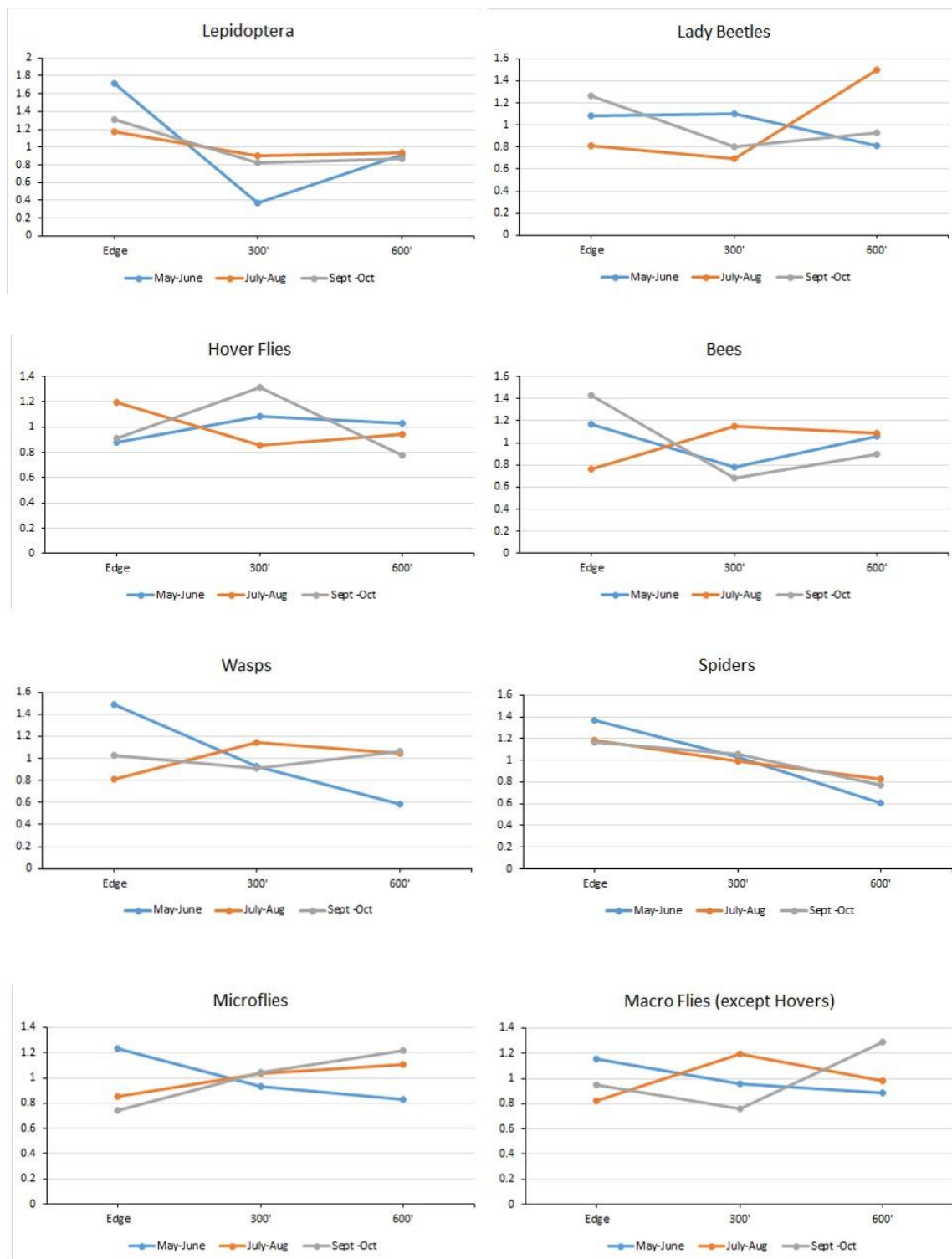


Figure 13. Standardized (across distances and season) captures of select taxa for three time periods: May-June, July-August, and September-October. Notice how edge captures tended to be higher than deeper field captures in early sampling (May-June).

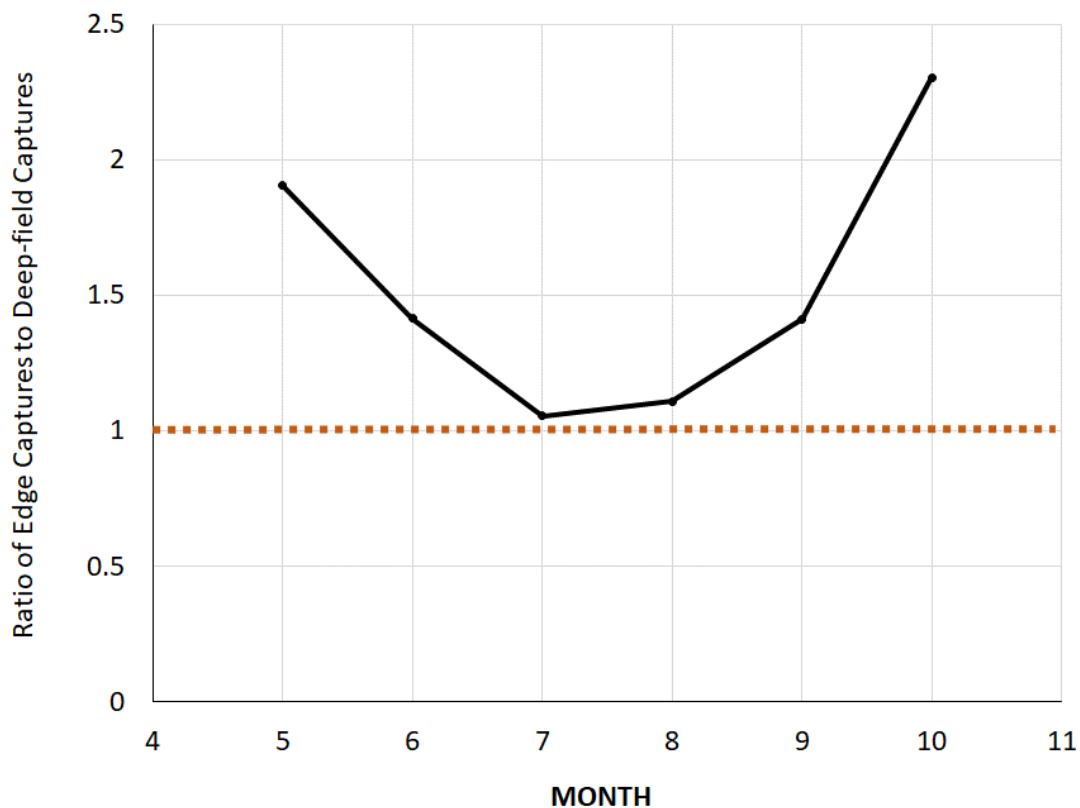


Figure 14. The ratio of edge captures to average captures at 300' and 600' for multiple methods, years, and taxa. Early- and late-season peaks are suggested. A value of one would indicate a relatively uniform distribution across distances.

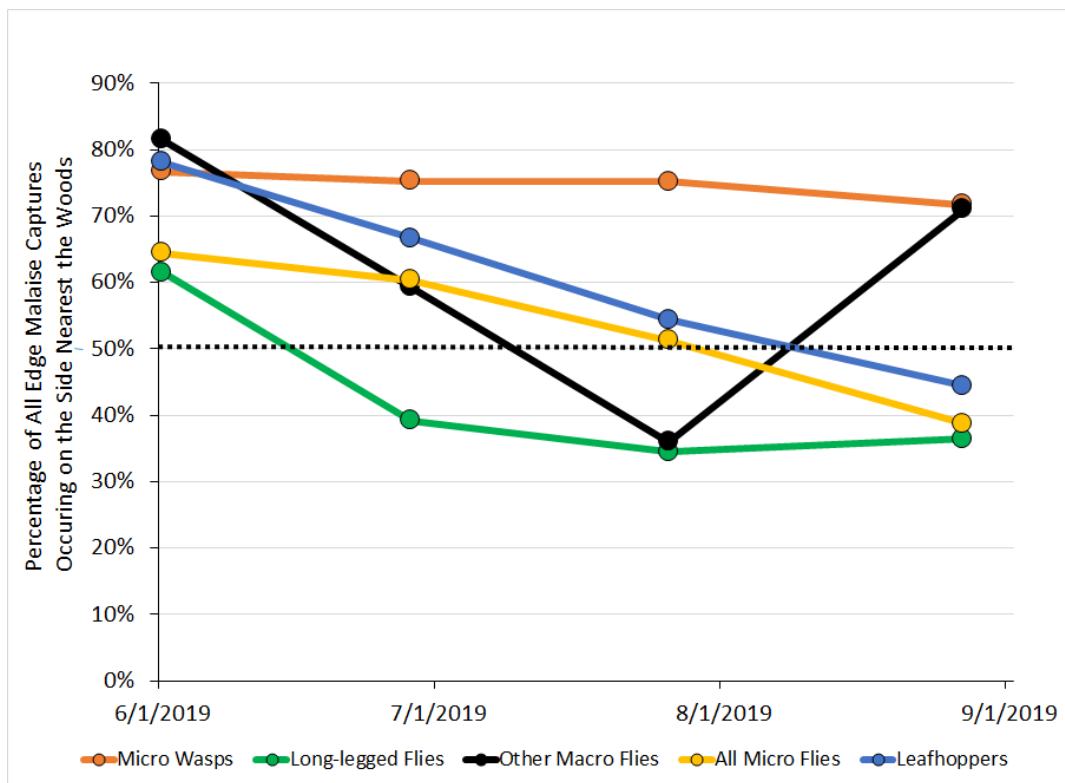


Figure 15. The directionality of captures in four-sided malaise traps located within 15' of the forest edge. A value below 50% would indicate that less than half of the captures were on the wilder side; however, if captures were randomly distributed, one would predict that, on average, only 25% of the total captures would be accounted for by the side facing the woods. An early-season peak is suggested.

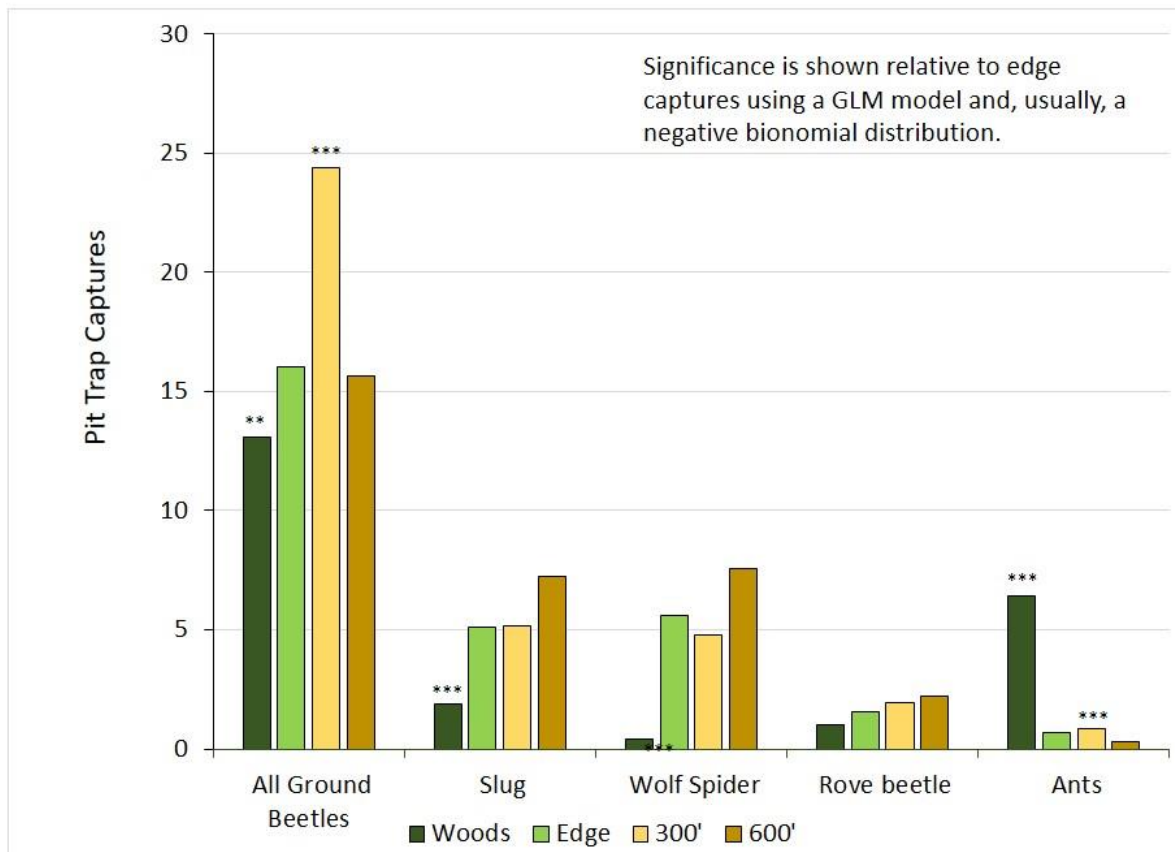


Figure 16 Pit trap captures by distance and taxon. As a group, ground beetles appeared to favor 300' in, while ants again were most common in the woods.

These data can be compared to the captures from our directional malaise traps (Fig. 15). Those traps, set at the edge sites, registered whether captures appeared to enter from the forest or non-forest side of the traps. Because some taxa are not well-represented in malaise captures (e.g., bees), we can only inspect the patterns for a subset of our taxa. For those taxa, there is a consistent pattern: in Spring, the majority of all edge captures occurred on the woods side of the trap. For all groups, this proportion declined in mid Summer (although for the micro wasps, the decline was miniscule). In late Summer, the pattern may have reversed for some groups. The point is that both our transect data and our directional capture data support the notion of especially high edge activity early in the growing season. Edge and/or woods habitats may be serving as early source habitats. We have found strong apparent edge flows in our own work at other sites (Vispo et al. 2015, 2018), as have others for select groups elsewhere (Macfadyen et al. 2015, González et al. 2016). It is also important to recall that our 'woods' measurements, taken within 15' ft of the forest edge, are surely influenced by the adjacent agricultural land (e.g., Rand et al. 2006 for review, and Schneider et al. 2016 for agricultural effects on ground beetles of adjacent natural grasslands).

It would appear (Fig. 16) that, other than ants, when taken as a general group, the creatures captured in our pit traps may be field residents, whose in-field presence is little affected by distance from edge.

Clearly, talking about broad taxonomic groups can hide important finer patterns. Fournier and Loreau (1999) and Tscharrntke et al. (2005) proposed a categorizations based on how individual species react to a crop/wild interface. For example, some species may occur primarily on one side or another of that divide, others might favor the very 'ecotone'



itself, and others might disperse into the crop habitat and becoming less abundant with distance from the edge. Overlaid on this, one can imagine a categorization based on the temporality of inter-habitat movements, with some species crossing between habitats daily and others making only seasonal migrations. Different ground beetle species, for instance, respond differently to agricultural impacts, with some being more or less favored or challenged by such habitat conversion and the resultant landscapes (e.g., Cole et al. 2002, Bertrand et al. 2016); Holland et al. (2009) classified ground beetles as field and boundary species. Just looking at the edge-to-field center data for our ground beetles (Fig. 17), *Elaphropus* (*anceps* or *incurvus*), *Pterostichus melanarius*, and *Poecilus* (*chalcites* and *lucublandulus*) seem to be ‘deep-field’ species, while *Harpalus pensylvanicus* seems to have more edge affinities. A Pennsylvania study, which included many of these same species, found a rapid transition in field ground beetle communities within less than 30’ from the forest edge (Leslie et al. 2014).

Bee species also respond differentially to habitat change (e.g., Carré et al. 2009, Bennett and Lovell 2019). Likewise, amongst bee genera (Fig. 17), *Peponapis* and *Halictus* seemed to be most common farther into the fields, while the majority of the *Agapostemon* captures and many of the *Bombus* captures were nearer the edges. The relevance of these patterns for agroecology will depend upon the influences of the particular species on the crops.

Finally, one of the reasons why we undertook the standardized long-term monitoring was to begin gathering regional data on insect population trends. Given the growing concern about insect declines, having long-term standardized data sets is important. Our data only partially serve that purpose, evolving field management (such as the introduction of the NMTs around field 8 and the 2018 use of field 19 for vegetables) adds habitat effects that may, at least in the short-term, swamp any annual trends. Fig. 19 shows sweep net captures across all three fields and all four years for commonly captured taxa. It illustrates the large year-to-year fluctuations and the lack of any conspicuous trend over time. This does not mean that trends are not present, but one cannot expect them to be apparent in such a limited time series, especially given the ‘swamping factors’ mentioned above.

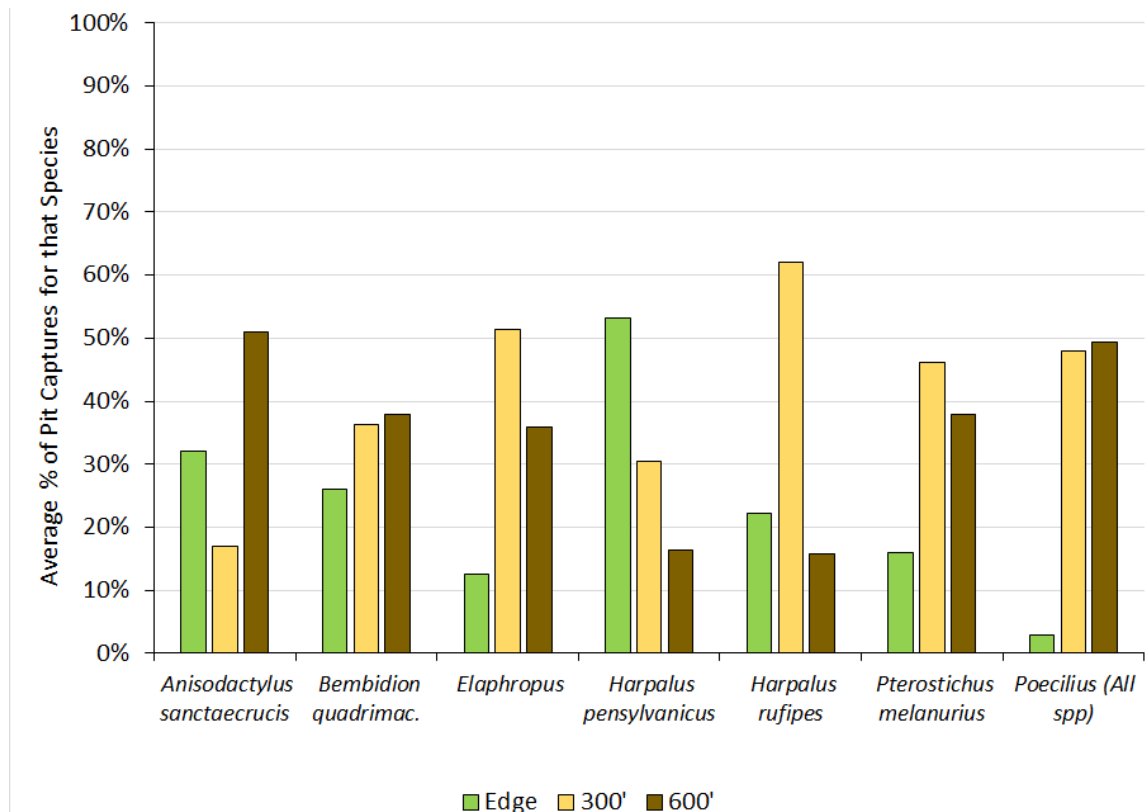


Figure 17. Standardized captures across distances for select ground beetles. *Harpalus rufipes* was the most common species, and its distribution helped drive the group captures shown in Fig. 16. No statistical tests were done.

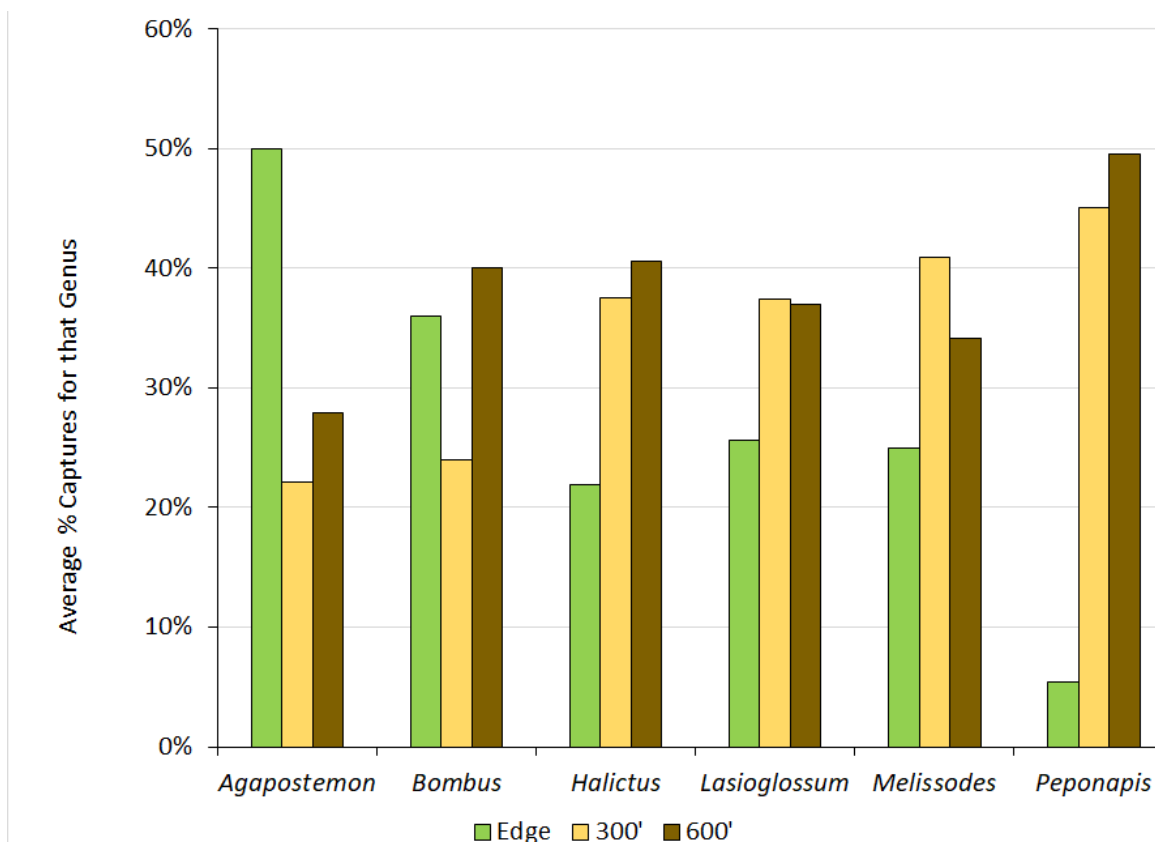


Figure 18. Captures across distance for select bee genera. Notice how relationship to edge varied amongst genera. No statistical tests were done.

Pit trap captures across the four years (Fig. 20) do show a major evolution: ground beetles declined dramatically and slugs increased markedly. Relatively speaking, millipedes and ants also increased. It is not clear what is responsible for this change, but its reality is supported by our last set of data, that from the baited time-lapse cameras (Fig. 21). The most dramatic pattern in the data is the rising importance of slugs across the years. Basically absent from the cameras in 2017, they were appreciable in 2018 and dominant in 2019. At least part of this pattern may be due to climate: according to records from Poughkeepsie, NY, 2015 and 2016 had slightly below-normal precipitation, whereas 2017-2019 had progressively above-normal precipitation levels.

Total visitation logged by the cameras – one index of potential ground predation - was higher at the field edge than farther towards the field center during all three years. In 2019, the only year when in-woods predation was assessed, edge visitation rates were also higher than rates in the woods. Interestingly, this pattern does not mirror the pit captures of the same organisms (Fig. 16), suggesting that simple predator captures may not accurately reflect predation (as also noted by Grieshop et al. 2012 and, to a lesser extent, by Walton 2013). Bait removal in 2019 averaged 100% in the woods, 98% at the edge, 75% at 300' and 88% at 600', but there was very large variability. However, direct predation or parasitism may not be the only way that predators deter herbivory – their mere presence may alter pest behavior (Losey and Denno 1998, Ingerslew 2016)

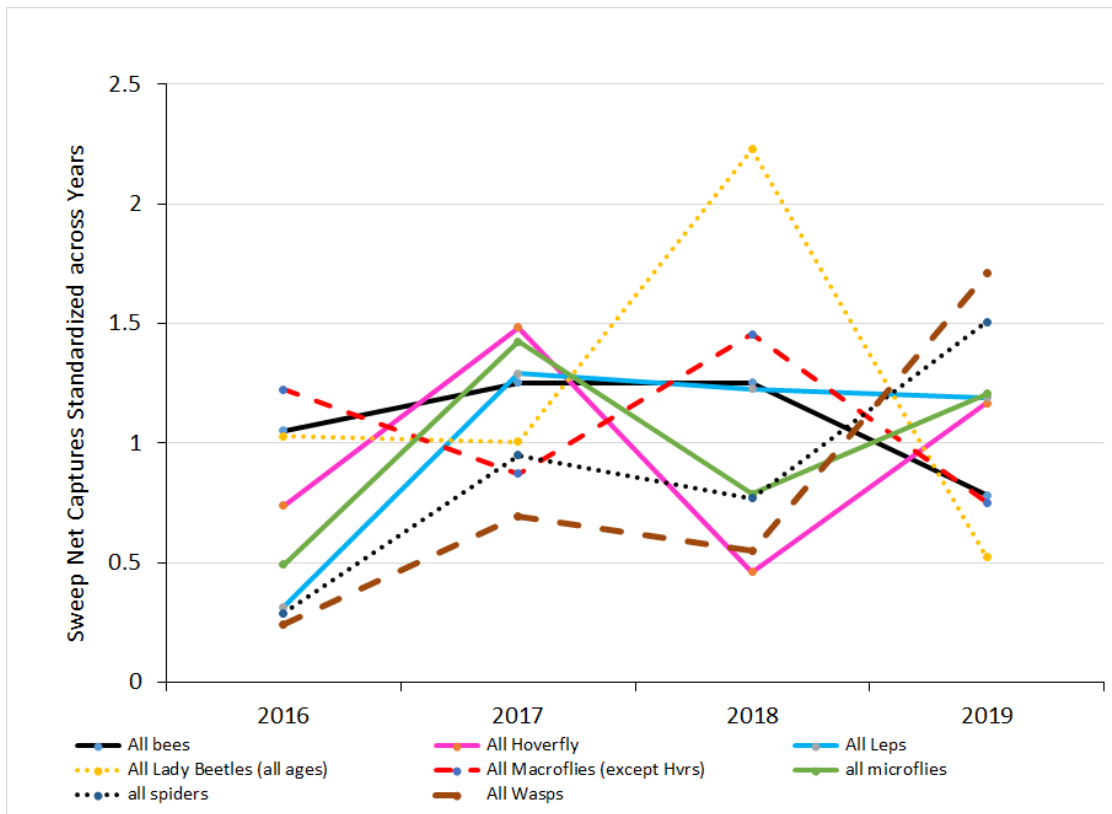


Figure 19. Standardized sweep net captures across all distances by year. There are some possible taxon trends, but little evident overall pattern.

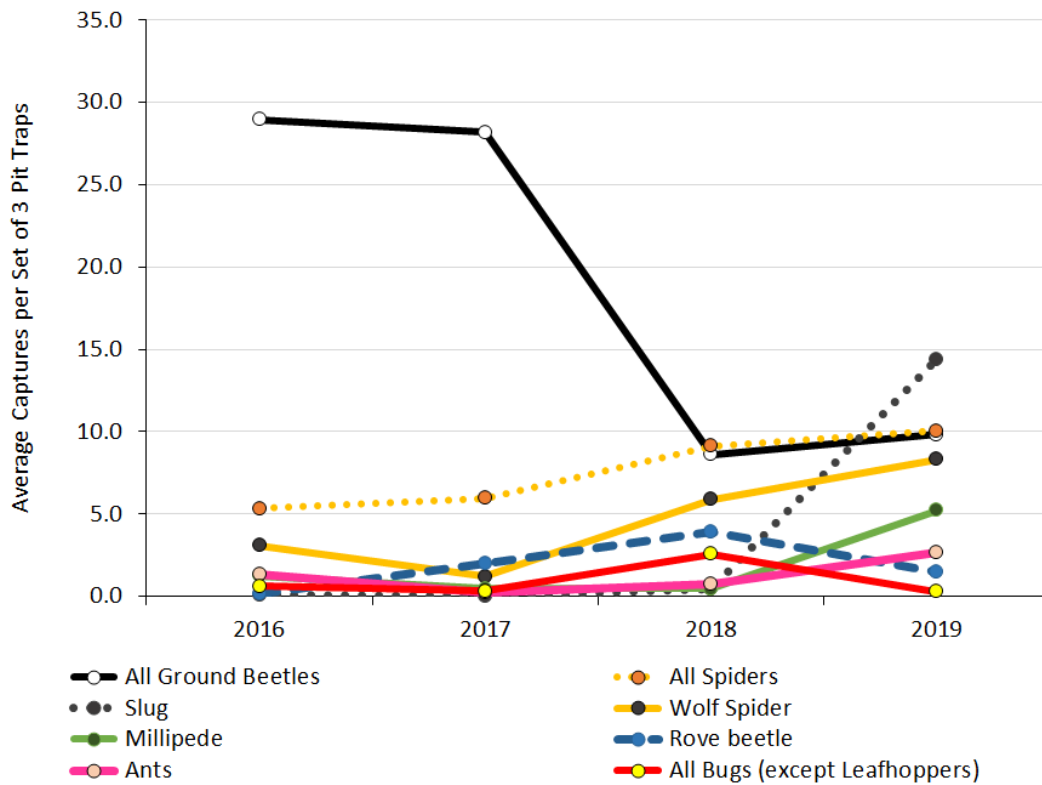


Figure 20. Average captures per set of pit taps by year. The decline of ground beetles and rise of slugs seems marked.

## General Discussion

Taken together in the context of agroecology, this work and our study of the NMT test plots above focuses our interest on seasonality and flows, and emphasizes the importance of farm-scale habitat distribution (Haan et al. 2019): *What is the ideal distance between crops and semi-wild habitat? At what time of year is that distance most crucial for crop production?* Our NMT work suggests that pollination troughs may exist immediately adjacent to wildflower plantings, hence the smaller squash adjacent to Seed Mix A. At the same time, our transect work suggests that, at least during certain seasons, bee activity may decline substantially within 300' of semi-wild habitat. (Could we somehow index pollination activity across our transect?) Nonetheless, our work hints at the possibility that field-scale increases in bee populations may occur in response to habitat increases. What's the sweet spot in terms of the distance between crops and beneficial habitat? *How might it be influenced by crop and wildflower choice?* Simultaneously, our NMT work suggested that there may indeed have been a physically immediate benefit in terms of pest control by parasitoid wasps – more rapid squash growth next to the Fallow Control may have been associated with that treatment's greater wasp abundance. Early in the growing season, when some crops might be most susceptible to pest damage, our transect data suggest that wasps may have marked decreases in abundance at both 300' and 600' from habitat patches. Finally, our transect work showed substantial declines in apparent predator activity at insect egg bait at 300' and 600' into the fields, further suggesting measurable influences of semi-natural habitats.

Refining our information on seasonal activity and on patterns over distance may be crucial for understanding how best to co-manage crops and semi-natural habitats so as to maximize benefits to the crops. As a simplified example, an early-summer crop which is heavily affected by pests, but does not require pollination might be planted close to habitat patches such as wildflower plantings. Potentially, the same holds true for late-summer crops. During mid-summer however a crop which experiences only minimal commercially-relevant pest damage, but which does require insect pollination might best be planted at a moderate distance from semi-wild habitats. Others have likewise emphasized the understanding of seasonal patterns in relation to management and landscape context (e.g. Leong et al. 2016 on bees).

To a certain extent, this report has erected castles in the air. Some of the patterns noted here may not withstand the test of time. However, rather than being considered hard and fast conclusions, the above patterns can be considered hypotheses, which our continued monitoring should help support or refute.

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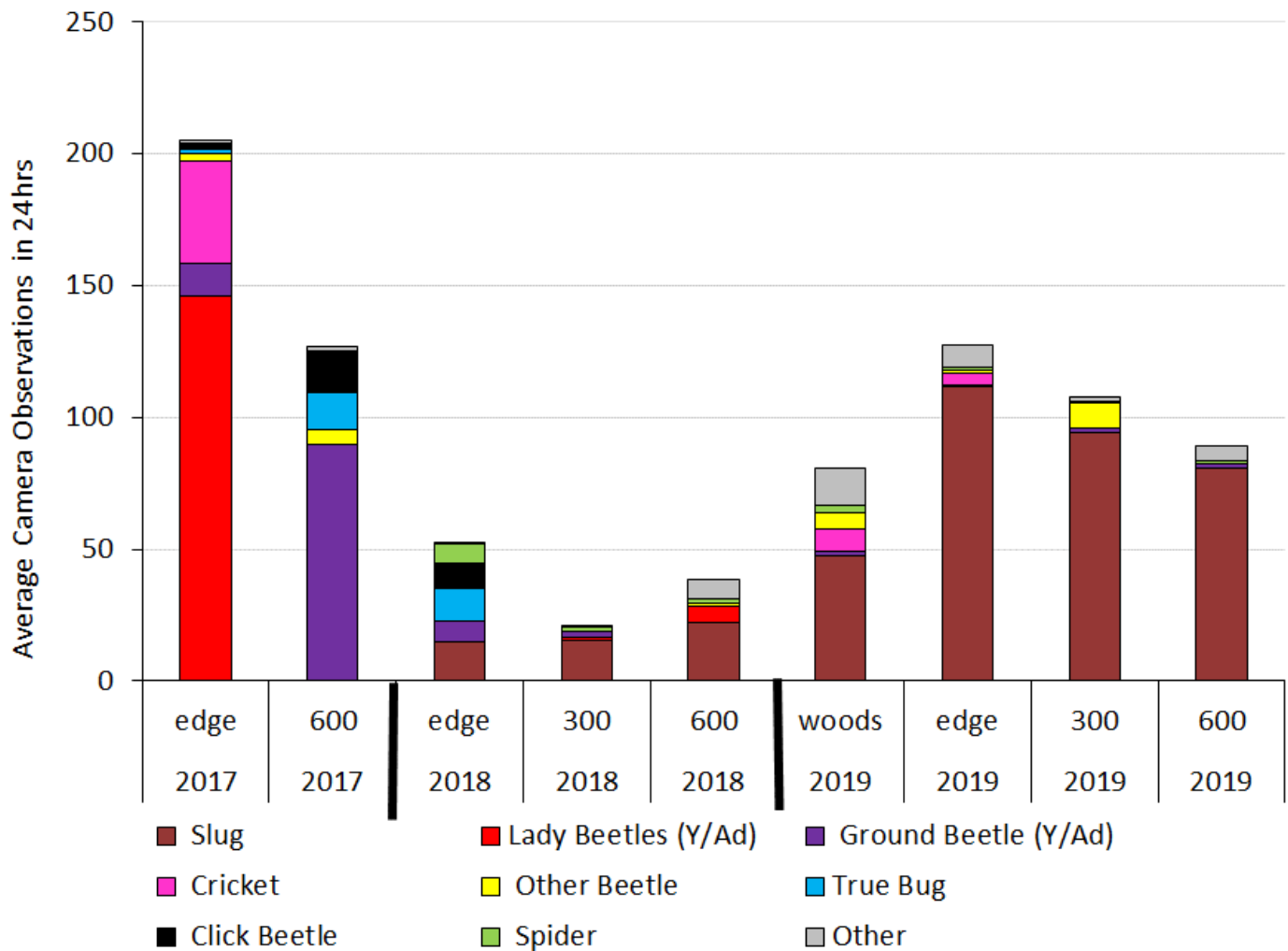


Figure 211. The composition and abundance of visitors to Fall Armyworm bait, as recorded by time-lapse cameras for three different years and at different distances. In 2017 and 2018, the composition of edge visitors was distinct from that further into the field. However, by 2019, the increasing slug presence appeared to have largely homogenized visitor composition. Notice too that, in each year, the highest average rate of predator visits occurred at the edge sites.

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