The Unseen Farm: A Contribution to Mid-Hudson Valley Farmscape Ecology.

Conrad Vispo, Claudia Knab-Vispo, Dylan Cipkowski, Julia Meyer and Liam Henrie.
Hawthorne Valley Farmscape Ecology Program
conrad@hawthornevalleyfarm.org

[**Please note**: This is a preliminary summary of our 2017 fieldwork. While ample time has been spent exploring the data, emphasis has been on producing a coherent report not on polishing the format. As will be evident, this is not a draft journal publication. The review of relevant literature is far from complete.]

Introduction.

Over the past several years, the Farmscape Ecology Program has been exploring aspects of on-farm ecology in Columbia County, NY and the surroundings. As illustrated in Fig. 1, much of this work has focused on the dual questions of '*What can farms provide to regional nature conservation?*' and '*What can wild nature provide to farm production?*'.

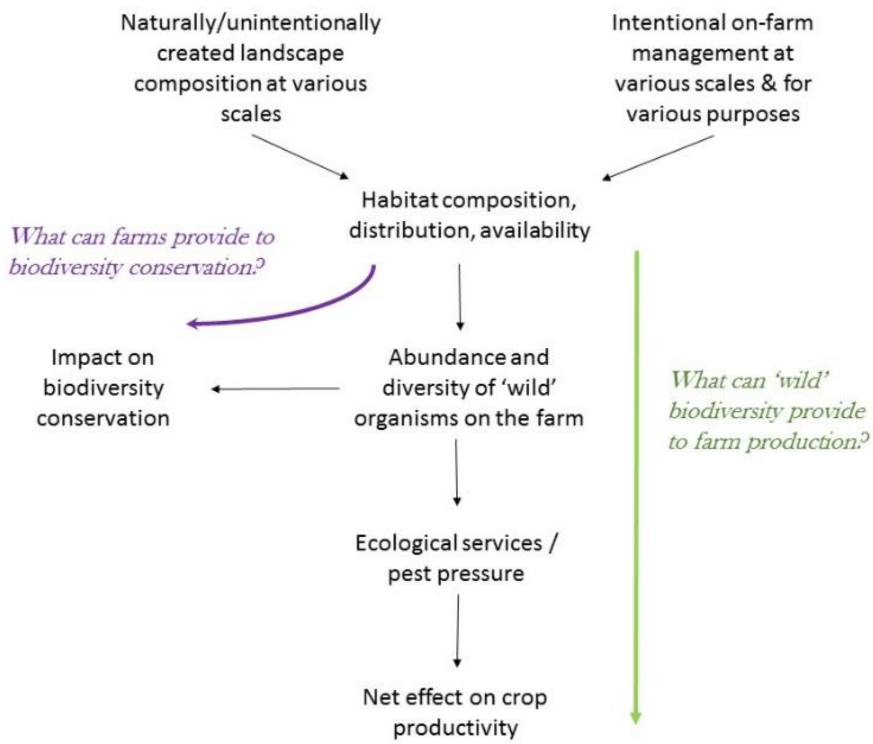


Figure 1. Schematic of our research approach.

This report summarizes some of our recent information relating mainly to the second question. Our response to the first question can be found in on-line summaries such as this. Of course, as the flow chart implies, because beneficials (and pests) are part of regional biodiversity regardless of their agronomic role, the two questions do interact. For example, understanding ground beetle diversity on farms both hints at potential beneficial services and provides an inventory of one aspect of regional biodiversity.

This report tackles the general question, *How can habitat management on and around farms best support net beneficial arthropod-mediated agricultural services?* In large part, this approach of managing on-farm beneficials by managing the habitats for those creatures (as opposed to importing and releasing them) is what is termed 'conservation biological control' (see, for example, this description by Xerces), although we apply it not only to agents of biological control but also pollinators.

We break this larger question down into several more specific questions:

Who are the relevant beneficial organisms in our area?

Aside from in the crops, where are these beneficial insects (and spiders) found in the landscape?

Do we have any evidence that such habitats help support higher levels of in-crop beneficials (without supporting higher levels of in-crop pests)?

Can we tie habitat characteristics on and around farms to improved levels of services such as pest control?

Can we suggest on-farm or off-farm management activities that enhance such beneficial services?

These questions form the organizational basis of this report. We are not the first people to explore any of this, however relatively little has been done in our geographical area, and, if nothing else, we hope this report provides some regionally-useful information.

Although the vegetation analyses conducted as part of this project contributed to the above questions, in and of itself it also posed and answered certain questions about on-farm floral resources. A summary of those questions and results is presented in the accompanying vegetation report.

Methods.

We have conducted various studies looking at the distribution of plants and animals on farms. Some of those past results are included in this report. Many of the methods for the past studies are listed in the respective reports (i.e, 2009, 2012, 2015, 2016, 2017) and will not be detailed here.

During 2017, we worked on four mixed vegetable farms (the Hudson Valley Farm Hub, Hurley, Ulster County; Hearty Roots Community Farm, Clermont, Columbia County; Ironwood Farm, Claverack, Columbia County; Hawthorne Valley Farm, Hillsdale, Columbia County). All four farms are organic, although they differ widely in size from more than 1000 acres in the case of the Farm Hub to roughly 40 acres in the case of Ironwood. Each farm was visited three times in a rotation which started in early June and ended in early October.

Insect Sampling. Figure 2 presents a schematic of the study design that was followed on each farm during each visit. Three sampling sites were located along drive strips within the cropfields of each farm. At or around each of these sites, four pit traps (two in permanent drive strips, two in adjacent cultivated ground), three vane traps (one yellow, two blue), and one large SLAM malaise trap (Bugdorm/Megaview) were run for 24 hours. In addition, one set of 25 sweeps was taken around each site, and a time-lapse camera focused on a yoghurt lid baited with about 140 freeze-killed Fall Armyworm eggs was erected and took photographs every minute for (ideally) 24hrs.

At each farm, three 'wild' habitats were selected to represent shrub (forest edge, hedgerow and shrubby streamside), short herbaceous (lawn, pasture, and headlands) and long herbaceous (wet meadow, old field, and uncut Red Clover) habitats. As the parenthetical descriptions show, it was not possible to standardize these habitats rigorously across farms, and they encompassed an array of situations. Although we will use these habitat names as short hand and they do represent a gradient of increasing vegetation height and woodiness and of decreasing management intensity, the ecologies of these habitat categories sometimes differed widely across farms (for example, see Fig. 4 of the Vegetation Report).

A trap array similar to that used in the cropfields was used in the three 'wild' habitats, although only three pit traps were used at each 'wild' site.

In between each 'wild' habitat and the adjacent cropfield, a large, four-headed SLAM trap (Bugdorm/Megaview) was set, also for 24 hours. Trap sides were labelled A-D with side A of the trap parallel to the edge of the wild habitat and side C directly opposite of that and opening onto the vegetable fields.

The pit traps were made from quart yoghurt containers. Their lids were attached and a roughly 2" hole was cut into each of them. The pits were dry (no bait or drowning solution) and this lidded design was intended to reduce the loss of live insects. Pit traps were checked in the morning and afternoon, and the catch was tallied in the field. When necessary, representative specimens were collected for identification. The rest were released near the site of capture. Soapy water (Dawn unscented liquid concentrate) was used to kill insects who entered the vane and malaise traps; their catch was collected in ethyl alcohol. Sweep net samples were tallied in the field using an aspirator and see-through bug house; representative specimens were collected for future identification.

Using the relevant literature and web resources, captures were identified to species for wolf spiders, hoverflies, bees (identification not yet complete), ants (identification not yet complete), and ground beetles. Wasps were identified to family and, for Braconids and Ichneumonids, to subfamily. Specimens were retained for future identification.

Vegetation/Site Conditions Survey. At each insect sample location, the vegetation/site condition was documented photographically with four images taken from the location of the malaise trap into the four cardinal directions.

In addition, eight circular plots of 3 feet radius (area of 28.26 ft^2 = 2.6 m^2) were established around the malaise trap, with two plots placed in each cardinal direction, one at 2m from the trap, the other at 6m. The following variables were documented in each plot:

Ground Cover: % of the ground (as seen from eye height) covered by crop, wild herbaceous plants (or weeds), wild woody plants, dead vegetation, bare soil, mulch (straw or bark placed there by the farmer), plastic sheets (placed there by farmer for weed control), and others (e.g., agricultural fabric, rocks, cow paddies, water).

Canopy Cover: % of the sky (as seen from eye height) covered by overhead foliage of trees or tall shrubs

Maximum Height of crop (if present), wild herbaceous, and wild woody (if present) vegetation: This was calculated as the average of four height measurements which were taken for each plant category present in the plot by randomly lowering a yardstick in each quadrant of the sample plot vertically into the vegetation and recording the height of the tallest plant (of each category present) touching (or nearest to) the stick.

Presence and relative abundance of structures on the ground surface: The presence of low thatch (dead herbaceous vegetation lodged within 1 inch of the ground), elevated thatch (dead herbaceous vegetation lodged above 1 inch of the ground), leaf litter (fallen leaves from shrubs or trees), hollow stalks (e.g., dried grass, stalks of weeds/wildflowers, straw), woody debris (branches, bark, or wood pieces from trees or shrubs), and rocks were noted and their relative abundance categorized into "some" or "lots".

Flower Survey. We documented the diversity and abundance of flowers (concurrent with the insect sampling) at two spatial scales:

- around the insect traps placed in crops (mixed vegetables) and directly adjacent semi-wild habitats
- at the local landscape scale, i.e., in all habitats within 125m from the center of the crop (mixed vegetables) field

The basic sampling unit was a circular plot of 3 feet radius (area of 28.26 ft^2 = 2.6 m^2).

Around the insect traps, we sampled 8 plots within a 6m radius of the trap, two in each cardinal direction at 2 and 6m distance (the same plots used to describe the vegetation/site condition).

In the habitats within 125m of the center of the cropfield, we sampled 10 (or multiples of 10, if the habitat patch was very large) plots along a linear transect with the plots +/- evenly spaced.

For each plant species in flower, the number of flowers or inflorescences within the sample plot was documented. For species that showed considerable variation in flower/inflorescence size (e.g., dandelion, wild carrot), we also noted the range of sizes present. Floral area per species and total floral area across all species could then be calculated using Aaron Iverson's unpublished spreadsheet of flower/inflorescence dimensions, augmented by our own observations.

Statistical Analyses. Invertebrate/habitat relationships were explored at two levels: first, for each farm and each outing, we had detailed site condition, plant species composition and floral area information from around each trap. This resulted in 71 data points (6 sites/farm x four farms x 3 outings – one lost set of data). Exploratory analyses looked for correlations between the afore-mentioned site information and the invertebrate catch at each trap location on each outing. No effort was made to include the 125m, local landscape-scale vegetation data in these analyses. The data were further summarized to create a second data set of the average captures in the cropfields for each farm and each outing (i.e, four farms, 3 outings each =12 data points). This data set also included the average trap-level habitat data and the local landscape level (i.e., 125m) vegetation data. Analyses of these data looked for correlations between arthropod captures and site data at both the trap and local landscape scales

The analyses reported here are largely exploratory. Pseudoreplication is rife because only four farms were included in the study and results from the traps or habitats at any one farm likely are linked to other results from that farm. "Farm" was included as a potential factor in most multivariate analyses, but may not have resolved this issue completely. Likewise, in this exploratory analyses a lot of 'fishing' for patterns was done, our hope being to identify potential patterns that could form the basis for future, more rigorous hypothesis testing. No attempt was made to control significance levels for multiple comparisons nor, in most cases, to transform the data.

Unless otherwise specified, patterns were tested using linear regression with a $p<.05$ taken to be indicative of 'statistical significance', although, for the reasons just outlined, this determination is not rigorous and should only be seen to hint at the possible existence of true statistical significance and of ecological patterns. In some cases, it was possible to analyze correlational data using a general linear model based on a Poisson distribution. While this may have been more appropriate for our occurrence data, such models often did not converge, and linear regression was usually used. In most cases, scattergrams of the data were inspected as part of the modelling process, however, with the notable exception of date transformations to more accurately model non-linear date effects, no variables were transformed. Collinearity was commonly tested for and an effort was made not to include collinear independent variables.

The Biodiversity of Beneficials.

"Beneficial" is a surprisingly slippery term; it depends not only on local biodiversity but also on the pollination and pest-control needs of local farmers, and the way in which the natural history of that biodiversity interacts with the relevant crop flowers and pests. In some cases, the distinction is not clear – we have several photos of spiders consuming other so-called beneficials, such as hoverflies. Assessing whether or not a particular species is truly beneficial to a particular farm operation is no simple task and will form one core of our upcoming work. In the meantime, we've identified beneficials based largely on published accounts and categorizations.

Bees. Pollination is central in the reproduction of many plants including some crops. In our area, various fruits, such as apples and blueberries, and certain vegetables, such as cucurbits, seem to be strongly dependent on insect pollination. Several others may benefit from it, but not be dependent on it (such as some varieties of strawberries, tomatoes and peppers). Of course, many more crops need pollination to produce seeds, but seed growing is a relatively limited agricultural activity in our area. Although various types of organisms can pollinate flowers, including, for example, butterflies, moths and flies, bees are generally believed to be the most important pollinators of our crops. Which bee species is most important in crop pollination varies amongst the crop species. For instance, early-flying mason bees (genus *Osmia*) can be important pollinators of apples, while our squash plants are frequently pollinated by the Squash Bee (*Peponapis pruinosa*).

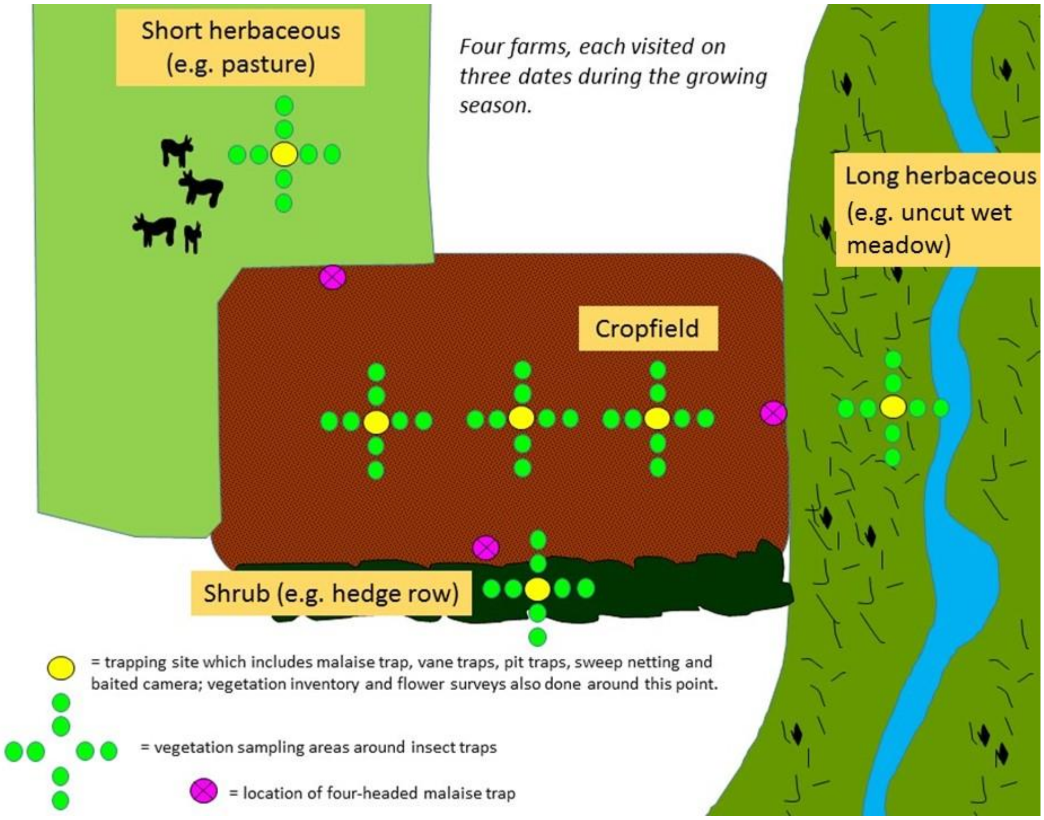


Figure 2. A schematic of our study design during 2017.

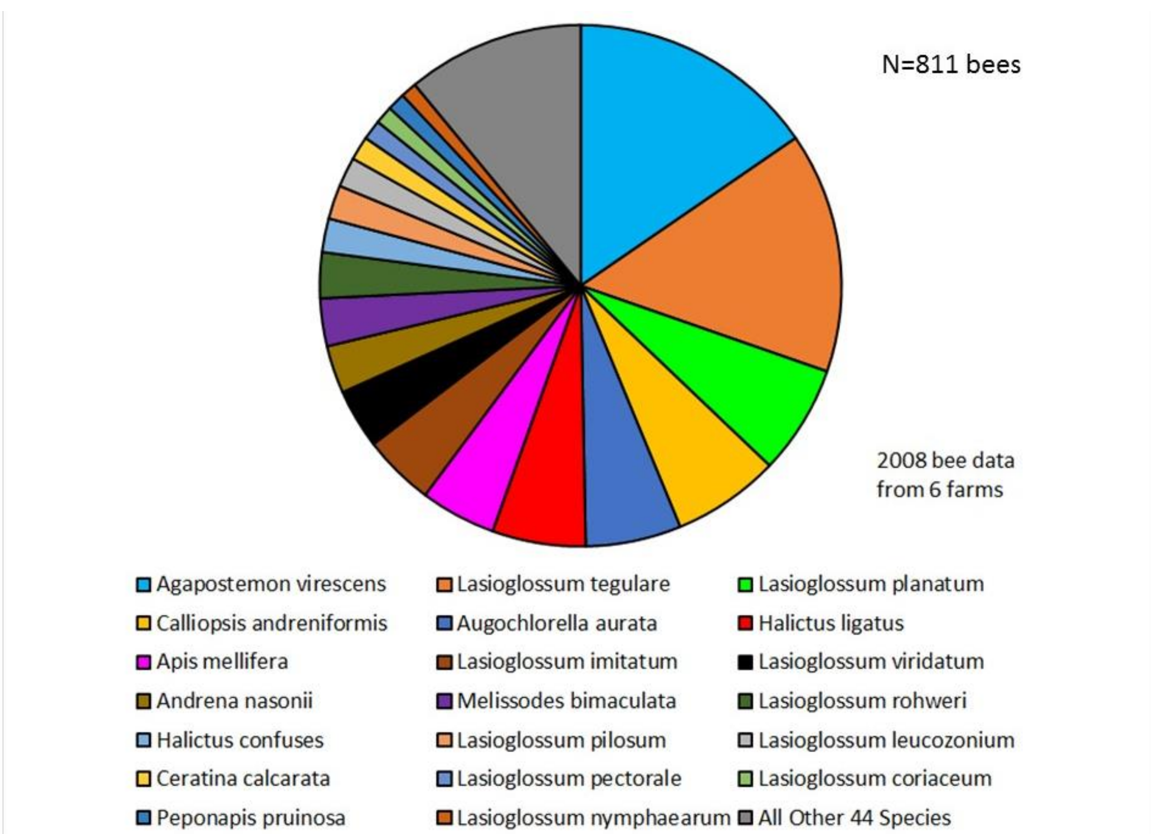


Figure 3. The composition of in-field bee populations at six Columbia County farms studied in 2008. Fieldwork by Martin Holdrege.

We have only begun to identify the bees that we captured during the past field season, however in 2008 a student working with us, Martin Holdrege, conducted fairly detailed bee surveys on six regional farms. He identified 65 species of bee, and the composition of his captures is shown in Fig. 3. *Agapostemon virescens* and two species of *Lasioglossum* were the most common species captured. As a word of caution, 'your farm may vary'. During 2016 work at the Farm Hub in Ulster County, for instance, we noted that *A. virescens,* the single most abundant bee in the 2008 work when it accounted for 15% of the captures, was responsible for only 4% of the catch, while the Squash Bee accounted for 10% of recent captures, but only 1% in the older data. Crops being grown, pesticides use, soil texture (many bees are ground nesters), local habitats, the proximity of Honey Bee hives, and annual climate variation can all account for such differences. For context, our regional bee list for all habitats we've studied both on- and off-farm contains about 155 species.

While we do not yet have regional, species-specific information on which species are pollinating which flowers, our flower watches can be used to describe the relative importance of native bees vs. Honey Bees (Fig. 4). These results suggest that the relative importance of native bees can differ markedly amongst the types of flowers being pollinated. Although the natural histories of native bee species differ from that of the Honey Bee and amongst themselves, most bees need ample flower resources throughout their flight season, whether those be provided by crops or wild flowers.

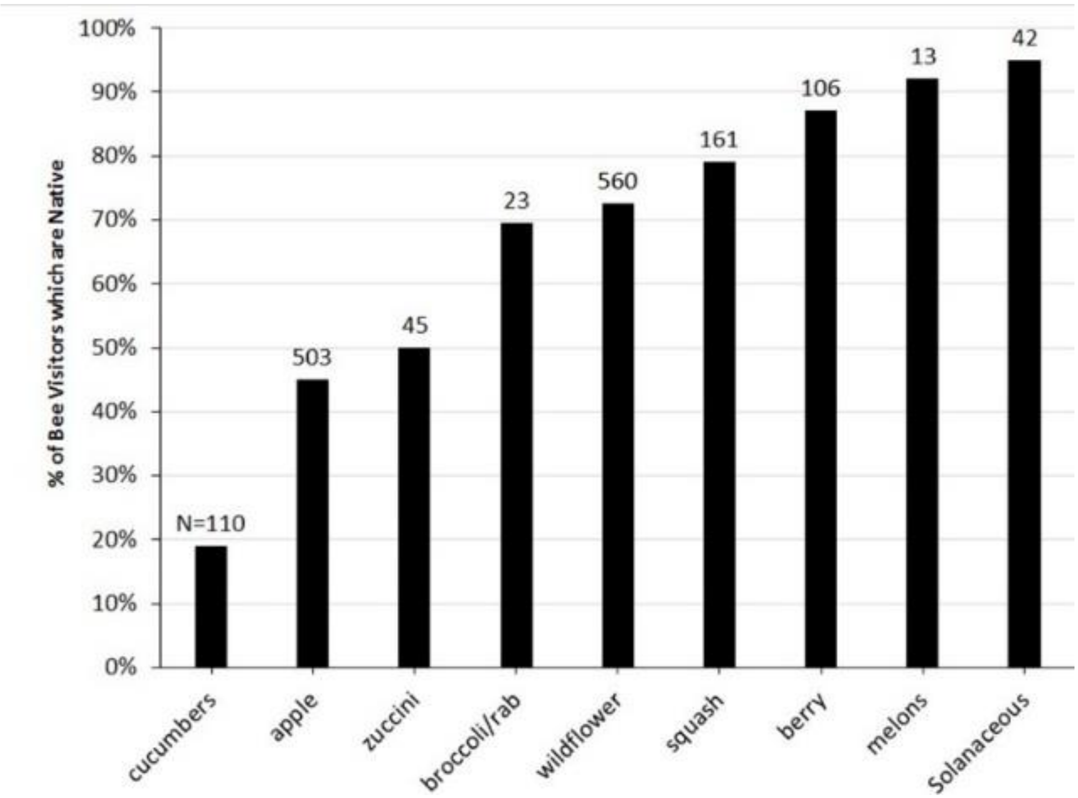


Figure 4. Percentage of bee visitors which are native species, by plant being pollinated. N is the total number of bee visits observed.

Wasps. Wasps are somewhat unsung as beneficial insects. Most species are tiny, inconspicuous insects which pose little risk to humans. Many of these are parasitoids, laying their eggs on or in various life stages of hosts which are subsequently consumed and killed by the growing larvae. Some wasp species parasitize and kill important crop pests. *Trichogramma* wasps, whose larvae consume various types of moth and butterfly eggs, are amongst the best known wasps used for biocontrol and are commercially available. Importantly, most adult wasps are nectar feeders, and so self-sustaining population of these species are thought to require flowers (or extra-floral nectaries) with nectar that is accessible to the short tongues of these species. Study of these wasps is made difficult by their diversity – it is likely that, worldwide, just two of the parasitic wasp families, the Braconids and Ichneumonids, may have more than 100,000 species – and many species probably remain unidentified (Quick 2016).

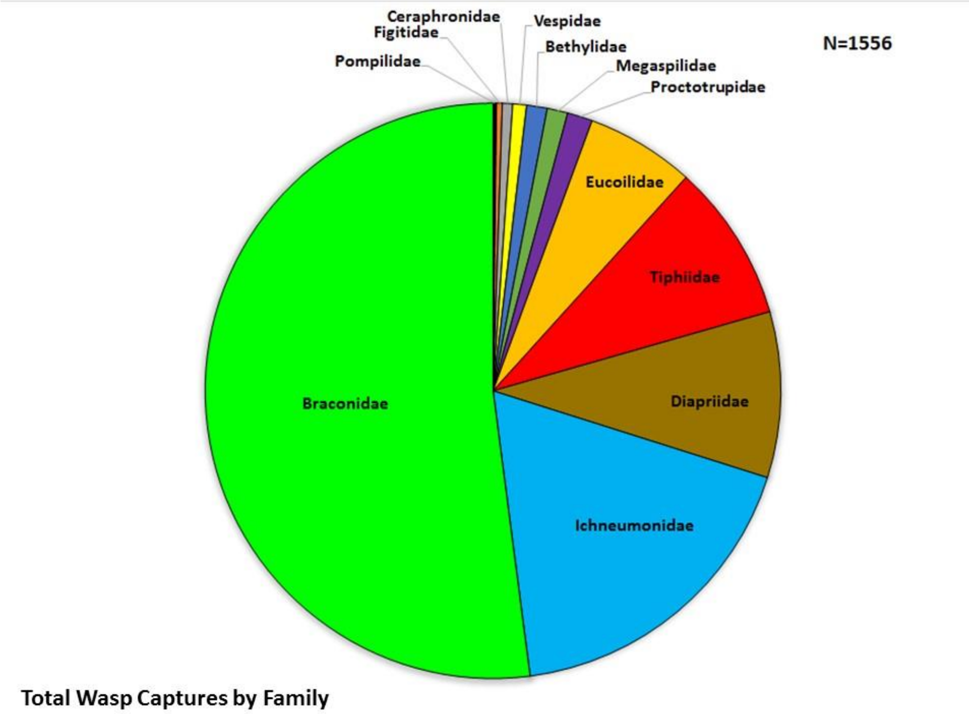


Figure 5. The composition of wasp captures by family on four farms during 2017.

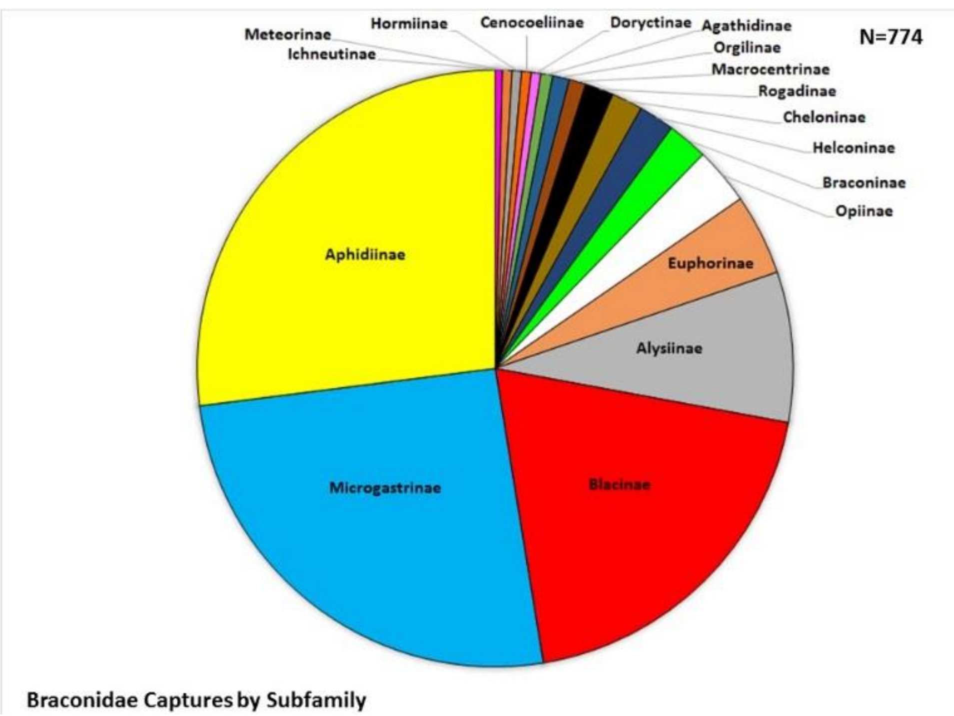


Figure 6. The composition of subfamilies within the Braconidae in 2017 captures.

In most cases, we have only been able to identify the wasps we've captured to family and, sometimes, subfamily (Fig. 5 and 6). Braconidae and Ichneumonidae predominated amongst the families and, within the Braconidae, the subfamilies Aphidinae, Micrograstrinae, and Blacinae were most common. Nonetheless, even this level of detail is useful, because taxa often share certain life-history traits such as host groups and because similarity in community composition at this level can indicate the potential for species-level similarity among habitats. We estimated that there were at least 100 species in the roughly 1900 wasps we collected.

Hoverflies. Hoverflies (aka Flower Flies or Syrphids) are usually medium-sized yellow and brown/black flies somewhat resembling bees. The adults are considered pollinators, although they are probably less effective than bees. The larvae are often predators of soft-bodied insects such as aphids and caterpillars. There are approximately 400 described species in the Northeast; we have so far identified about 30 species in the region (Fig. 7, 8, and 9). *Toxomerus* species of hoverfly appear to be particularly common on farms, with one species, *T. marginatus*, accounting for more than 2/3rds of the captures.

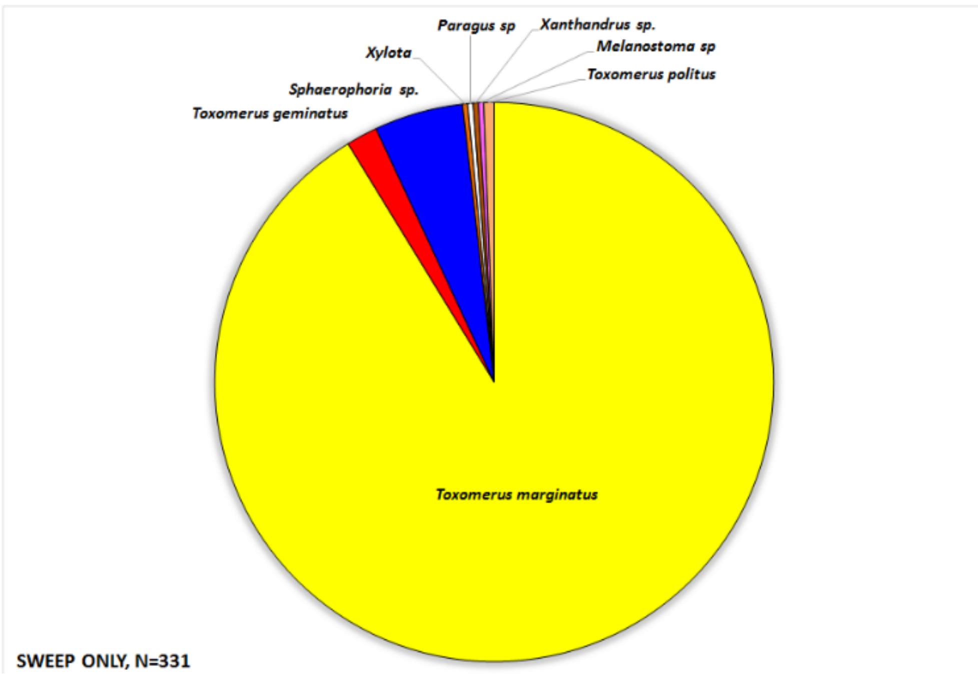


Figure 7. Sweep net captures of hoverflies during the sampling on four farms in 2017.

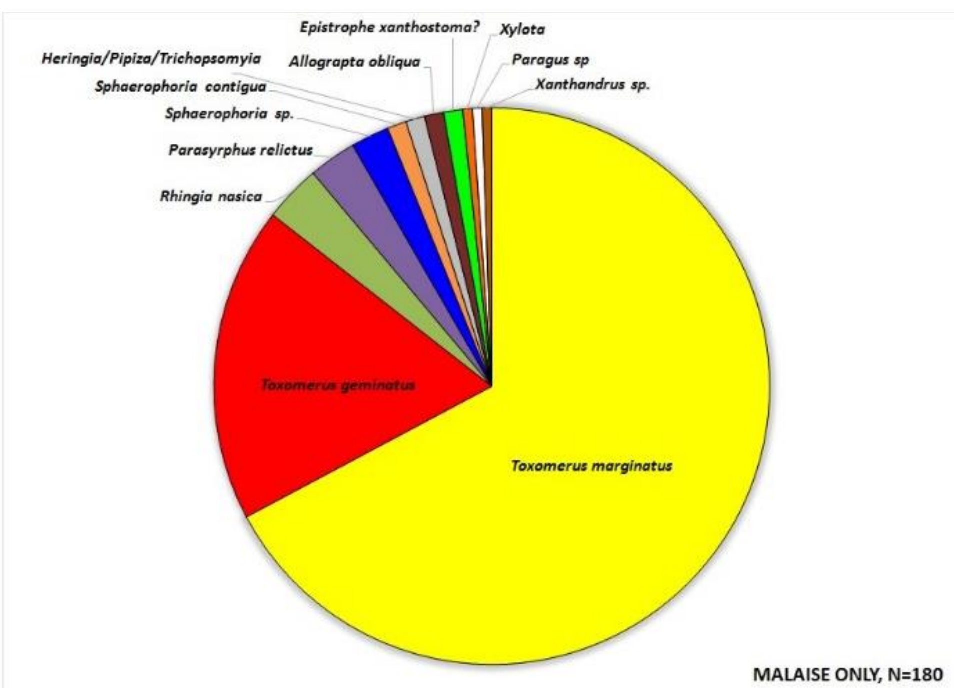


Figure 8. Malaise trap captures of hoverflies during the sampling on four farms in 2017.

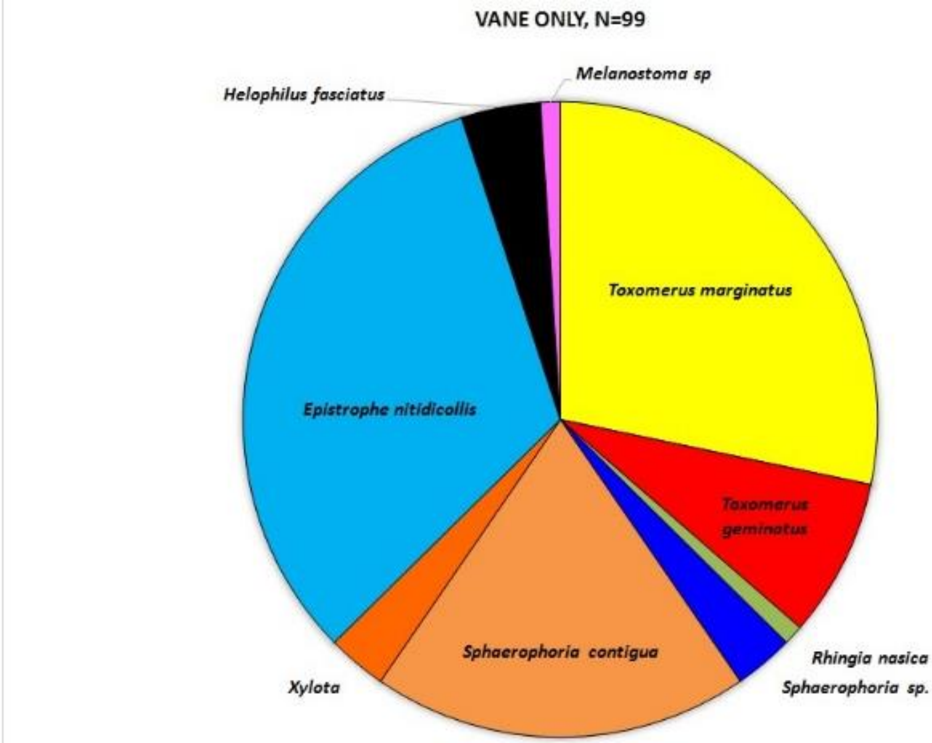


Figure 9. Vane trap captures of hoverflies during the sampling on four farms in 2017.

As shown in Figs. 7-9, the hoverflies are a good group with which to illustrate the dependence of apparent diversity on the methods used for capture. We collected hoverflies using three different techniques – malaise trap, vane traps and sweep net – and the species composition of the captures differed markedly amongst techniques. Vane traps in particular appeared to be catching certain species that were rare or absent from our sweep and malaise samples. It is not surprising that captures vary with technique – some types of traps are better able to capture and hold a given insect and some are more passive than others. For example, malaise traps probably intercept fly-bys, while sweeps actively gather them from on or near vegetation, and the colored vane traps may actively attract certain species. No single method is right or wrong but these biases need to be recognized.

Ground Beetles. Ground beetles compose the Carabidae beetle family. Most of them are dark, medium-sized beetles which, appropriately enough, prefer scurrying across the ground to taking flight. A few species top 1.5” in length while others are the size of a rice grain or smaller. Iridescent greens, sometimes mixed with bronze or blue, are relatively common and tan or reddish markings sometimes occur. There are about 590 reported species in New York State and, in almost a decade of working with them, we have tallied roughly 260 species in Columbia County and the surroundings. Of these, we found 48 species during our 2017 farm study (Fig. 10). Based on this and our earlier work, only 5-10 species are regularly common in cropfields or pastures, including *Harpalus rufipes, H. pensylvanicus, Elaphropus cf anceps, Bemebidion quadrimaculatum, Amara spp., Anisodactylus sanctaecrucis,* and *Pterostichus melanurius*.

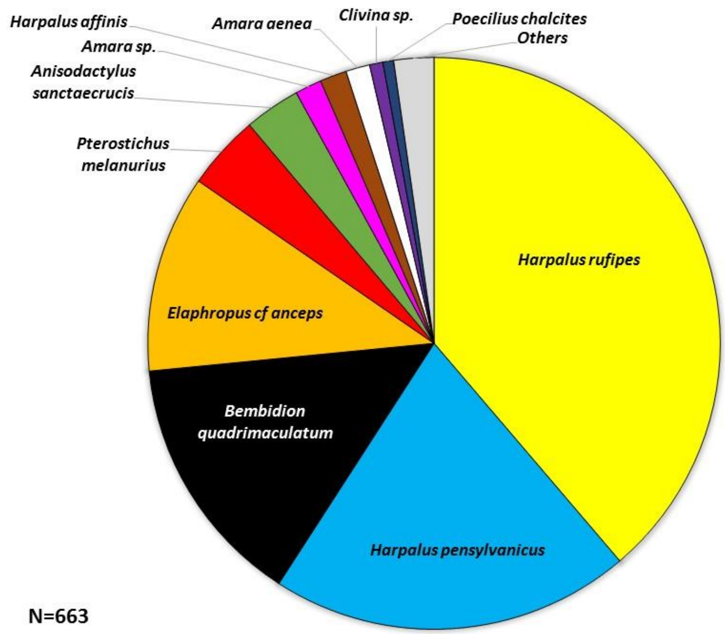


Figure 10. Captures of ground beetles during the sampling on four farms in 2017.

Ground beetles are generally described as beneficial because the adults and larvae of some species consume pest insects and weed seeds. A few species occasionally are deemed to be pests when, for example, they include strawberry seeds in their diets. In our previous work, ground beetles accounted for about 20% of all visitors to baits of meal worms and armyworm eggs, the single largest group of visitors after slugs.

Ants. The on-farm work of ants is perhaps more nuanced than that of some of our other beneficials. While some species certainly do consume certain pests others may tend and defend aphids (Offenberg 2015, Wagner et al. 2014)(Choate and Drummond 2011). Further, much of their work in recycling organic matter and soil turning may go largely unnoticed. Quantifying their effects is challenging, but they regularly appeared at our bait stations, and we assume that they contribute to controlling insect pests and perhaps weed seeds.

During multi-year work, we have identified 77 species of ants from throughout Columbia County. For comparison, a recent field guide to the ants of New England listed 132 species for the entire area. As seems to be true for the other taxa, a relatively modest subset of species are most active on farms. We collected ants during 2017, but most have yet to be identified. However, during our 2010 study of 19 different vegetable farms in Columbia County, we identified about 17 species (Fig. 11). Two species, *Lasius neoniger* and *Myrmica detritinoides*, accounted for more than half of the captures. Initial work suggests that at least *Lasius neoniger* was also common in the 2017 captures.

Spiders. Spiders are mostly generalist predators, although size and hunting style does influence prey choice. Experimental work by others indicates that, at least in some cases, spiders can help reduce pest populations and damage (Marc et al. 1999). Web-building spiders, such as the orb weavers, commonly prey on flying insects which get caught on their silk. Crab and ground beetles, on the other hand, capture their prey ‘on the hoof’, the first with a pounce and the latter with quick darting. While certain spiders seem to be associated with the control of particular pests, for the most part spiders probably contribute to reducing pest outbreaks as part of the generalist predator clan which also includes ground beetles and predatory bugs.

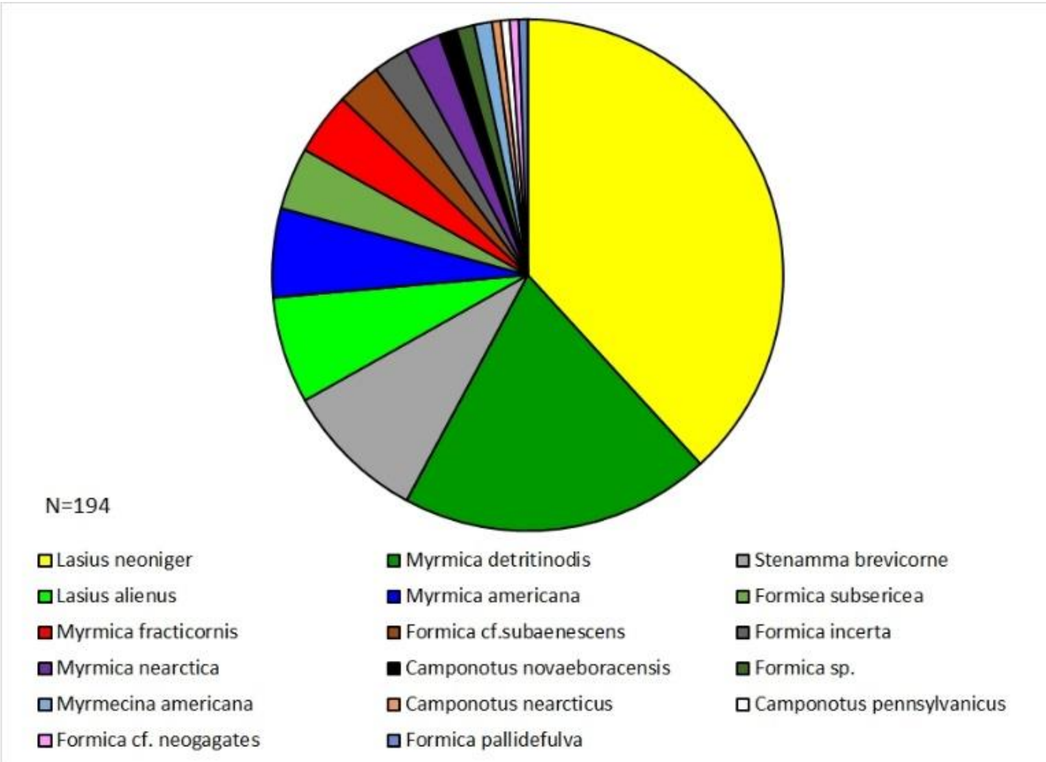


Figure 11. Ant captures by species during 2010 studies on 19 Columbia County vegetable farms.

Certain spider families, such as Crab, Wolf and Jumping Spiders, are relatively easy to identify to family while still alive and, in our sweep netting, we've tallied these groups, along with 'other spiders'. In 2010, during work on Hawthorne Valley Farm, we compared spider communities at the family level across several habitats. In sweep and vacuum samples, the web-spinners in the hard-to-distinguish families of Araneidae, Linyphiidae and Theridiidae accounted for about ¼ to 1/3 of the captures, followed by Long-jawed Orbweavers, Jumping Spiders and Crab Spiders.

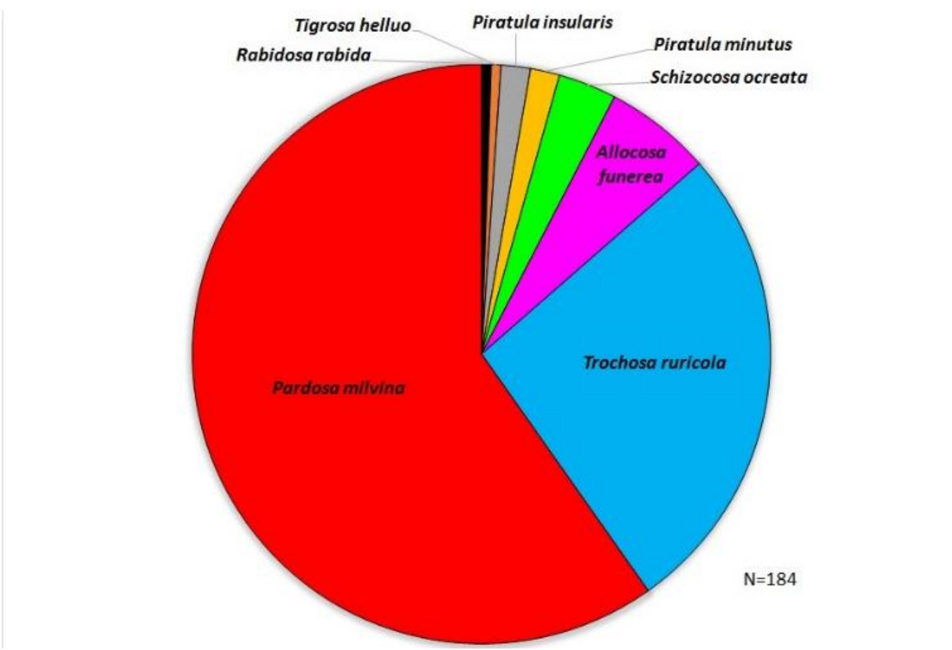


Figure 12. Wolf spiders captured during the sampling on four farms in 2017.

During 2017, we focused spider identification on ground beetles, a group frequently captured in pit traps. Eight species were identified in and around the cropfields with one, *Pardosa milvina*, predominating (Fig. 12).

In some ways, these lists may seem like biological trivia, however species-level identification is important for at least three reasons. First, species identification serves as a name tag that allows one to use the findings of others to increase one's own understanding. For example, although we have no direct observations of the feeding behaviour of *Pardosa milvina*, work by others (Schmaedick and Shelton 2000) has shown that they can help control Cabbage White populations. Secondly, and leading into our next section, taxonomically precise community information is necessary if we want to understand which semi-wild habitats are supporting cropfield beneficials, using gross categories such as "ground beetle" or "spider" is less useful. If, for example, I simply surveyed forest birds and then supposed that those species would populate adjacent fields, I would ignore the fact that, other than Flickers, most woodpeckers are rarely found in cropfields. Finally, while not the focus here, such lists help us understand the potential role of agricultural land in supporting regional biodiversity conservation. For instance, the only place we have ever captured the native ground beetle *Tetragonoderus fasciatus* is in a farm field adjacent to a flood plain forest. While this does not demonstrate that such fields are its only or even favored habitat (the literature suggests that floodplains seem to be key), it does suggest the potential of this relatively rare species to take advantage of on-farm habitats.

Where are Cropfield Beneficials Found, Other Than in Crops?

A central precept of conservation biological control and of our general approach is that one can augment the populations of in-crop beneficials by not only suitable in-field management (e.g., reduced use of pesticides, low-till practices) but also through the creation and/or conservation of certain habitats in the surroundings. Part of our work has thus concentrated on understanding which 'semi-wild' covers around cropfields are habitat for in-field beneficials.

When we began this work almost a decade ago, we were often general in our identification of organisms. While these data are of limited use, it is also true that even when gross categories are used, some ecological generalities might be derivable. Figure 13 summarizes this earlier work. One pattern that appears evident at this very general level is that one size is unlikely to fit all. In other words, different groups of organisms appear to benefit from different sorts of habitat. Spiders may abound in open wet meadows, certain species of ground beetles can reach high densities in cropfields themselves, wasps and ants do well in forests, while hoverflies, lady beetles and assassin bugs may favor the frequently mowed but uncultivated areas surrounding farm fields. This low level of habitat specification and taxonomic rigor precludes basing management on these observations, but does begin to hint at the importance of habitat diversity in supporting a diverse (and hence potentially responsive) set of beneficial insects. Others (e.g., Hendrickx et al. 2007) have noted such a relationship when comparing insect communities to remotely-derived summaries of landscape composition.

Our 2017 work was, in part, meant to refine our understanding of the role of open or semi-open non-crop areas in supporting beneficials, because our species level work was beginning to suggest that forest interiors held relatively few species in common with cropfields.

We do now have more detailed information on species composition and habitat structure. In the text that follows, we will consider those data by benefical insect group.

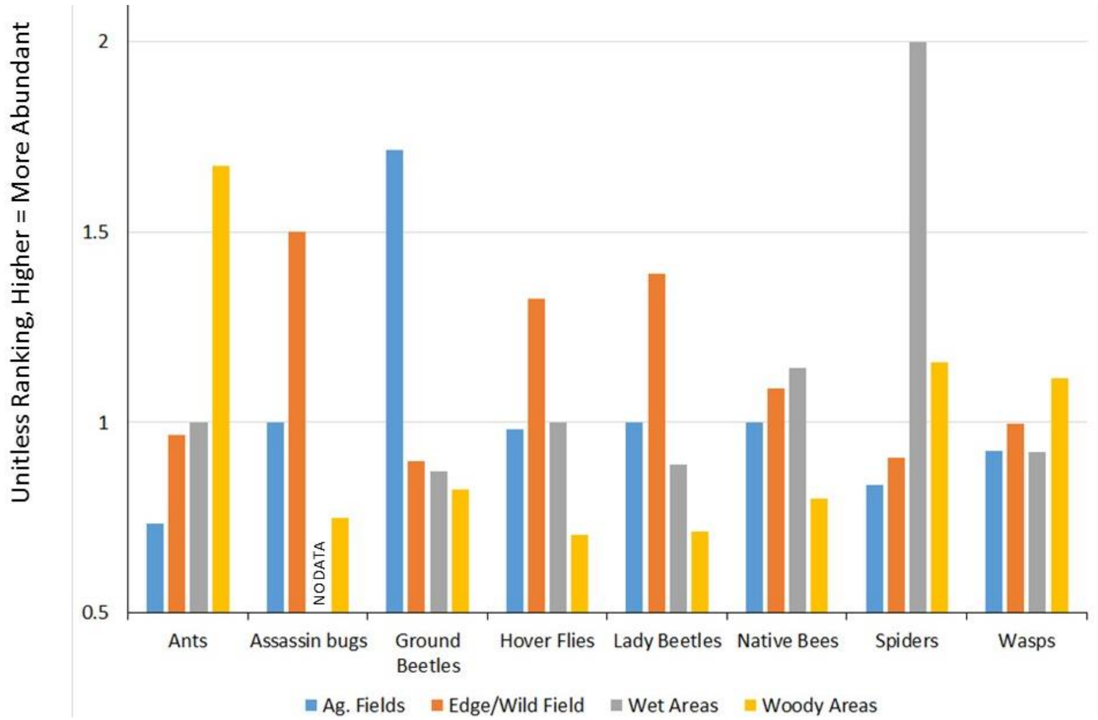


Figure 13. The relative abundance of various taxa across gross habitat types, based on various of our past studies. Three to ten data sets were included depending on the taxon.

<u>Bees.</u> We are still identifying our bees from 2017. Analysis at a gross level (Fig.14) illustrates the afore-mentioned importance of capture technique. For example, if one just looks at the distribution of bees at the Hub (orange), one sees that relying on vane trap captures might lead one to underestimate the importance of shrub habitat in supporting bees. Likewise, vane and malaise captures provide a different picture of bee abundance in lawns at Ironwood than do sweep samples. Even the apparent bee abundance across farms differs with technique, with the Hub predominating in bee

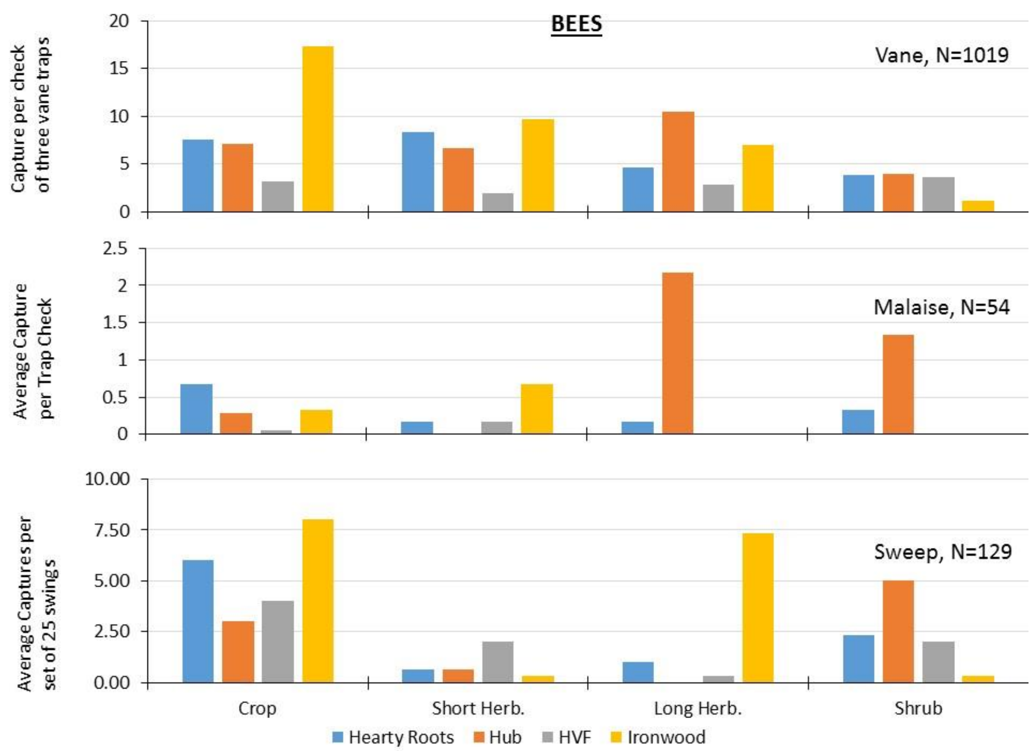


Figure 14. 2017 bee captures by habitat, farm and trap method.

captures in the malaise traps, but not in the captures from the other two techniques. That said, few generalities are apparent, suggesting that we need to drill down further with both our taxonomic work and/or our habitat characterization.

Work from previous years hints at some of the species-level patterns. Martin Holdrege compared the bees he found in spring on floodplain forest spring ephemerals with those he found later in summer in adjacent cropfields. More than a quarter of the summer-time crop bees were also found on the floodplains in spring, suggesting the potential agronomic importance of having such early-flowering habitats in the landscape around farms. At the same time, our 2016 captures (Fig. 15) along transects from woods into cropfields suggested that only a small subset of bees (six out of 29 species) were found in both woods and crops during the summer. Not surprisingly, nesting ecologies reflected this habitat distribution: all three of the 'woods only' species are reported to nest primarily in stalks or woody debris, whereas almost half the 'field only' bees were ground nesters and most of the rest were generalized cavity nesters. At least a couple of the relatively common bees of cropfields were also found in adjacent forests, although the majority of cropfield species were not encountered in the forests.

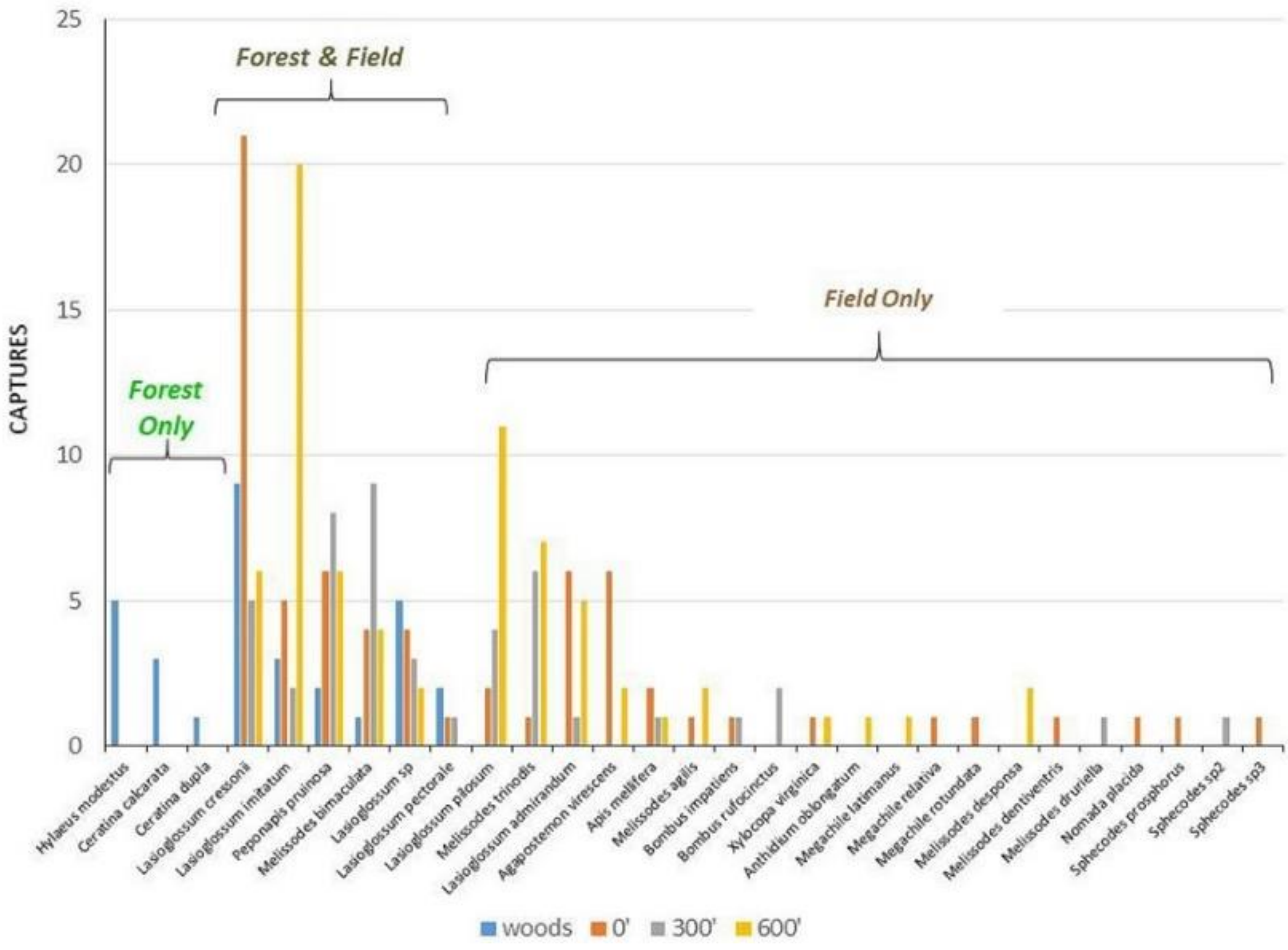


Figure 15. 2016 data along a forest to field transect at the Farm Hub.

Another approach to the question of habitat use, and one we will repeat with other taxa, is to ask what habitat characteristics are associated with a greater abundance of cropfield bees, regardless of their species. Future refinement of cropfield bees into, for example, long-tongued and short-tongued species will probably be important. However, for now, we asked what trap-site and local landscape-level (i.e., 125m) vegetation characteristics were most strongly correlated with bee abundance in cropfields?

Table 1. ANOVA illustrating the correlation between combined vane and malaise captures of bees in crops at the four farms studied in 2017. (Since the vast majority of bees captured were native; an essentially identical relationship held for native bees.) The twelve points reflect the unique combinations of four farms and three outings.

```
anova AllBeeVM c.WildCarrot c.avgherb c.NonCropbeesVM

                         Number of obs =         12    R-squared     =  0.9929
                         Root MSE      =     2.6437    Adj R-squared =  0.9902

                  Source | Partial SS         df         MS        F    Prob>F
              -----------+----------------------------------------------------
                   Model |  7764.9757          3   2588.3252    370.33  0.0000
                         |
              WildCarrot |  1890.0026          1   1890.0026    270.42  0.0000
                 avgherb |  41.706342          1   41.706342      5.97  0.0404
             NonCropbe~M |  545.16668          1   545.16668     78.00  0.0000
                         |
                Residual |   55.91323          8   6.9891537
              -----------+----------------------------------------------------
                   Total |  7820.8889         11    710.9899
```

Perhaps most notable is the absence, when assessed at the trap scale or at the local landscape scale (i.e., 125 m circle), of a significant correlation of bees with total floral area of all flowers or even of flowers thought to be bee favorites. It may be that flower availability is rarely a limiting local factor in landscapes as diverse as those included in this study or that we are inaccurately grouping flowers and/or indexing their floral resources. In our study, the floral area of Wild Carrot and higher vegetation ("avg herb") were positive correlates of vane and malaise bee captures in the cropfields, together with capture of bees in adjacent non-crop areas (Table 1). Our best non-linear model of the date factor was also included in this model, but was not significant. Farm, as a controlling factor, explained some variability but didn't change the apparent pattern. The abundance of bees captured in *non-crop areas*, in turn, is also correlated with Wild Carrot (Fig. 16) around those traps, even after accounting for date and farm. Annual Fleabane danced in and out of significance at various scales. Date effect is strong when modeled to account for a mid-summer peak in bee abundance. Native bees in *sweep* captures were not strongly correlated with any vegetation characteristics, however bee captures in sweeps were less than 1/10th those in the vane and malaise traps (89 vs 1078, respectively).

There are a variety of good reasons why these correlations should be viewed as no more than hints of potential patterns. Nonetheless, they could suggest that the maintenance of wilder areas supporting bees outside of the crops together with allowing the presence of taller vegetation with wild flowers, such as Annual Fleabane or the non-native Wild Carrot around the crops, could be beneficial (see Fig. 17 for summary of apparent patterns).

Although it is recognized as being attractive to bees, the relationship with the non-native Wild Carrot (aka Queen Anne's Lace) might not suggest a particularly strong relationship between bees and this plant. Because we only had four farms, Wild Carrot somewhat served as a marker for one particularly bee-rich farm (Ironwood). Nonetheless, we attempted to remove farm effect by using a blocking variable for farm, and the average bee captures for the four points with the highest Wild Carrot in Fig. 17 was 64, while the average captures for all lower levels of Wild Carrot (N=67) was only 12. The high bee abundance of Ironwood may, indeed, have been due partially to its flora (vs. some other farm-specific trait), but these are relationships we won't be able to tease apart until we include more farms in our data collection.

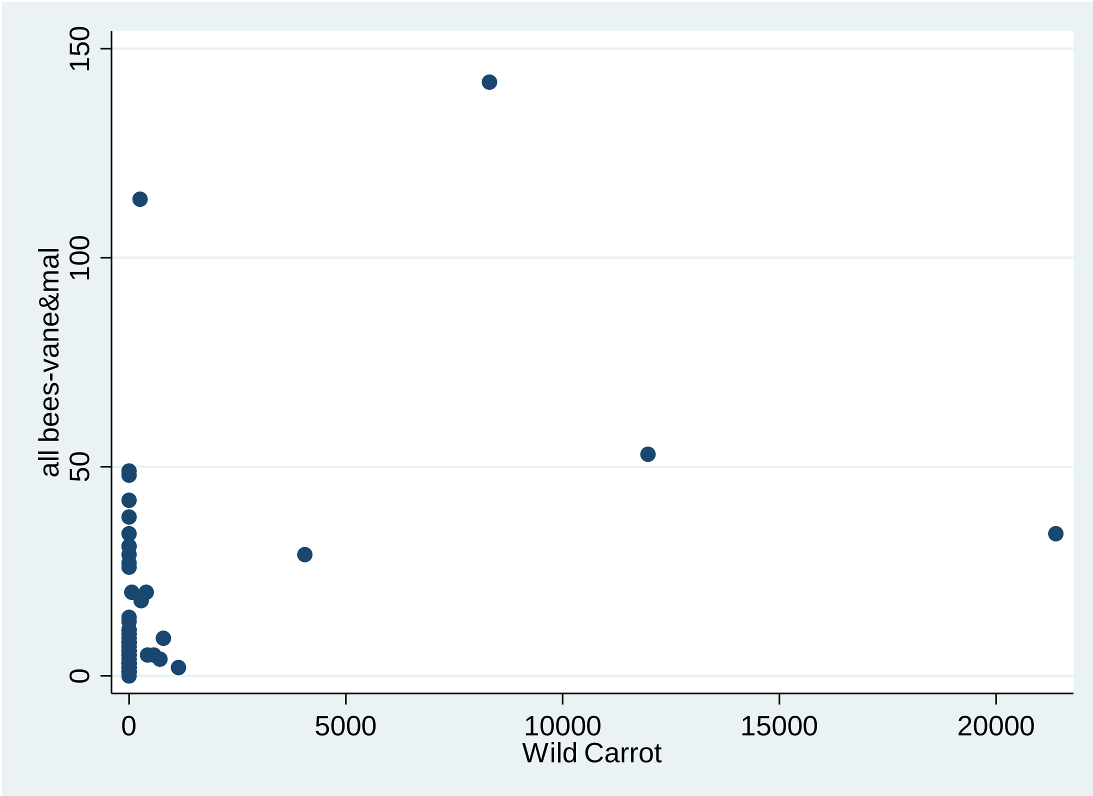


Figure 16. Scattergram illustrating the relationship between trap-level Wild Carrot floral area (mm²) and all bee captures in vane and malaise traps. The linear relationship is not strong, although mean been captures with high levels of Wild Carrot (above 2500 mm²) averaged xx% higher than those at traps with lower amounts of that flower.

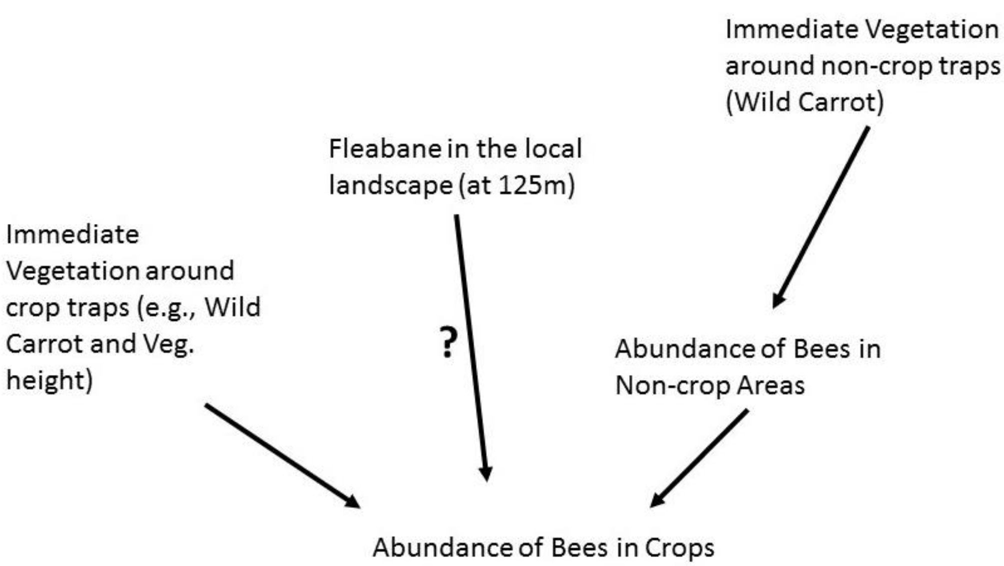


Figure 17. Hypothesized relationships affecting bee abundance in the crops, as suggested by the correlational exploration of the data described in the text. All indicated relationships are positive. Annual Fleabane was significant once one point with extremely high Fleabane but relatively few bees was removed from the correlation.

Wasps. At a general level, the different sampling techniques for wasps suggested different patterns of habitat use. Wasps were most abundant in sweep net samples from in and around crops (Fig. 18), with short herbaceous habitats apparently being the next most favored habitat. The pattern was not apparent in the malaise samples. Specific habitat relations appear to differ when we compare wasp captures in malaise/vane traps with those from sweep netting. This is not surprising given the apparent taxonomic differences in the composition of the captures across sampling methods. For example, at the family level, Braconid wasps made up 37% of the malaise captures but 54% of the sweep samples. Even at the subfamily level within the Braconids there were distinct differences (Fig.19), for instance, Aphidines made up a quarter of the sweepnet captures, but less than 5% of the malaise catch.

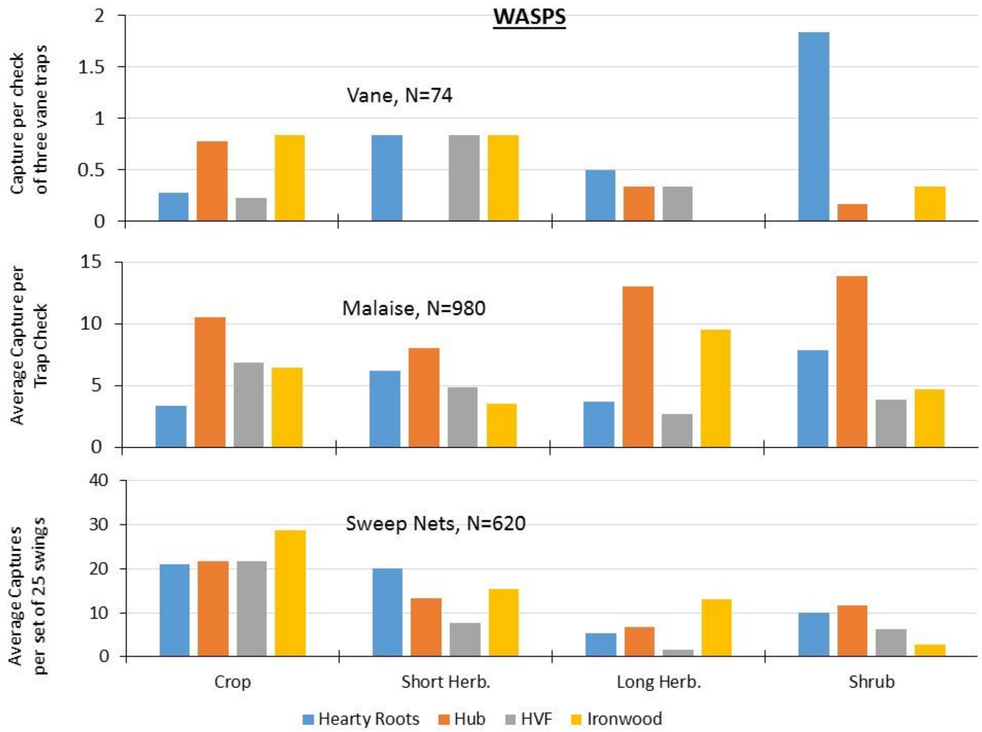


Figure 18. 2017 wasp captures by habitat, farm and trap method.

Furthermore, habitat use differed among wasp families (Fig. 20). In the malaise captures, for instance, Braconids were most common in the crops and short herbaceous habitats, while the remaining common families, with the possible exception of the Eucloidae, seemed to favor taller vegetation. Amongst the Braconid subfamilies themselves (Fig. 21; note that here captures have been summed across trap types because of small sample size), the Aphidines and Blacines apparently favored crops and other short herbaceous habitats, while long herbaceous and shrub habitats were relatively more important for the other subfamilies.

There were ample wasp captures in both malaise and sweep sampling, and, perhaps for the reasons discussed earlier, the suggested correlations with habitat characteristics differed somewhat depending on trapping methods.

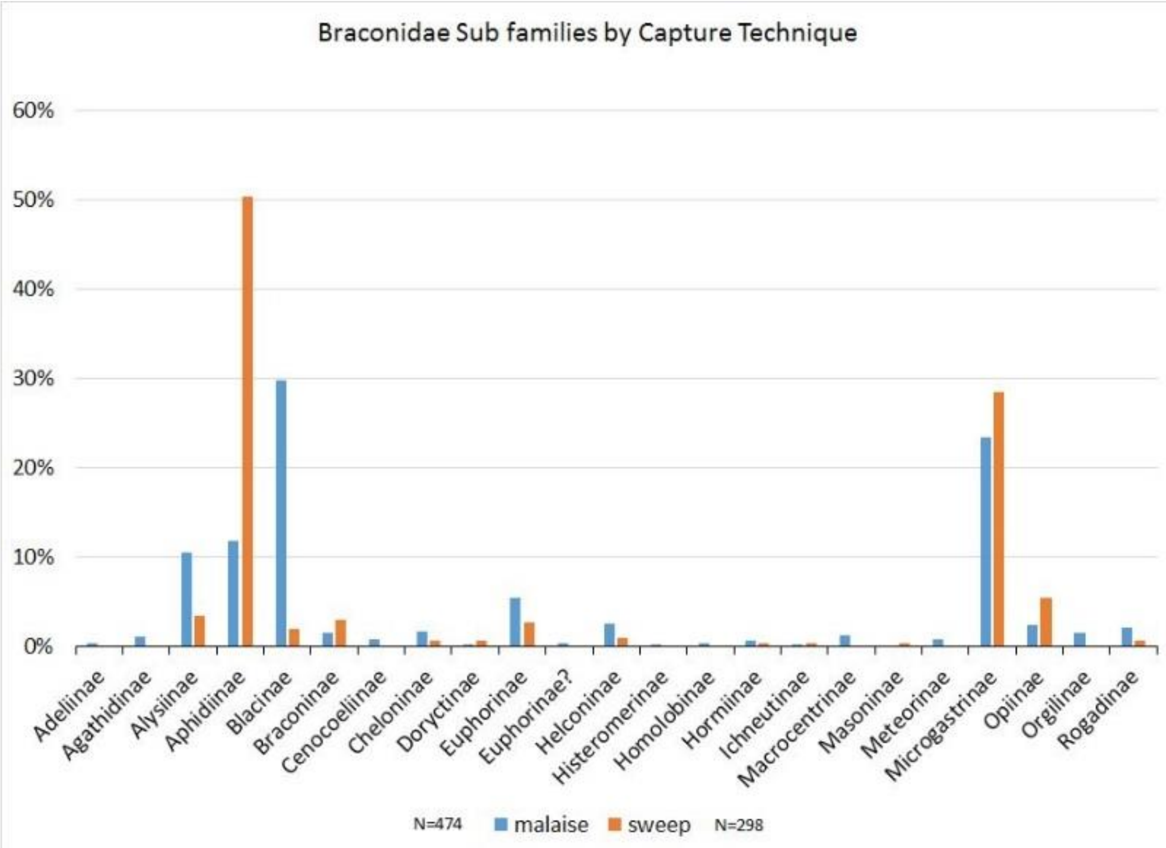


Figure 19. Braconid subfamilies in 2017 captures by capture technique.

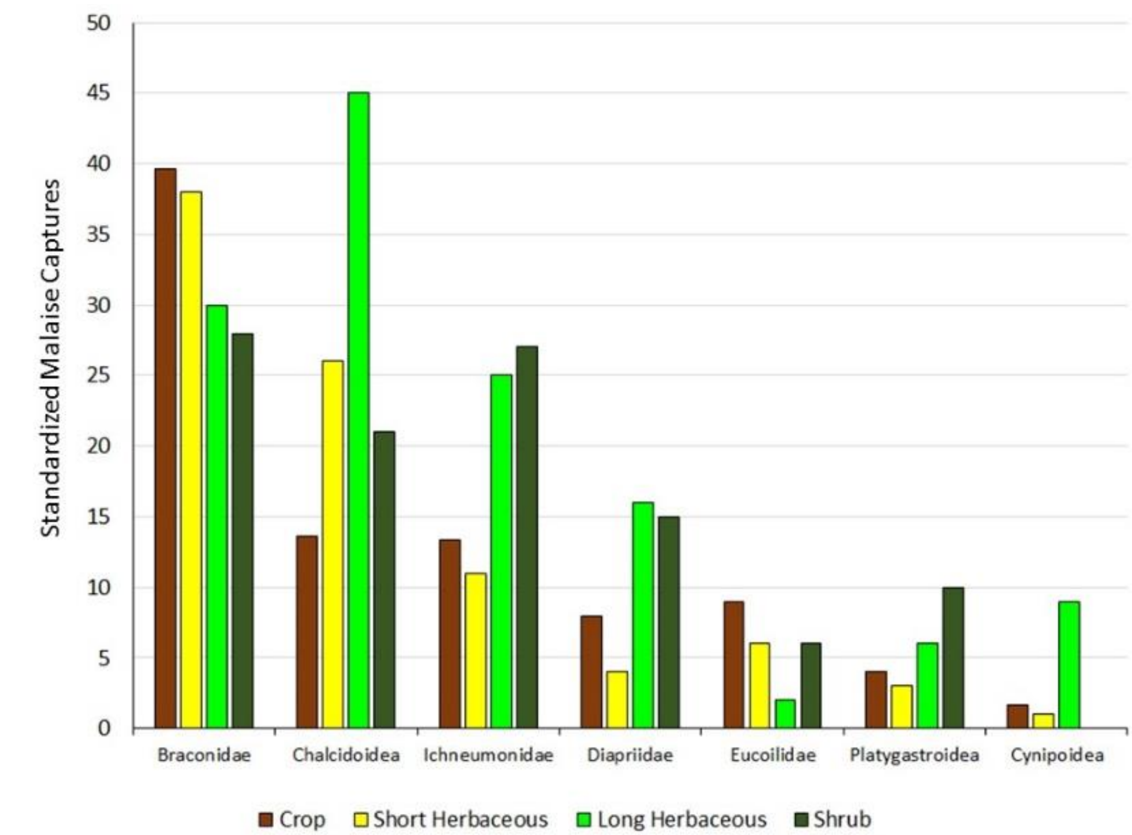


Figure 20. Wasp families by habitat.

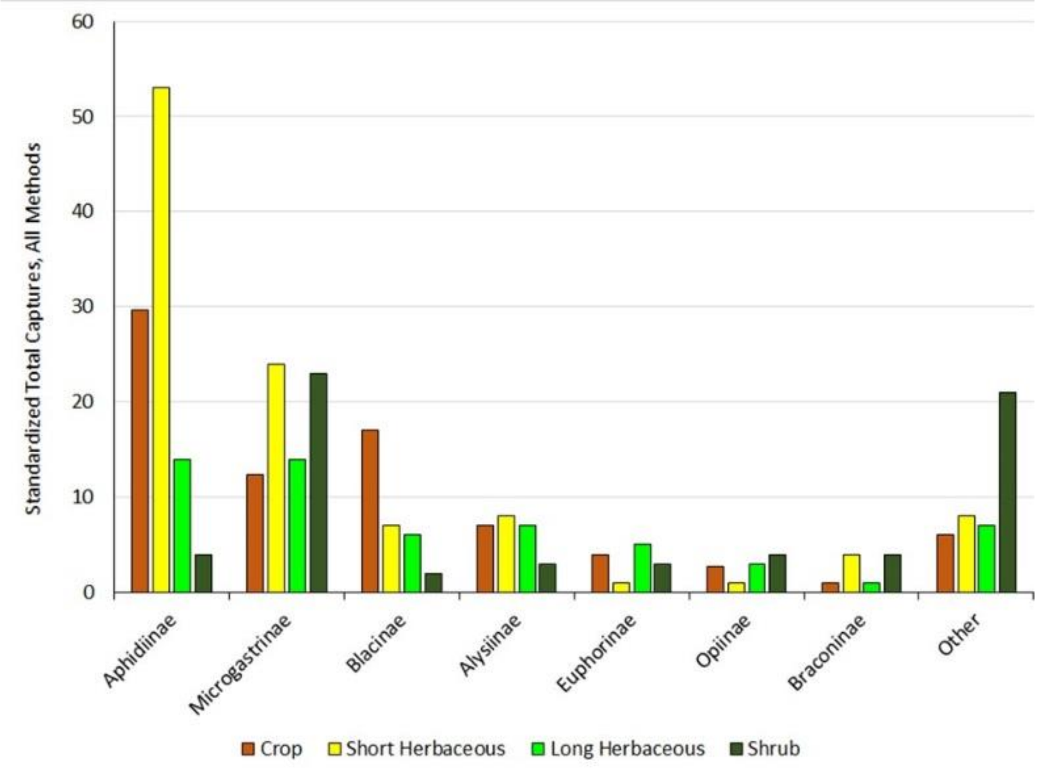


Figure 21. 2017 Braconid wasp subfamilies by habitat type.

At the level of farm and outing, in-crop sweep net captures were most closely correlated with the abundance of wasps in non-crop habitats. Wasps in non-crop habitats were, in turn, positively correlated with the floral area of all asters (Asteraceae) at the local landscape level, but negatively correlated with the floral area of all non-native flowers at the same scale (Fig. 22). These two vegetative descriptors were not significantly correlated. The negative relationship with non-native flowers may have derived from a joint correlation with season, because non-native floral area declined late in the season when wasp numbers peaked. However, date itself was not a good linear predictor of wasp numbers in this sample set. Delving into patterns at the trap level, sweepnet captures of wasps appeared to be significantly positively correlated with date, abundance of aphids and the floral area of native wildflowers around the trap (Table 2). The floral

Table 2. A general linearized model indicating the relationship between wasp sweep captures and date, aphids and the floral area of wild native plants.

```
Generalized linear models                    No. of obs      =         71
Optimization     : ML                        Residual df     =         67
                                             Scale parameter =          1
Deviance         =  291.6356432              (1/df) Deviance =   4.352771
Pearson          =  287.9491006              (1/df) Pearson  =   4.297748

Variance function: V(u) = u                  [Poisson]
Link function    : g(u) = u                  [Identity]

                                             AIC             =   7.482086
Log likelihood   = -261.6140625              BIC             =   6.036091
```

MicroWaspswp	Coef.	OIM Std. Err.	z	P>|z|	[95% Conf.	Interval]
JDAY	.0578252	.0082819	6.98	0.000	.0415929	.0740574
Aphidsswp	.4946148	.0785435	6.30	0.000	.3406724	.6485572
allwildnatives	.0000312	9.26e-06	3.37	0.001	.000013	.0000493
_cons	-6.698636	1.572728	-4.26	0.000	-9.781126	-3.616145

area of asters (Asteraceae) was also positively correlated with wasp abundance at this scale, but the relationship was weaker than that of the floral area of all native wildflowers. In sum (Fig. 23), as assessed by sweep sampling, wasps in crops appeared to be relatively strongly tied to wasps in adjacent non-crop areas. In turn, the wasps in those wilder areas were linked to floral abundance at various scales and to the abundance of aphids, one the most common hosts. Wasp numbers peaked in late summer.

The combined malaise and vane wasp captures (in which malaise captures predominated by an order of magnitude) showed a slightly different pattern. In-crop wasps were again most correlated with wasps in non-crop habitats (in our by farm and outing data set), although strong predictors of wasps in non-crop habitats, as a group, were absent in this summarized data set. At the trap scale, captures were positively correlated with the floral area of all brassicas and all native wild flowers, although the model was not strong. Date and aphid abundance appeared to be relatively unimportant. Malaise traps may often be intercepting wasps en route to other sites and that might blur habitat relationships.

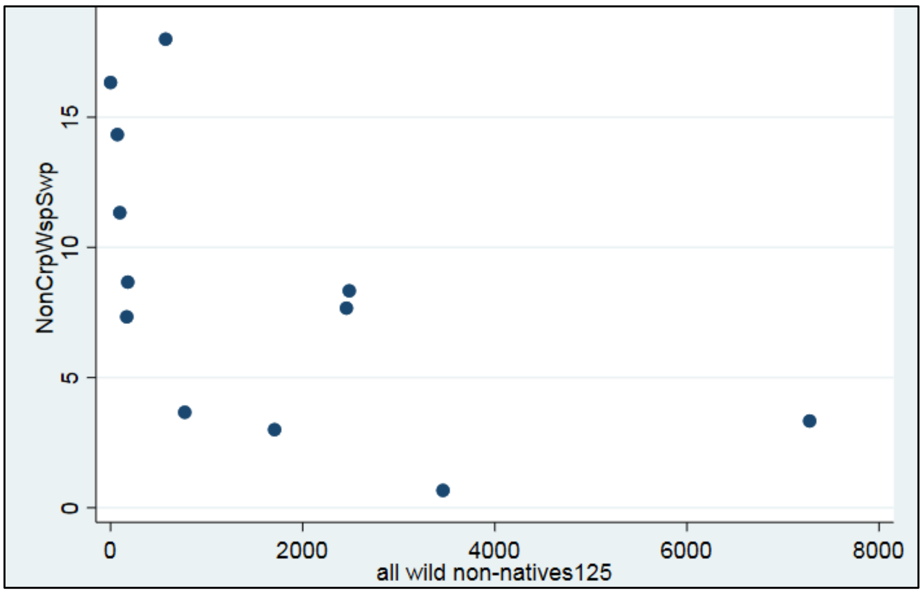


Fig. 22. The negative relationship between wasps captured in non-crop areas and the floral area of wild non-native plants at the local landscape scale.

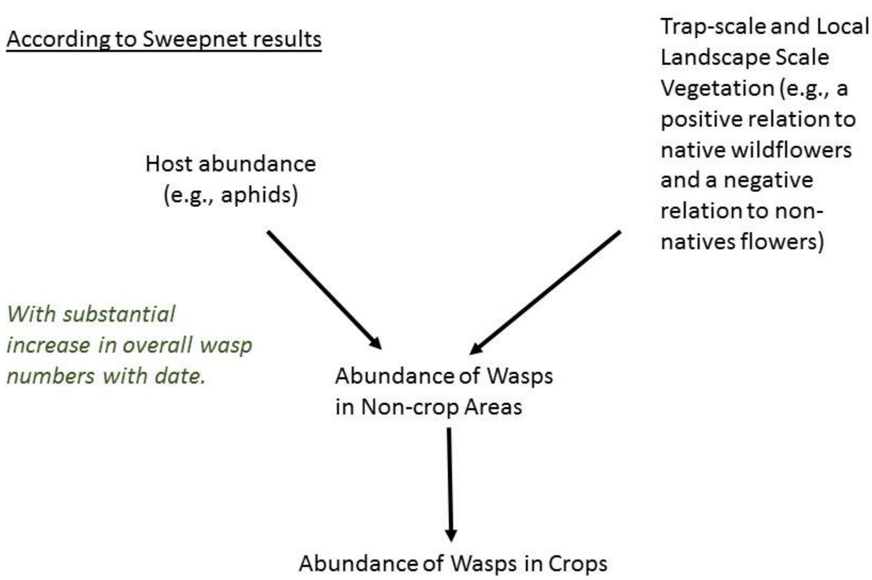


Fig. 23. The hypothesized relationship between cropfield wasps and certain other factors suggested by the results of analyses discussed in the text.

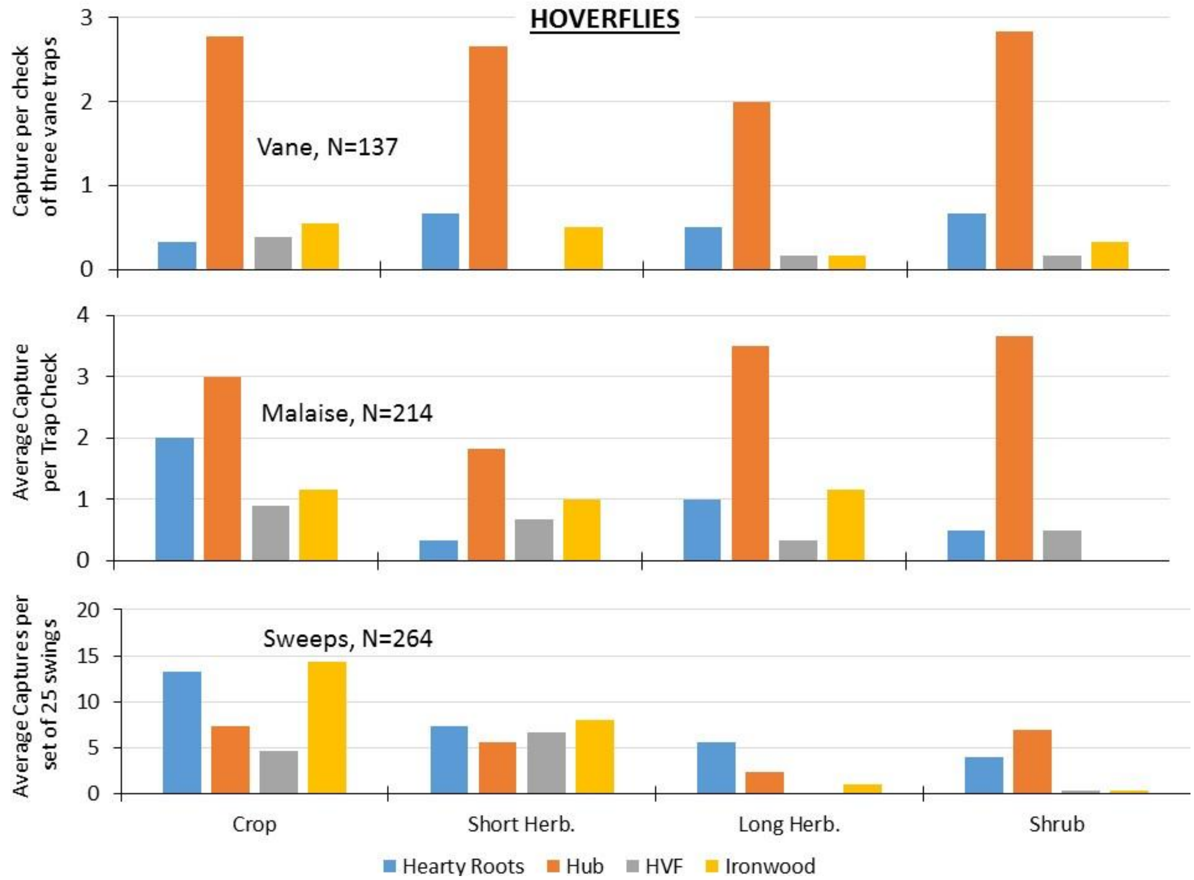


Figure 24. 2017 hoverfly captures by habitat, farm and trap method.

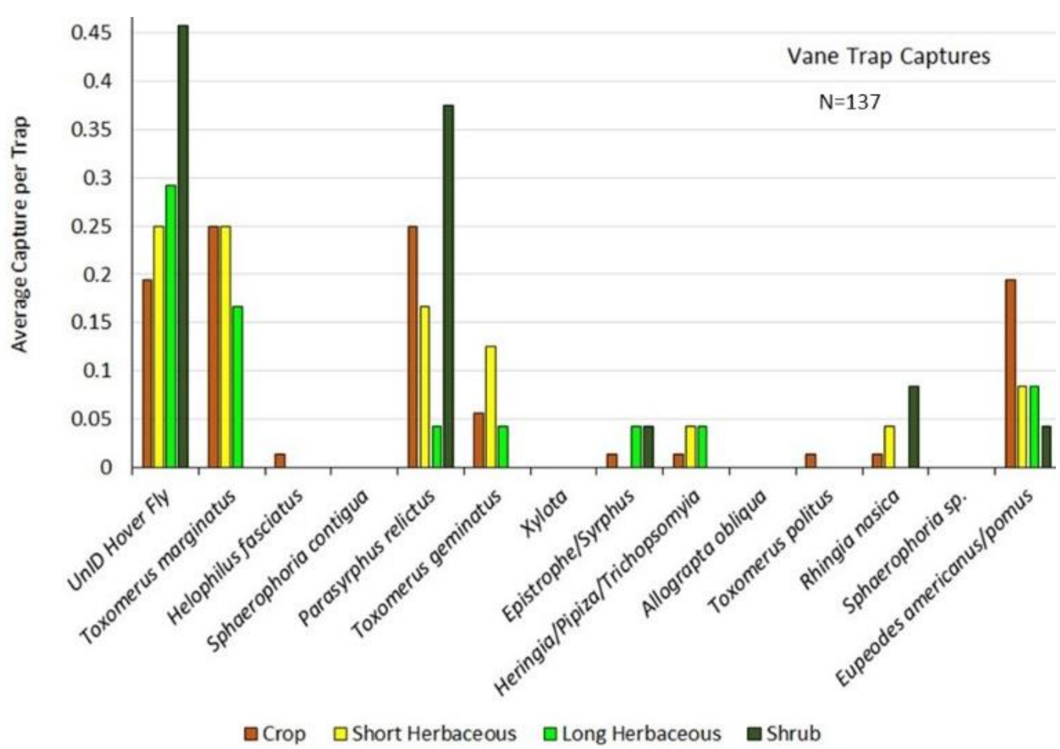


Figure 25. 2017 vane trap captures of hoverfly species by habitat.

Hoverflies. At the general level (Fig. 24), in our 2017 data hoverflies appeared to be most common in the crop habitats. The patterns weren't strong however, and they varied among farms and capture techniques; notice, for example, how malaise and vane sampling suggests a relative abundance of hoverflies at the Hub, whereas such a pattern is not evident in the sweep samples. We have summarized the species-level habitat data for the vane (Fig. 25) and malaise traps (Fig. 26). The most commonly identified species, *Toxomerus marginatus*, seemed to shun the shrubs (preliminary data from the sweep sampling suggests the avoidance wasn't as complete but crop and short herbaceous still seemed to be the favored habitats). The vane traps seemed to be noticeably more effective than malaise traps at capturing shrub-favoring hoverflies.

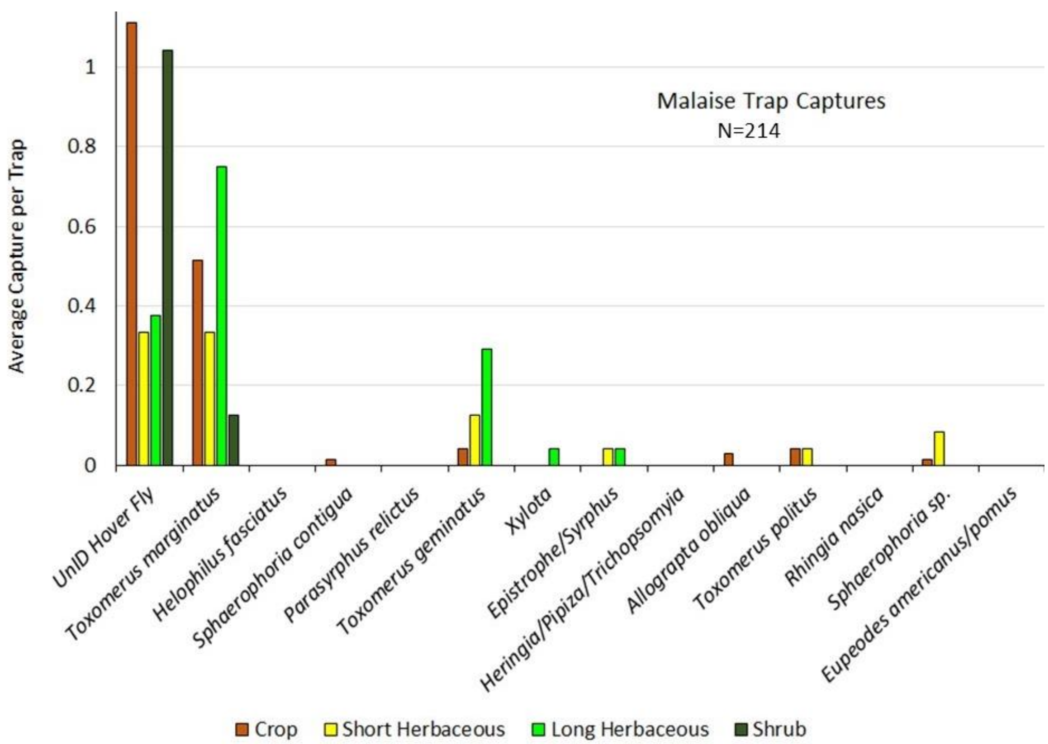


Figure 26. 2017 malaise trap captures of Hover fly species by habitat.

The combined vane and malaise hoverfly captures were strongly, positively correlated with date (modeled as a polynomial with a mid-summer peak) and the trap-level floral area of three mustards (Field Mustard, Wild Radish and Yellow Cress). For sweep net captures, the trap-level floral correlates were Hedge Mustard and Chickweed. These were positive as was the relationship to date. When looking at the relationship of cropfield hoverflies and vegetation, sweep samples were strongly correlated with non-crop hoverfly captures or date (these co-varied). Non-crop hoverfly sweep captures, in turn, had a strong, positive relationship with both date (as a polynomial) and the floral area of mustards at the local landscape scale (Fig. 27). Patterns were similar for malaise and vane captures, with date, floral area of mustards, and non-crop hoverfly captures influencing cropfield hoverfly captures. These data suggest that mustards may play an appreciable role in determining cropfield hoverfly populations, directly and/or via their influence on non-cropfield hoverflies (Fig. 28). Others (see review by Wäckers and van Rijn 2012) have reported the value of mustards, and other shallow-flowered plants, for hoverflies. It is likely that mustards happened to be among the most common shallow-flowered plants on the farms we studied, and these data may not indicate a unique tie between mustards and hoverflies at a broader scale.

Despite the fact that aphids are a larval prey of *Toxomerus marginatus*, the most common hoverfly in our captures, aphid catch was not correlated with hoverfly catch.

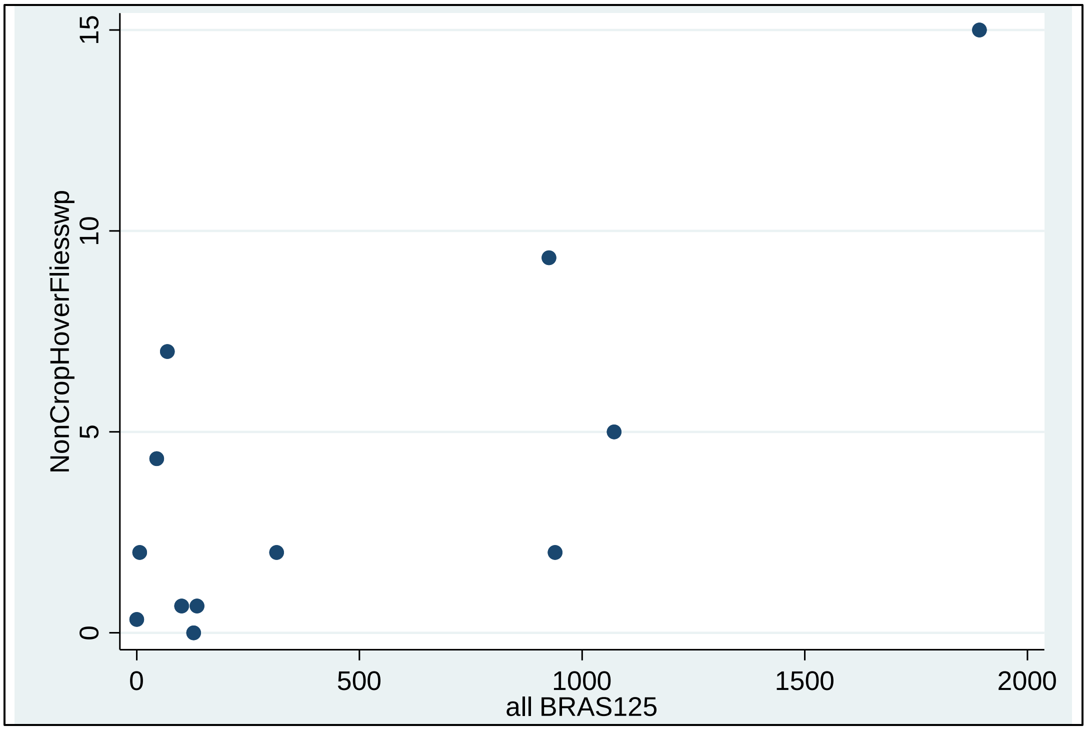


Figure 27. The relationship between hoverflies captured in sweeps of non-crop habitats and the floral area of mustards (aka brassicas) at the local landscape level of 125m.

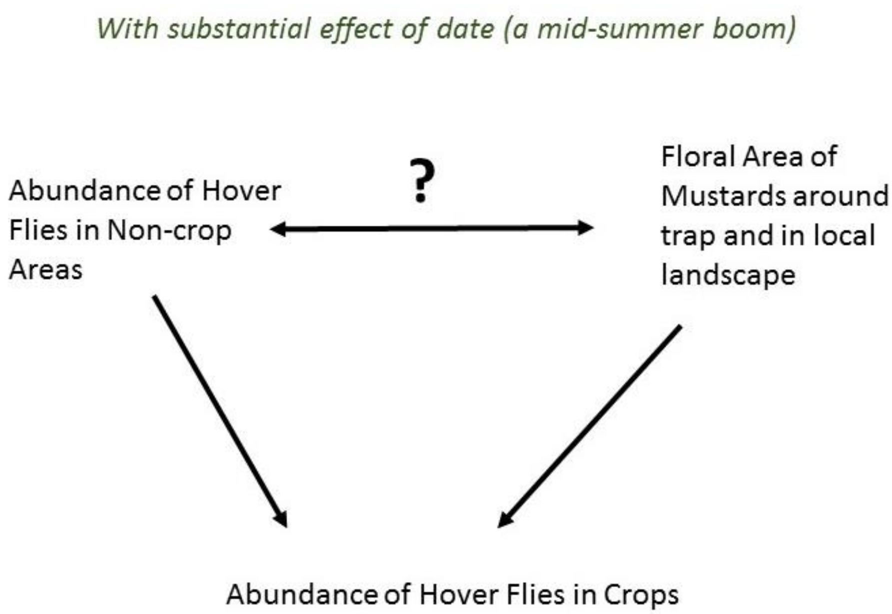


Fig. 28. Some of the hypothesized factors influencing cropfield Hoverfly populations as suggested by the results reviewed in the text.

Ground Beetles. At a general level (Fig.29), on three out of the four farms, crop was the habitat which produced the most ground beetles, reflecting the presence of a crop community of ground beetles that sometimes reached high densities. Also evident here, and on some of our similar graphs, is the radical between-farm differences in ground beetle abundance, with the Farm Hub showing up to 10 times the number of ground beetles in the shrub habitats, and being the lead farm in all four habitats. With so few farms in the study, it is impossible to disentangle various potential explanations for this difference. Land use history – decades of field corn – and topographic location - a sandy floodplain – may contribute to the Hub's high ground beetle densities.

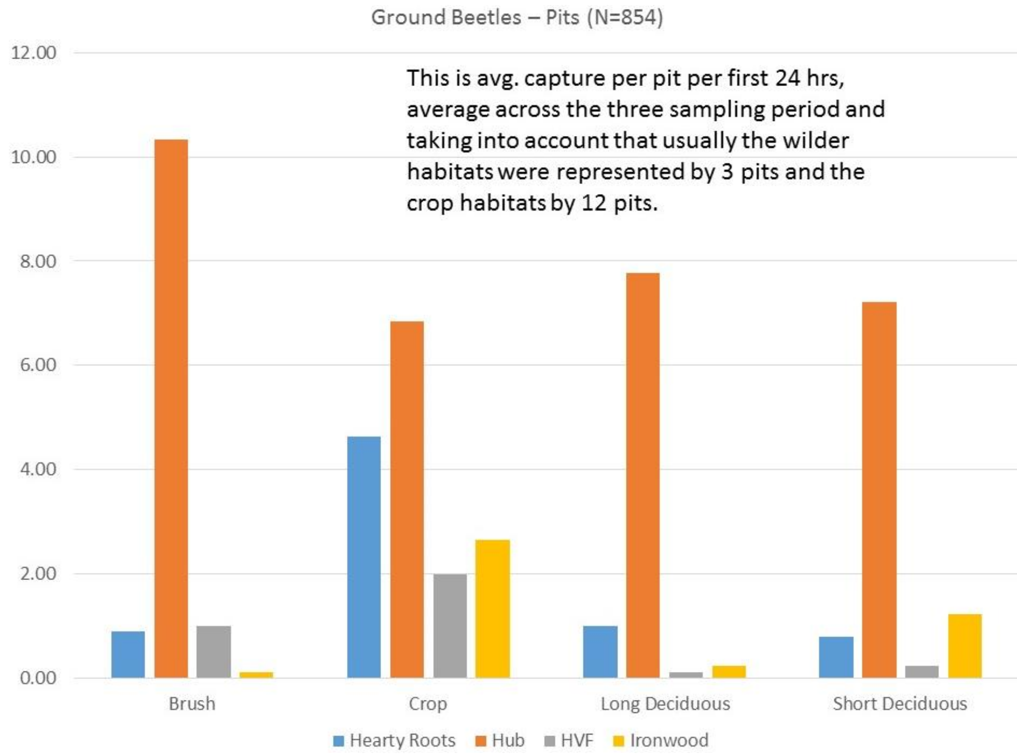


Figure 29. 2017 pit trap captures of ground beetles by farm and habitat type.

The habitat distributions of the five most common cropfield species (Fig. 30) shows that, with the apparent exception of *H. rufipes*, these creatures were most common in the crops themselves, with herbaceous vegetation perhaps being next in line, although those results seemed less consistent. Cropfield ground beetles were significantly positively correlated with percent ground in open soil, with border-line positive correlations with percent ground in herbaceous cover and flea beetle captures (in sweep netting). Flea Beetles were also related to ground beetle captures in our trap-level data, as was date (as a polynomial) and the presence of brassicas (probably an indicator of relatively open, agricultural land).

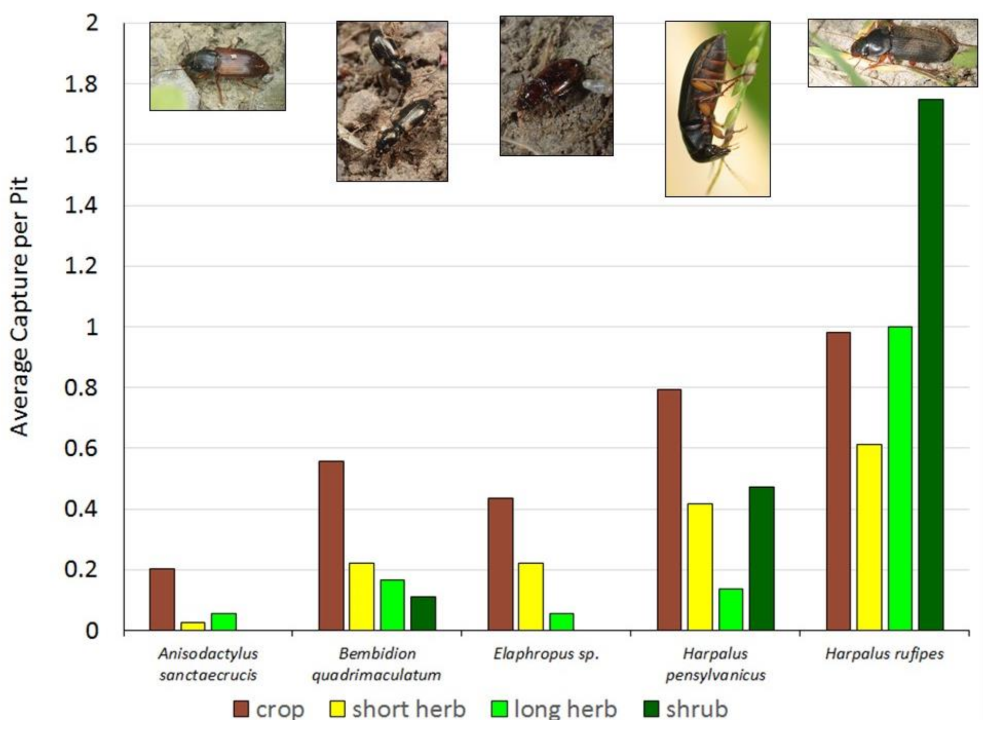


Figure 30. 2017 pit trap captures of the five most common cropfield ground beetle species.

The field diets of ground beetles are somewhat poorly understood, and our data on species-level ground beetle occurrence together with other potential prey items can hint at possible relationships (Fig. 31). For example, the trap-level data showed significant positive correlations between two of the smallest common ground beetle species (*Bembidion quadrimaculatum* and *Elaphropus cf anceps*) and flea beetle captures. In our farm and outing summarized data, cropfield Bembidion quadrimaculatum were also correlated with cropfield caterpillar captures in our sweep netting (caterpillar captures were relatively rare, so it is not surprising that any correlations with them are most evident in the summarized data). The field diet of *Elaphropus cf anceps* is essentially unknown, but *Bembidion quadrimaculatum* has been reported to feed on caterpillars (Bell 2015). Flea Beetle larvae and pupae occur in the soil where the tiny *Elaphropus* might well have access to them.

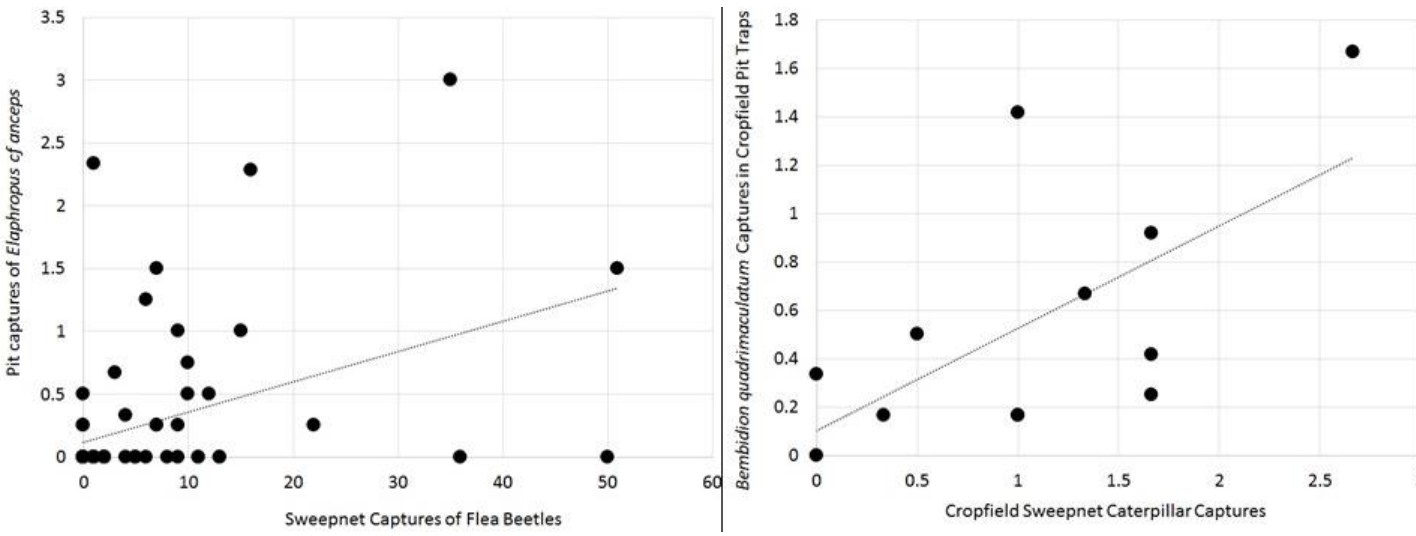


Fig. 31. Correlations between particular ground beetle species and potential prey items. On the left is the relationship between our captures of Elaphropus cf anceps and flea beetles; on the right is the relationship between cropfield captures of Bembidion quadrimaculatum and caterpillars. In both cases, the results are statistically significant, but, of course, are only suggestive correlations.

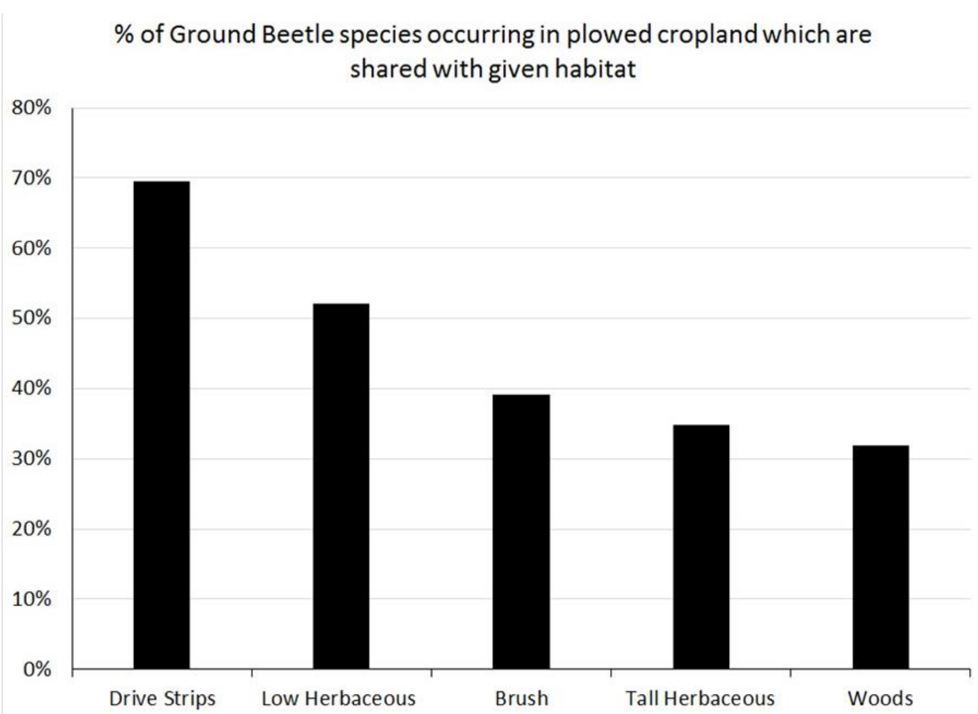


Figure 32. The percentage of shared ground beetle species between cropfields and five semi-wild habitats.

We have been studying regional ground beetle habitat use both on and off farms for several years. These data allow us to assess the similarity of the in-crop ground beetle communities to those in other habitats in the landscape (Fig. 32). In terms of community composition, drive strips through cropfields were most similar to the cropfields themselves, while woods were least similar. This is not surprising given the distinct openland and forest communities of ground beetles, a fact also reflected in Fig. 33 which shows the results of a three-year study of ground beetle communities across our county.

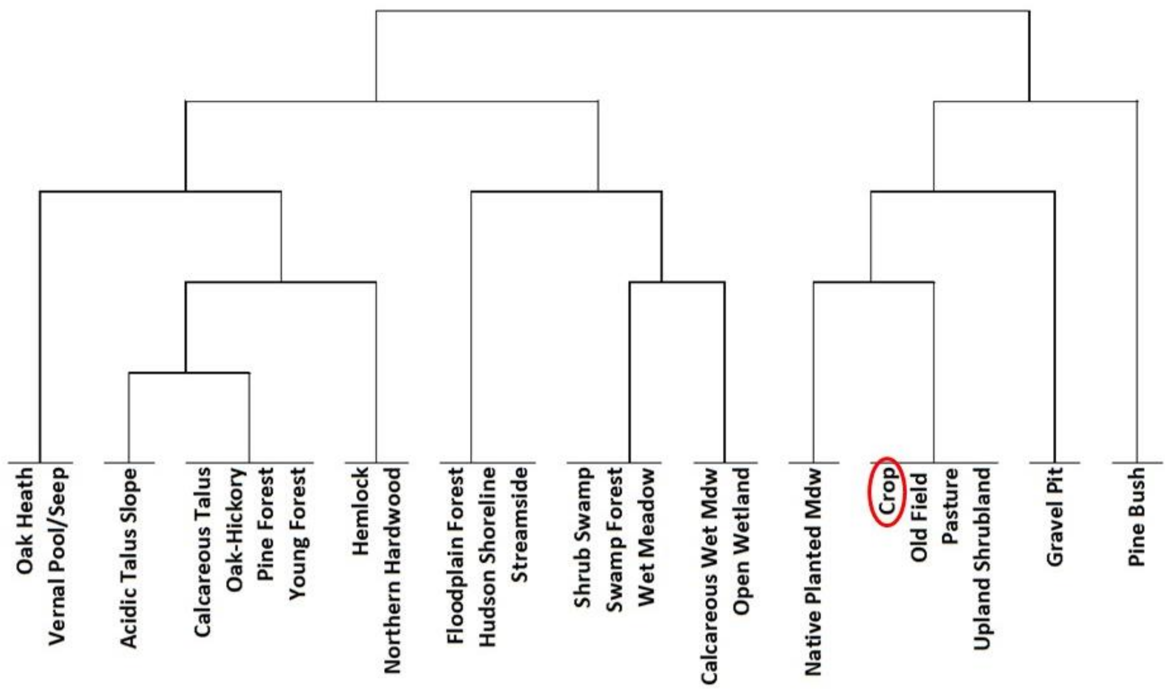


Figure 33. A Twinspan-based cladogram of Columbia County ground beetle communities, based on our county-wide natural history surveys.

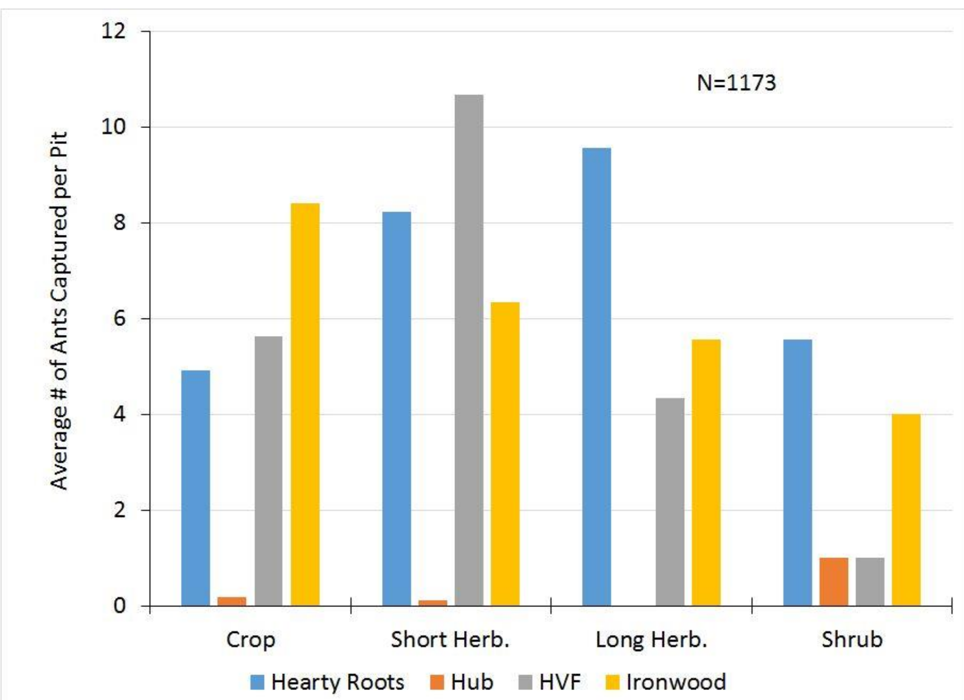


Figure 34. Total 2017 ant captures by habitat and farm in pit traps.

<u>Ants.</u> Our general data from 2017 (Fig.34) reveals yet another example of strong variation amongst farms, in this case the dearth of ants at the Farm Hub is notable. It also suggests relatively few ants in the shrubby areas. We are only in the preliminary stages of analyzing last year's ant data in more detail, but information from past years can hint at patterns. Work at 19 vegetable farms around Columbia County (Fig. 35) appears to show greater similarity of vegetable fields with adjacent open, uncultivated lands, than with woodlands. This conclusion is supported by our County-wide study (Fig.36). Although this last analysis did not include cropfields, the prime indicator species of dry fields, *Lasius neoniger* (aka the Labor Day Ant) was also the most common ant of vegetable fields; it was rare in areas with dense vegetation and/or closed canopy.

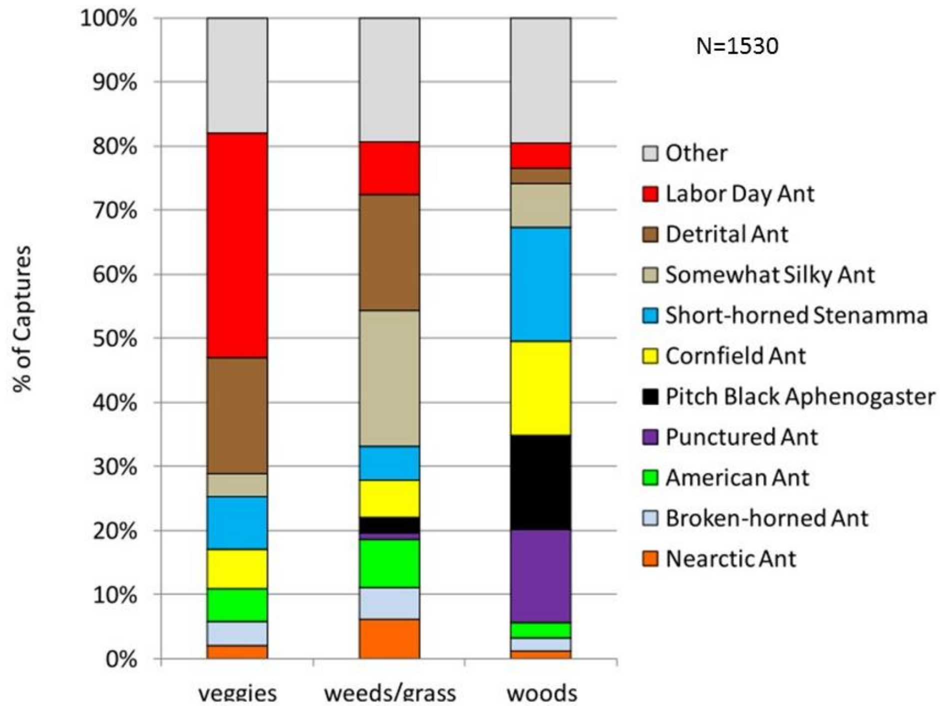


Figure 35. Relative composition of ant communities across three different on-farm habitats, based on 2010 work at 19 different vegetable farms around Columbia County.

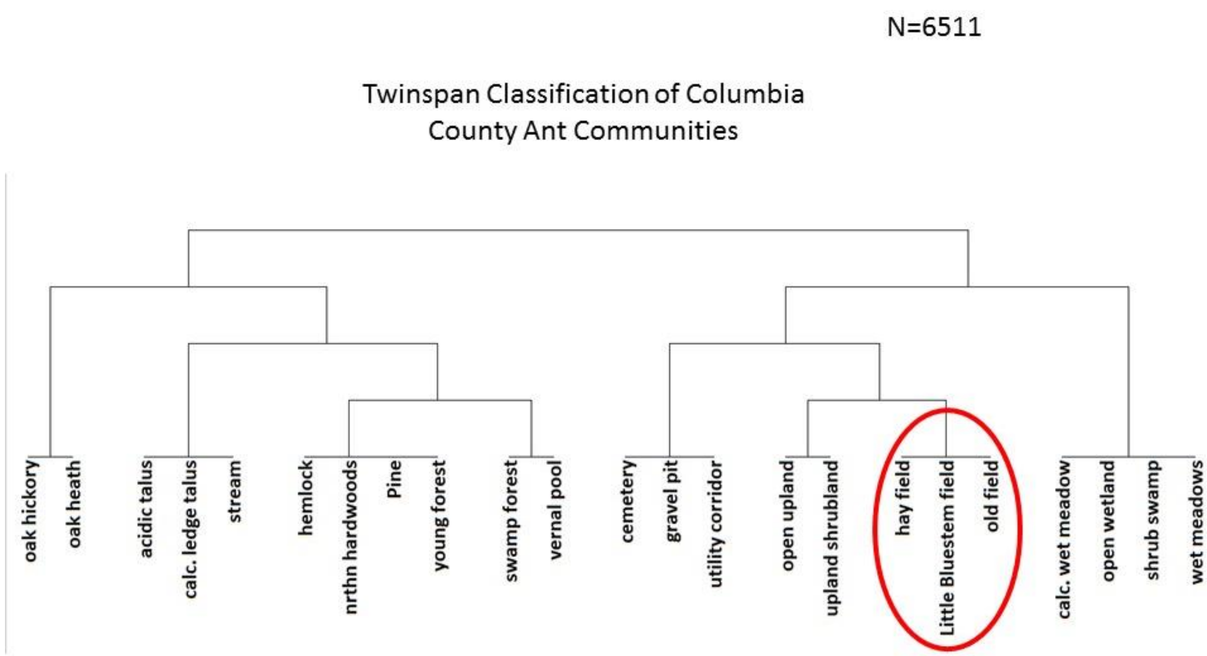


Figure 36. A Twinspan-based cladogram of Columbia County ant communities, based on our county-wide natural history surveys.

Wolf Spiders. Our family-level data (Fig.37) again suggests some marked inter-farm variation, although, intriguingly, the relative abundance of wolf spiders in the non-crop habitats of the Hub is not reflected in the abundances in the crop areas. In general, shrubby areas produced the lowest catch of wolf spiders. Looking at the species level data in more detail (Fig.38), it's clear that shrubby areas appeared to support few if any *Pardosa milvina* , the most common cropfield wolf spider species.

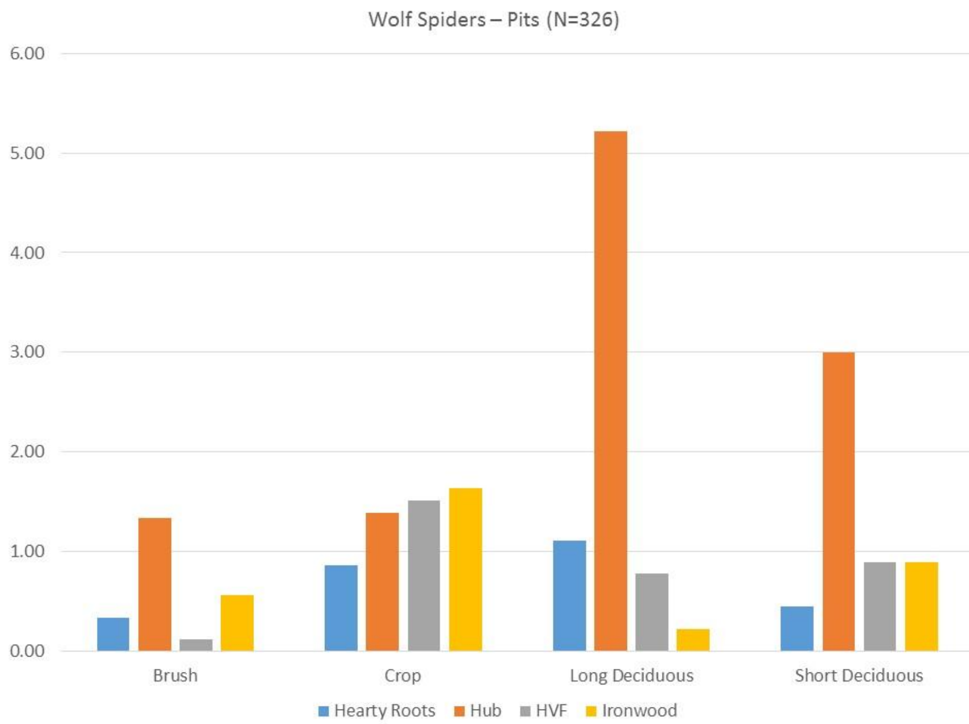


Figure 37. Total 2017 wolf spider captures by habitat, farm and trap method.

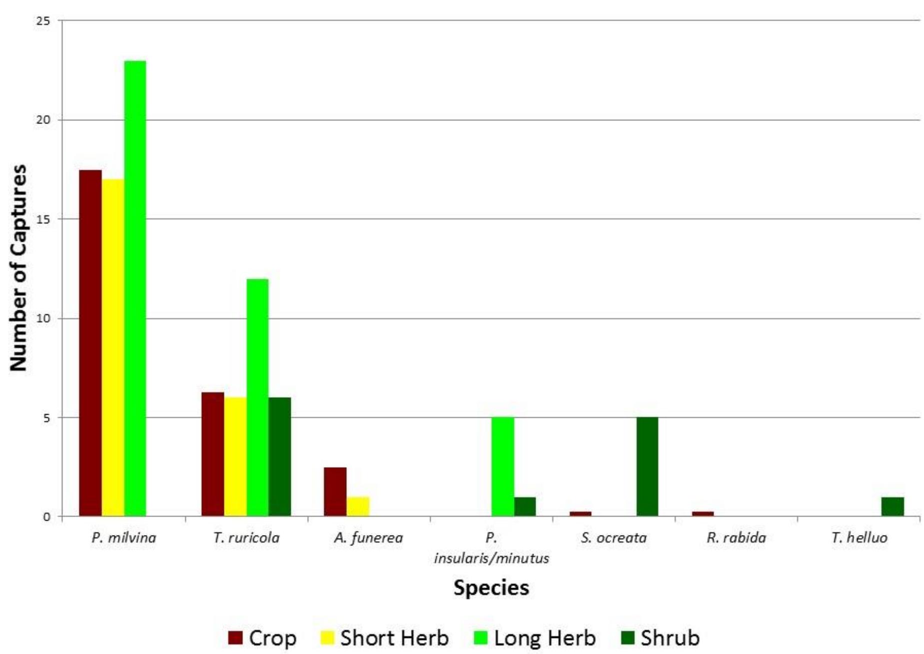


Figure 38. Wolf spider captures by species and habitat.

As with ground beetles, the abundance of cropfield wolf spiders was correlated with the physical structure around the trap sites, with the presence of mulch and dead vegetation being significantly positively and woody debris significantly negatively associated with wolf spider captures. It appears that non-woody cover may be beneficial to these creatures.

Seasonality. Taken together the above data support the relative value of more open areas in supporting cropfield beneficials during summer. Key exceptions may relate to certain wasp and ground beetle taxa. However, it could be wrong to jump to the conclusion that woodier habitats are relatively unimportant – they may, in fact, serve as important over-wintering habitat. We have minimal data on this, but initial work from one farm (Fig. 39) suggests that some organisms may favor woodier areas for overwintering. For example, wasp, spider and ant springtime captures were all relatively high in the forested areas. Thick herbaceous vegetation (aka 'rough') was also important. These data are very preliminary, but caution against quick conclusions based solely on summertime data.

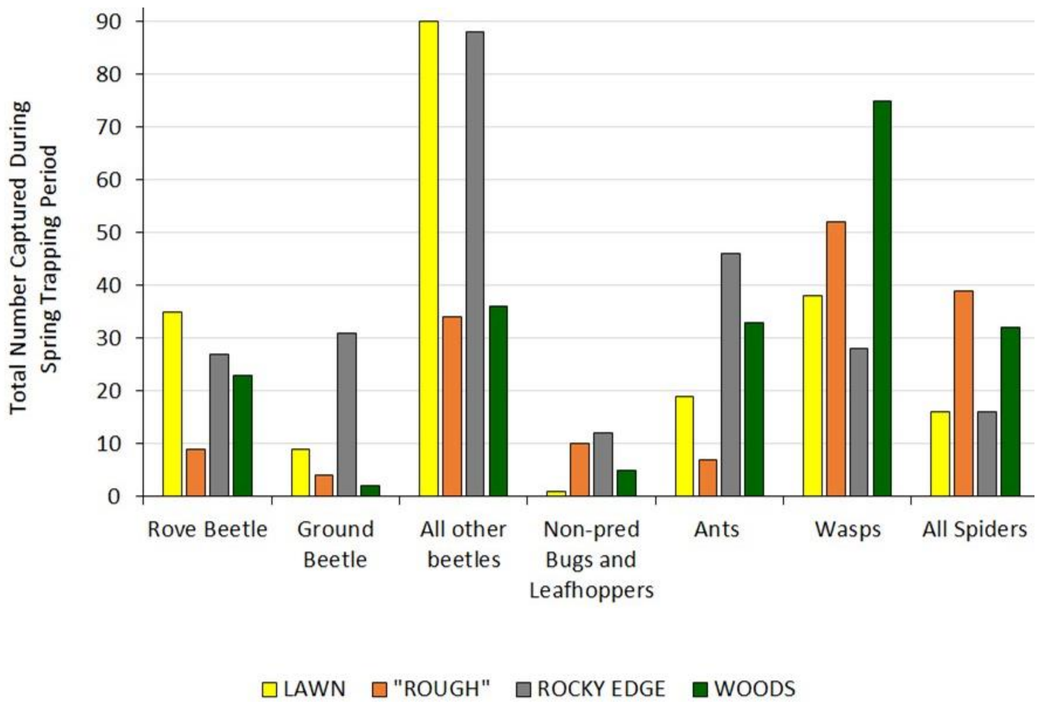


Figure 39. Springtime captures in emergence traps in four different habitats at Hawthorne Valley Farm.

Pests. Another caveat: we have blissfully ignored pests up until this point. Of course, pests also interact with the habitats around cropfields, although, because the crop itself is their food plant and many of these creatures have co-evolved with cropfields for generations, it's reasonable to assume that their links with the natural habitats might be weaker than those of many beneficials. A summary of our past data (Fig.40) suggest that some wetter areas may in fact support elevated pest species and that woody areas support relatively few. Our 2017 data (Fig.41) likewise suggests the relative unimportance of woody areas as vegetable pest habitat, at least during summer. However, there are multiple leafhopper, flea beetle and aphid species, only a few of which are crop pests, and greater taxonomic precision will be needed before strong conclusions can be made.

To look at the pest/beneficial balance in more detail, we ranked the abundance of in-crop pest and beneficial taxa across our farms and dates, averaged across the taxa in each group and then calculated a 'relative beneficial surplus' as the difference between average beneficial ranking and average pest ranking for any particular farm/date combination. Higher values of this statistic indicate higher numbers of beneficials relative to pests. This value declined with date because pest numbers increased more rapidly than beneficial numbers across the growing season. It was also negatively correlated with percent ground covered in crop (Fig. 42), although because of collinearity between this descriptor and date, it's not clear if this is an independent effect.

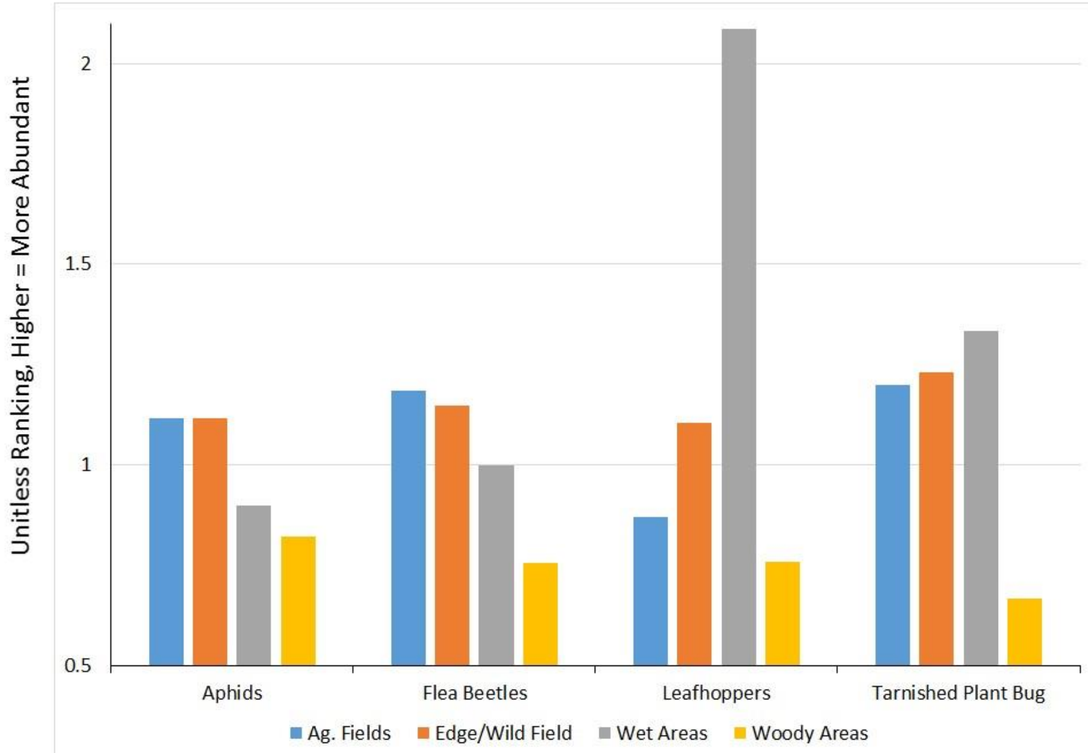


Figure 40. A summary of our past data on the captures of pests across four general habitat types.

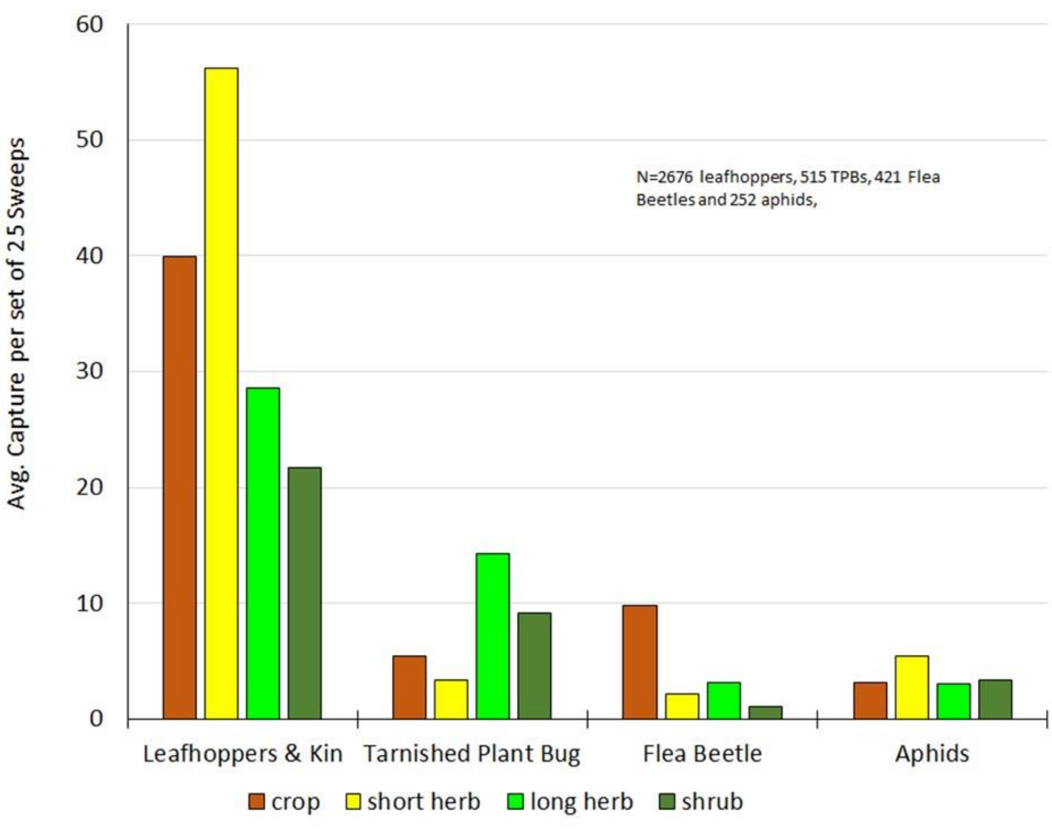


Figure 41. 2017 captures of pests in sweep samples by habitat types.

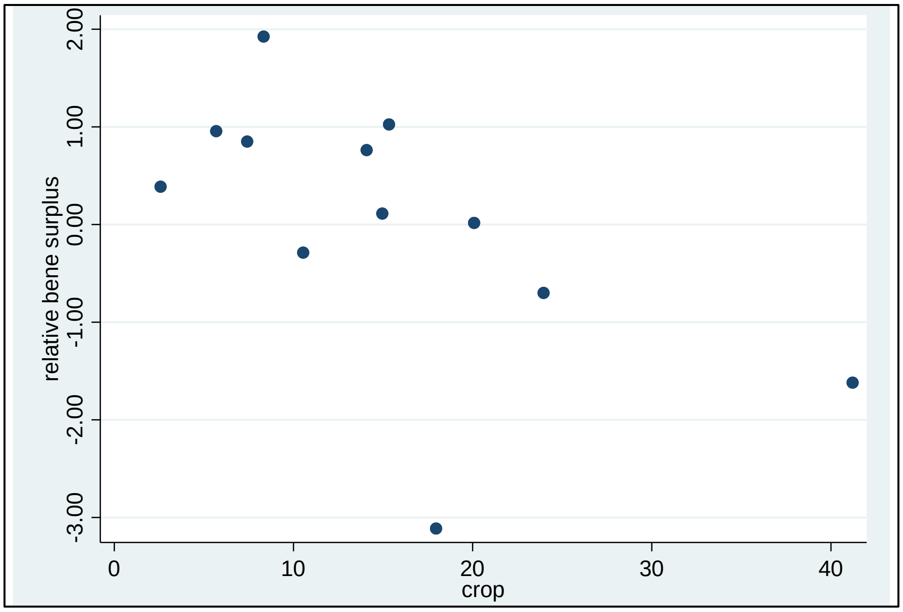


Figure 42 'Beneficial surplus' in cropfields compared to percent area in crops. Pests may benefit more than beneficials from area in crops, although this apparent relationship may be partially due to the correlation of both beneficial surplus and crop area with date.

Are Semi-natural Areas Providing Crop Areas with Beneficials?

So far, we have only looked at the static distribution of organisms across different cover types, however if semi-wild areas are actually supporting cropland beneficials, then one would expect to see movement between semi-wild areas and cropfields and, potentially, a gradual dilution of their density at increasing distances from the semi-wild areas. Below, we explore both these expectations – that of movement and of density dilution.

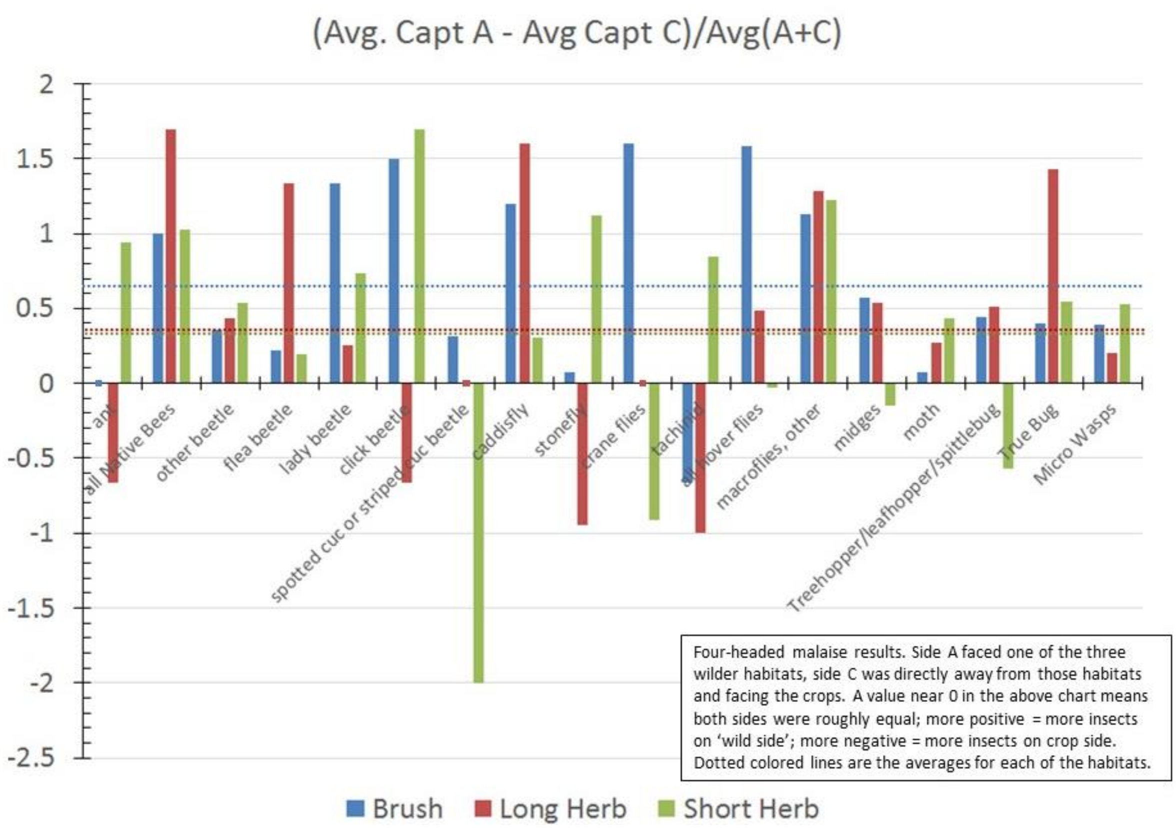


Figure 43. Relative captures of various taxa on the crop and wilder side of malaise trapping sites.

Apparent Movement. During 2017, we used four-headed malaise traps to detect movement between cropfields and our ‘wilder’ habitats (Fig. 43). Across almost all taxa and habitats, there were higher captures on the ‘wild side’ than on the crop side. This parallels the results of our 2014 work in orchards which used two-sided malaise traps to look at insect flow between orchards and adjacent woods (Fig. 44). It is unclear what is happening because if these captures represent flows, then insects are accumulating in the crop habitats, are rapidly dying in those habitats or are undergoing an undetected back flow. All of these are possible, although night-time captures provided no evidence of nocturnal back flow at trap level. Perhaps there is essentially a cloud of insect activity around the wilder habitats, and our traps were dipping into that cloud. In any case, the results do suggest that at least the edges with wilder habitats may be supporting increased insect numbers relative to field centers.

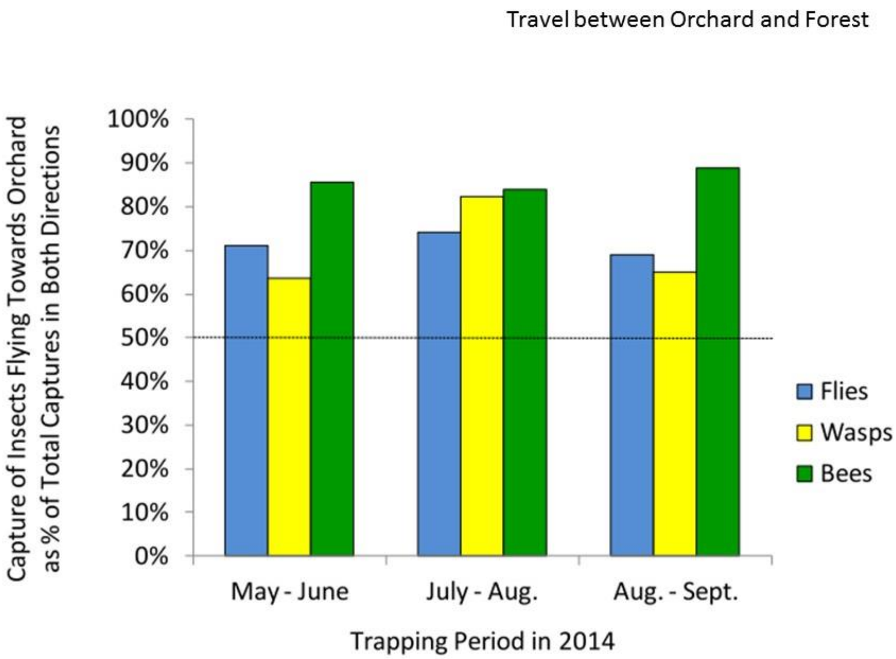


Figure 44. Relative two-sided malaise captures of three taxa in seven Hudson Valley orchards.In this case, equal captures on both sides would produce a 50% reading, with values greater than 50% indicating a prodominance of captures on the forest rather than the orchard side of the trap.

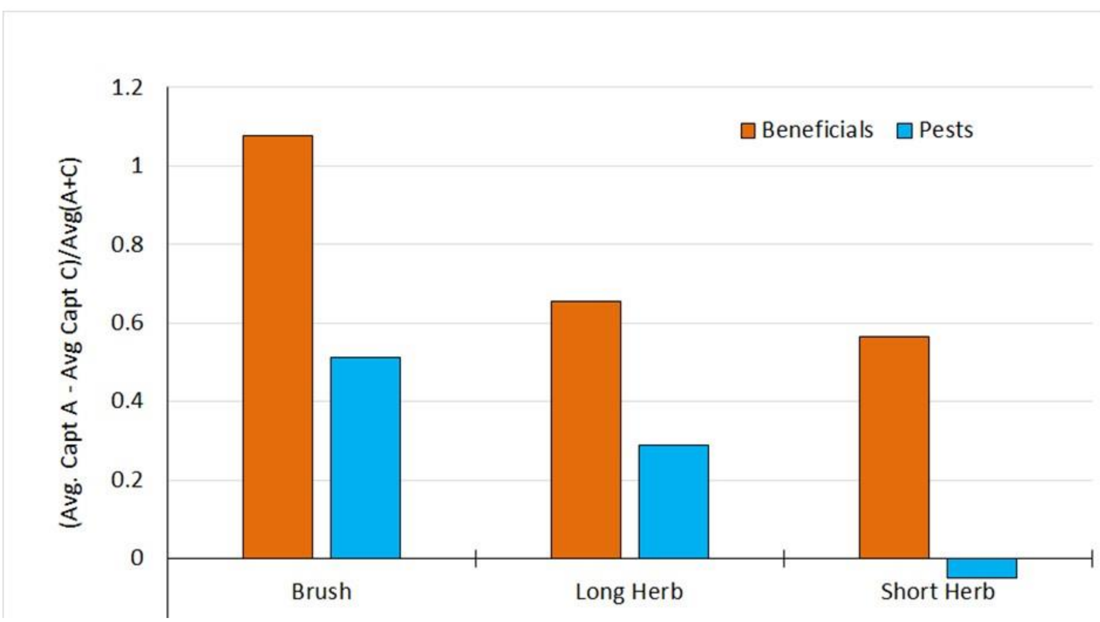


Figure 45. Relative captures of pests and beneficials at the edge of three different habitats.

Because such a cloud of activity might support both pests and beneficials, to look at this in a bit more detail we grossly categorized the tallied taxa as pests or beneficials (and some were left as neutrals). The difference between wild side and crop side captures (Fig. 45) appeared especially marked for beneficials, perhaps hinting that the effect of the wilder habitats on cropfield beneficials is greater than its effect on cropfield pests (although both may be enhanced). Alternatively, these results might simply reflect differences in the relative mobility of the groups we happened to categorize as pests and beneficials.

The agronomic consequences of this flow may differ depending on farm management. Our 2014 work in orchards (Table 3) suggested that in conventional orchards, where pest control is primarily through pesticides, edges may primarily signify an in-flow of pests which result in negative edge effects, whereas in organic orchards, edges as a source of beneficials may, if anything, produce positive edge effects. Sample sizes were small and overall pest levels were markedly higher in organic orchards, but patterns such as this suggest that the flow illustrated in Fig. 45 may mean different things for different modes of farming.

Table 3. Apple weight and damage relative to edge in conventional and organic orchards. Note that in organic orchards apple size is higher and damage lower near the edge, while the reverse is true in conventional orchards.

Conventional – IPM Orchards
(N = 2 orchards)

distance from edge tree	Relative Apple Weight (% of mean for given orchard)	% of Apples with Plum Curculio Damage	Non-PC Damage Index
0 ft	98	30	0.20
75 ft	97	15	0.05
150 ft	105	10	0.10

Organic Orchards
(N = 5)

distance from edge tree	Relative Apple Weight (% of mean for given orchard)	% of Apples with Plum Curculio Damage	Non-PC Damage Index
0 ft	105	62	1.36
75 ft	91	62	1.68
150 ft	103	66	1.42

Transect Data. If edges between crops and wilder areas are indeed providing an in-flow of beneficials to cropfields, then one would predict that cropfield locations farther removed from edges would have lower beneficial populations. In 2016 and 2017, we studied three fields at the Farm Hub, tallying captures within roughly 15’ of the forest/shrub edge, at 300’ and at 600’ into the cropfields. The results for spiders and flying insects (Fig.46) suggest a tendency for populations of both pests and beneficials to be highest near the field edge, although a clear gradient, with captures steadily diminishing from 0’ to 300’ to 600’, was evident for fewer groups. Pit traps captures on the other hand (Fig.47) indicate that the influence of edge on creatures which primarily travel by foot (e.g., ground beetles, ants, and wolf spiders) is less clear with uniformity of captures along the gradient perhaps being the common pattern.

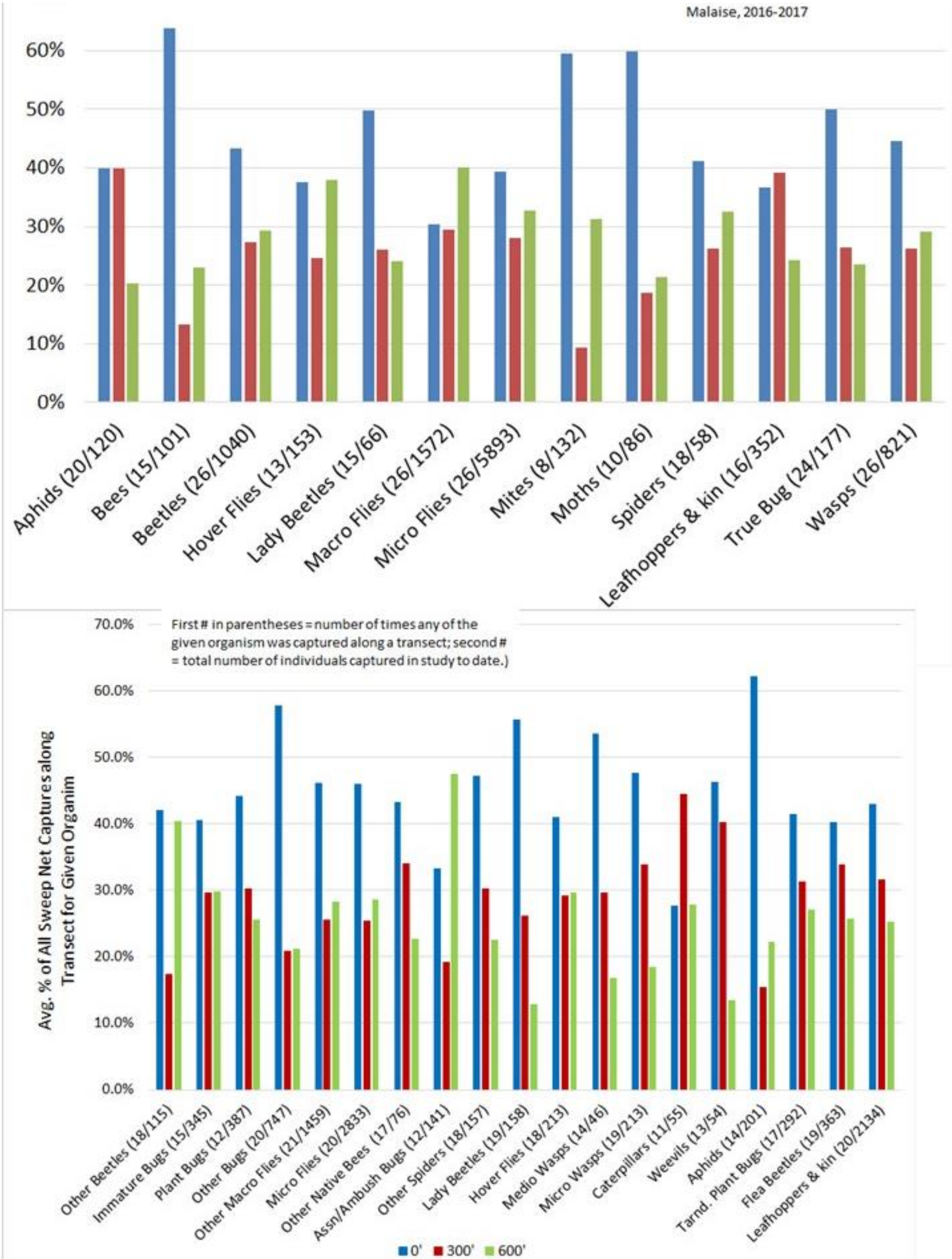


Figure 46. Combined 2016 and 2017 captures in vane and malaise traps (top) and sweep net samples (bottom) along transects in three fields of the Farm Hub. In the sweepnet chart, pest groups are located towards the right of the graph.

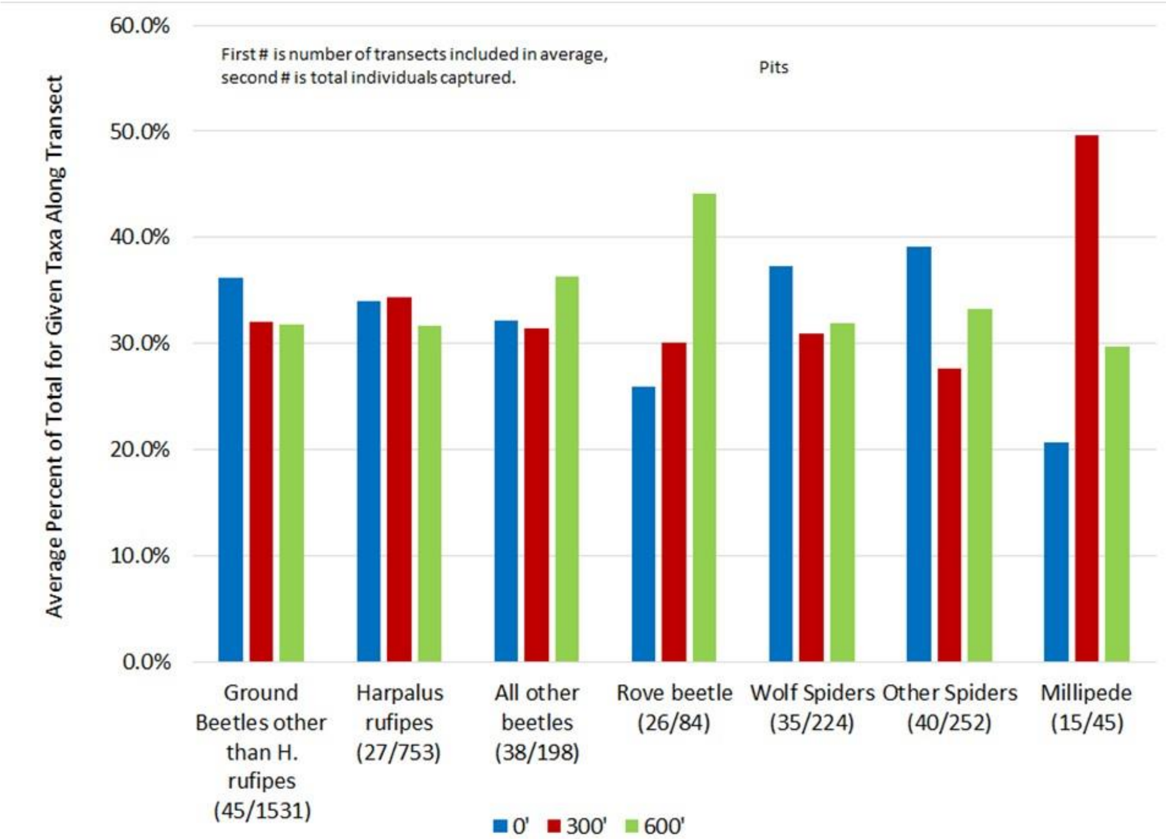


Figure 47. Combined 2016 and 2017 captures in pit traps along transects in three fields of the Farm Hub.

Again, seasonality likely plays an important role in understanding the importance of insect movements across agricultural landscapes. For example, our early work at Hawthorne Valley Farm is suggestive of a flow of spiders from wilder edge areas to crop center across the season (Fig. 48), and one might well imagine that early-season intercept traps and gradient work might be particularly revealing.

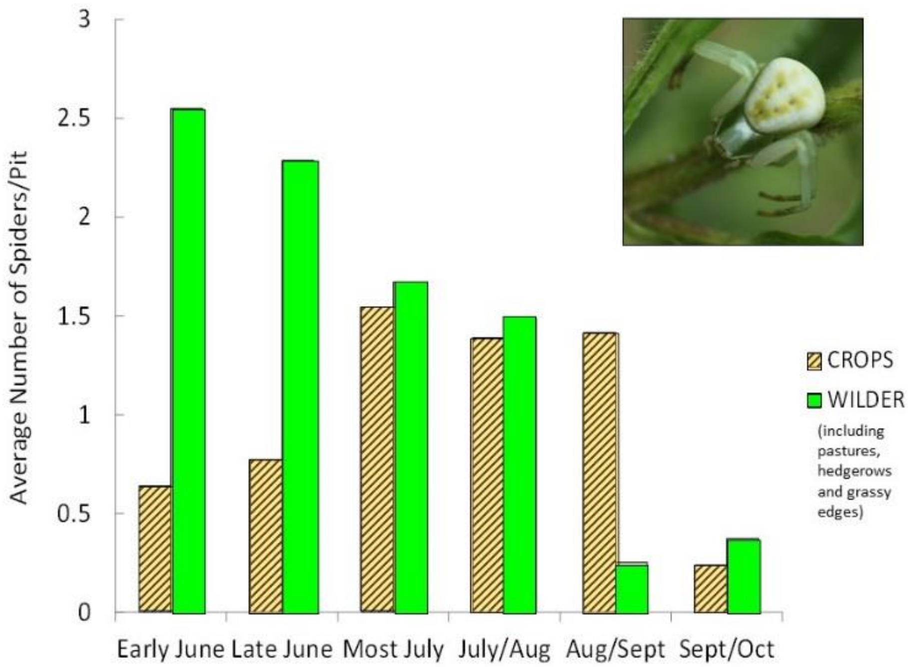


Figure 48. 2009 spider pit trap captures across habitat types and time of year at Hawthorne Valley Farm.

So What?

<u>Apparent Predatory Services.</u> Just because 'beneficials' are PRESENT doesn't mean they're ACTING beneficially. Pest control and pollination may not depend solely on the presence of certain groups of insects. For example, ground beetles might be present, but the pests of interest may not be palatable for them; or the tongue length of the dominant bees may not let them pollinate the flowers of commercial interest. Trying to document beneficial ACTIVITY is thus important. In 2017, we tried to index at least one type of predation by using time-lapse cameras to tally visitors to a bait of fall armyworm eggs. Fig. 49 shows the composition of the potentially predatory visitors. As we have seen in previous work, ground beetles seemed to be under-represented relative to their captures - they accounted for 27% of the bait visitors and 40% of the pit captures. Daddy Longlegs and slugs, which are relatively rarely captured in dry pit traps (perhaps because they can escape or avoid falling in), were almost as common as spiders at the bait. Nonetheless, in almost all cases, the abundance of a given organism at the bait was positively correlated with its abundance in the pit trap captures, even if the ratio of captures to bait visits differed amongst the taxa.

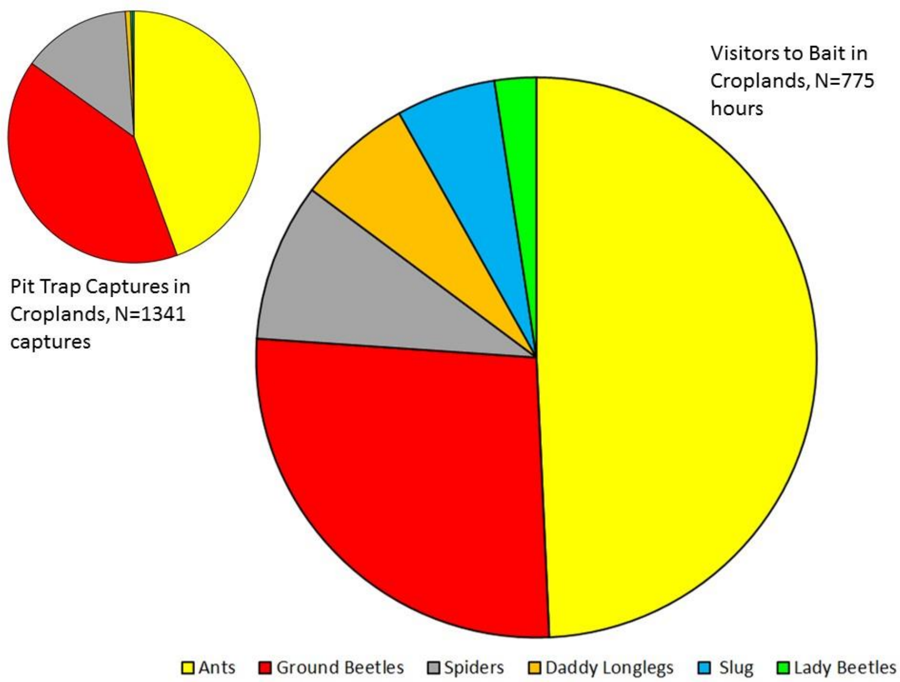
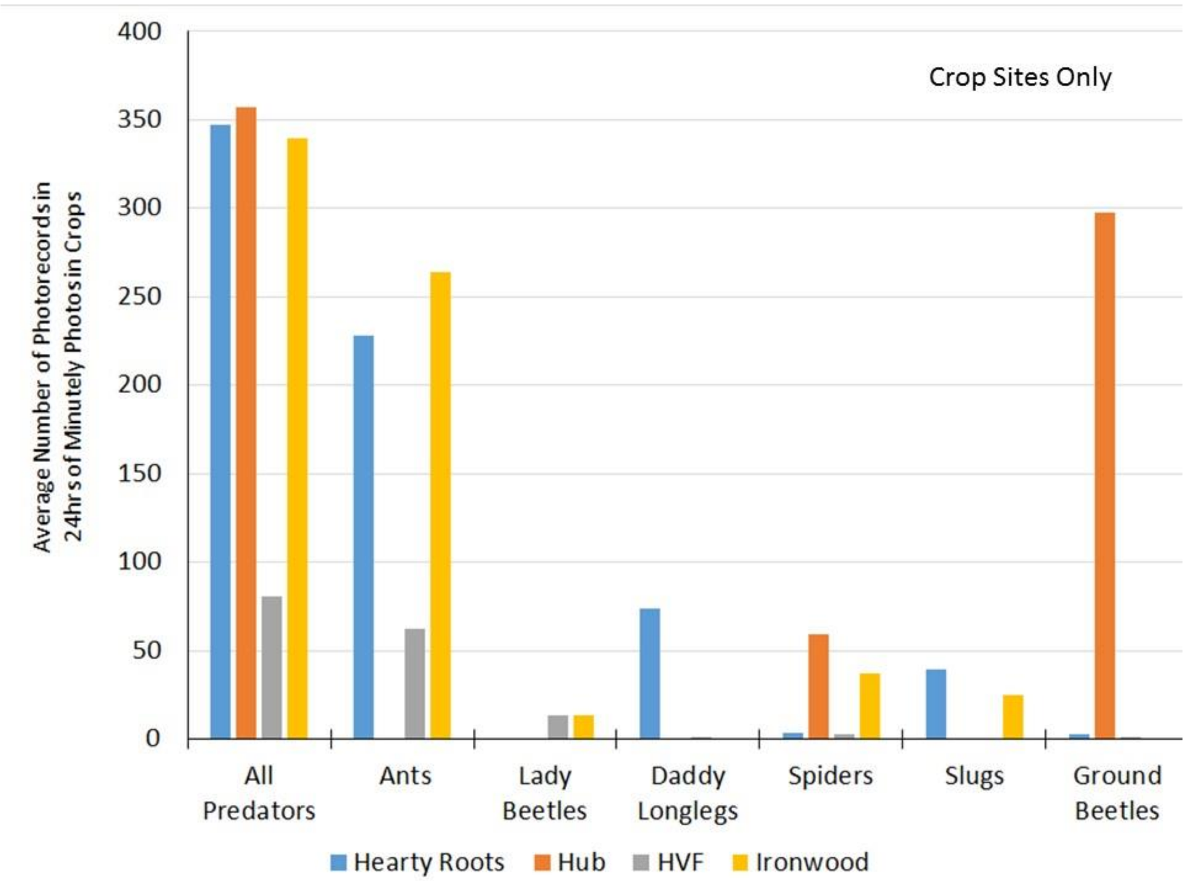


Figure 49. The composition of camera-tallied visitors to Fall Armyworm egg bait.

Fig. 50 top shows the abundance of visitors to bait in cropfields across the four farms. It is interesting to note that on three of the four farms, total visits by potential egg predators was roughly equal, even though the composition of that total sometimes differed dramatically: at the Hub the majority of visitors were ground beetles whereas at Ironwood and Hearty Roots, ants contributed the lion's share of the activity, with spiders being the second most common visitor at the Hub and at Ironwood and Daddy Longlegs (Opiliones) holding that position at Hearty Roots. One might speculate that in a community of generalist predators, composition of the predator community may vary more greatly than the total predation pressure.

Looking at the same information from the non-crop habitats (Fig. 50 bottom) presents a slightly different pattern. Again, Hearty Roots and Ironwood share similar overall apparent predation activity, and it seems reasonable to assume that this might be linked to their similar in-crop levels. However, the Hub and Hawthorne Valley now also share similar values, mainly because the ground beetles, which provided such a large proportion of the Hub's in-crop predation, were relatively inactive in the Hub's wilder areas. It will be interesting to see if the species of ants active in the non-crop areas of Hearty Roots and Ironwood are largely the same or distinct from those in the crops. If there were high similarity that



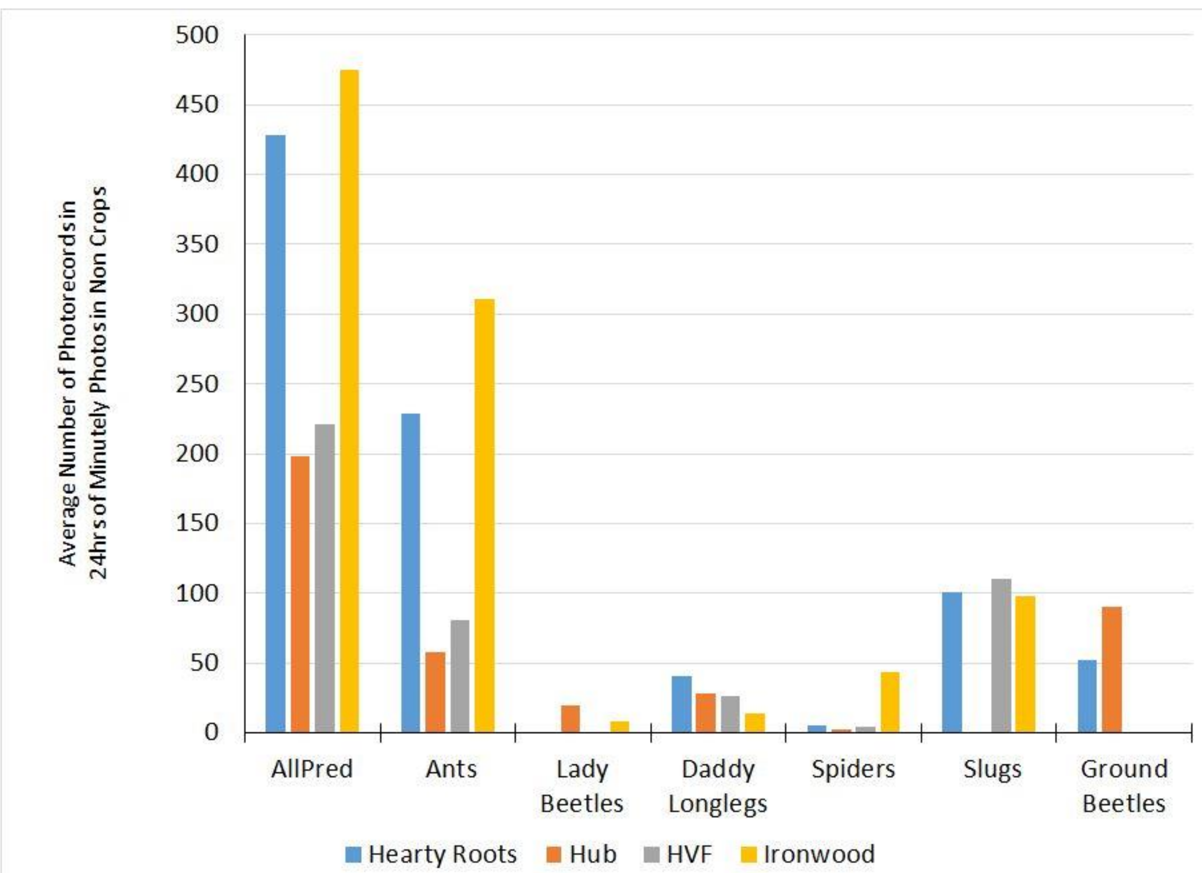


Figure 50. Activity at Fall Armyworm egg bait in crop (top) and non-crop (bottom) habitats across taxa and farms.

might suggest that these beneficial services at Hearty Roots and Ironwood are more closely tied to their surroundings than are those at the Hub. We are only just beginning to identify the ants captured during 2017.

Why Hawthorne Valley Farm had such little activity, in either crops or wilder areas, is unclear. Partially, as illustrated in Figs. 29, 34 and 37, predator abundance may have been lower, although recorded activity of creatures may have also been reduced, perhaps because of weather conditions on the particular days of sampling. Although three outings were made to each farm, it chanced that average air temperature during the Hawthorne Valley outings was the lowest of all farms, about 2°C cooler than that of the next coolest farm and a full 4°C cooler than the warmest average.

It's worth asking if any habitat characteristics were correlated with total predator visitation in the crop area? In fact, total predator visits was strongly correlated with % bare soil and average height of herbaceous vegetation in the neighborhood of the traps (Table 4, Figs.51 and 52). Looking at the components of this total, ant activity was strongly correlated with average herbaceous height, while spider and ground beetle activity responded positively to bare soil.

Table 4. Total in-crop visits to Fall Armyworm eggs as predicted by average herbaceous height and percent open soil.

```
. regress AllPredCam avgherb soil

      Source |       SS           df       MS      Number of obs   =        12
-------------+----------------------------------   F(2, 9)         =     19.59
       Model |  851775.261         2  425887.63   Prob > F        =    0.0005
    Residual |  195629.422         9  21736.6024   R-squared       =    0.8132
-------------+----------------------------------   Adj R-squared   =    0.7717
       Total |  1047404.68        11  95218.6075   Root MSE        =    147.43

------------------------------------------------------------------------------
  AllPredCam |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     avgherb |   67.29932    14.7278     4.57   0.001     33.98272    100.6159
        soil |   20.11765   4.187597     4.80   0.001     10.64465    29.59065
       _cons |  -653.9766   163.0234    -4.01   0.003    -1022.761   -285.1921
```

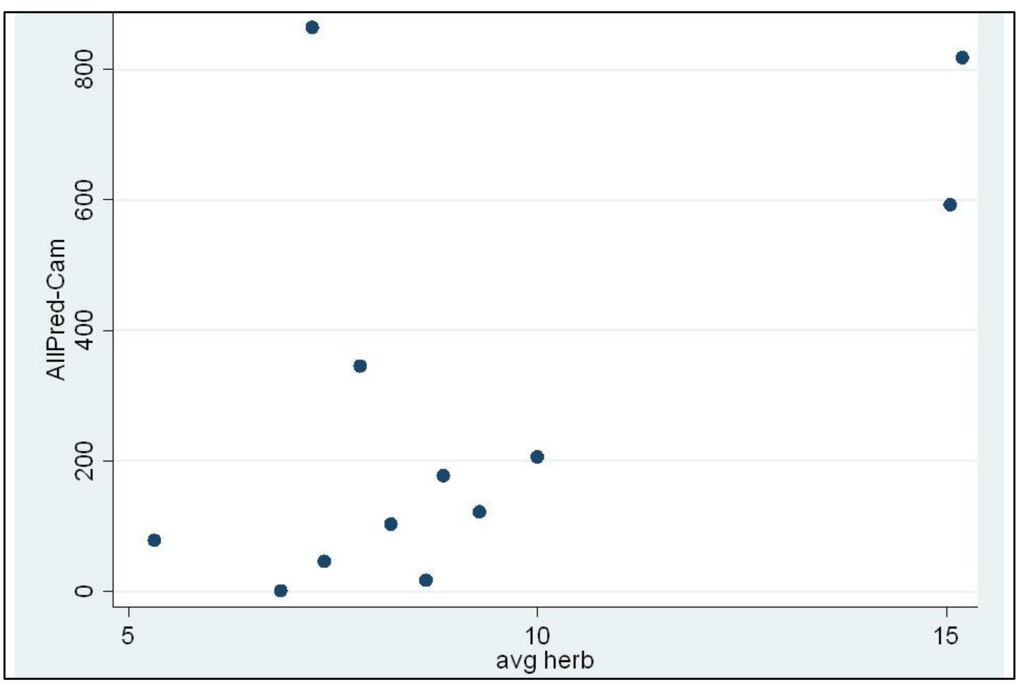


Figure 51. The relationship between the average height of herbaceous vegetation at the trap site and the sum of all predator visits to the Fall Armyworm egg bait.

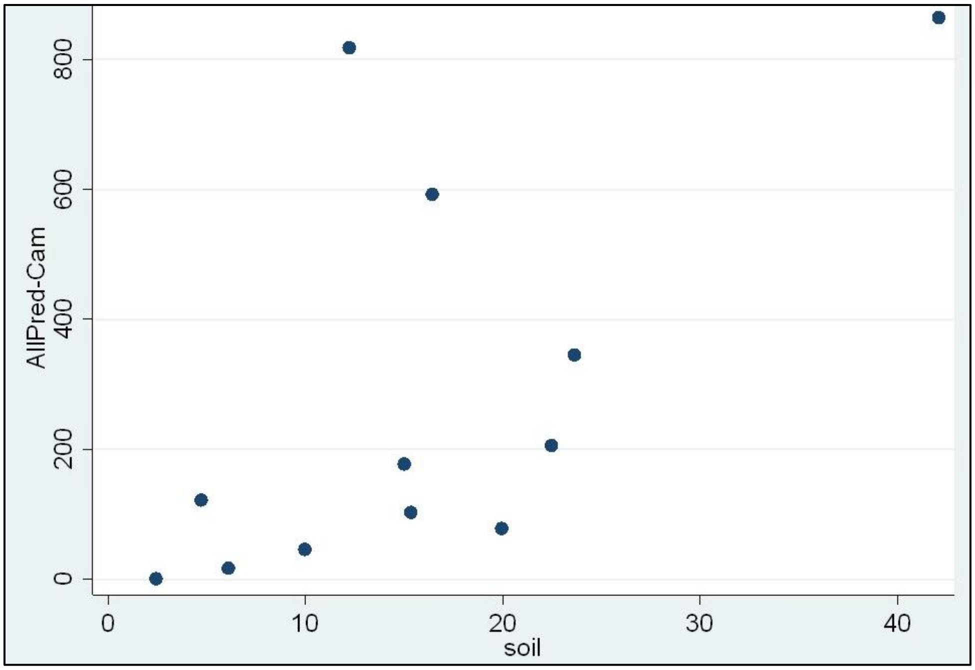


Figure 52. The relationship between the percent exposed soil at the trap site and the sum of all predator visits to the Fall Armyworm egg bait.

Finally, we can use our camera data from the transects to ask if there were patterns in apparent predatory activity (Fig. 53). Ants, lady beetles, and possibly crickets were most active near the field edges, while spiders, surprisingly perhaps given Fig. 47, were most active at 600', as were slugs. Ground beetle patterns were mixed.

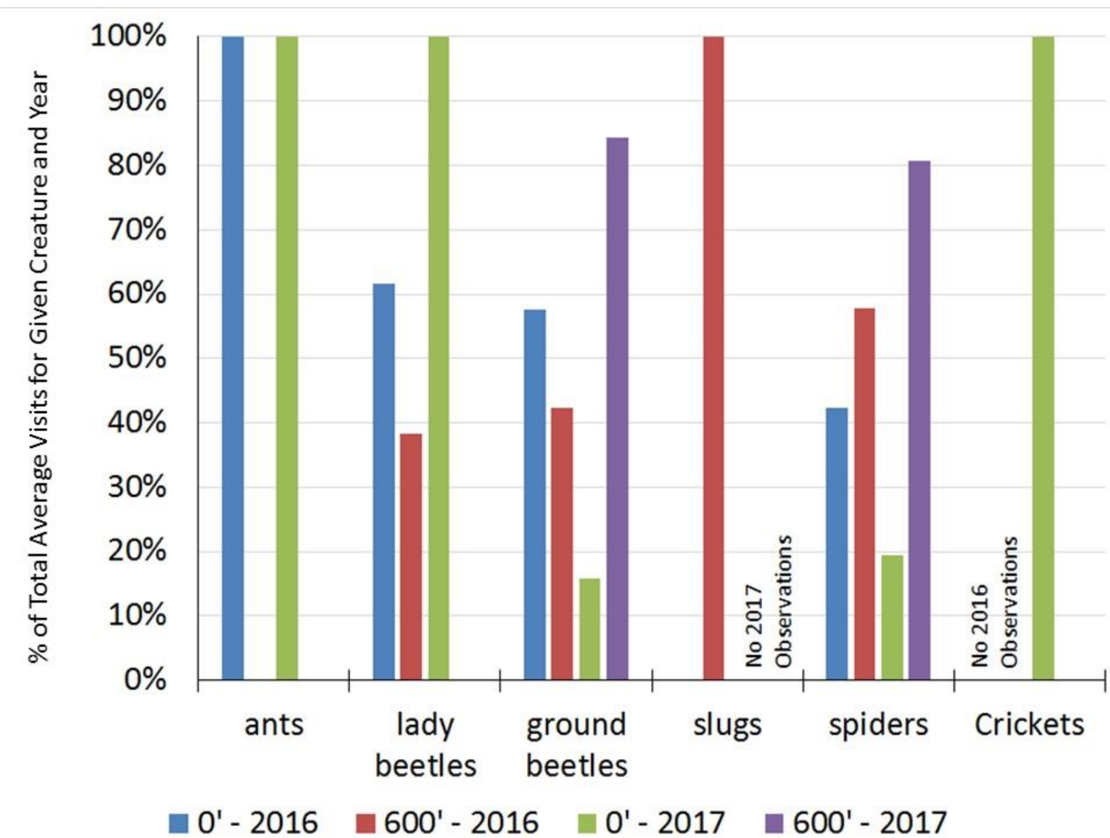


Figure 53. Activity at Fall Armyworm egg bait in cropfields across taxa and farms.

Table 5. The most common beneficials tallied in our 2017 study or, in the case of ants, in our previous work. Species shown composed at least 10% of total catch and the percent of a group's total identified catch accounted for by the listed species is indicated in parentheses.

Hoverflies (85-93%)*	Wolf Spiders (87%)
Toxomerus marginatus	*Pardosa milvina*
Toxomerus geminatus	*Trichosa ruricola*
Ground Beetles (85%)	**Ants (53%)**
Harpalus rufipes	*Lasius neoniger*
Harpalus pensylvanicus	*Myrmica detritinodes*
Bembidion quadrimaculatum	
Elaphropus cf anceps	

*- vane trap captures, which were notably fewer, were more diverse and are not included here.

Conclusions

- For several taxonomic groups, relatively few species appear to account for the most abundant in-cropfield beneficials – this is true for ground beetles, wolf spiders, ants, and hoverflies (Table 5); a higher diversity of bees and wasps may be relevant.
- As a result, studies of the movements and natural history of relatively few species could go far towards increasing our understanding of habitat use by regional beneficials.
- There were major differences in the results derived from different trapping techniques, at least in part because, even within groups of beneficials, trapping technique influenced not only the relative abundance of captures in different cover types but also the species composition of the catch.
- The apparent importance of the non-crop "habitats" (at the gross level of our categorizations) differed amongst taxa and so a general, one-size-fits-all habitat management recommendation is not evident. Conversely, these results indicate the importance of habitat diversity in supporting an abundance of beneficials across a variety of taxonomic groups.
- Although species-level data suggest nuances, transect data and the occurrence correlates (i.e., in-field vs. local landscape-scale) suggest that one might categorize beneficials as *crop-field residents* or *facultative visitors*. This distinction may partially reflect the relative mobility of these creatures.
- Adjacent non-crop habitats may provide important sources for *facultative visitors* (such as wasps and bees), and so landscape management at least at the local-scale might have large effects on cropfield populations of these organisms.
- *Cropfield residents* (such as ground beetles and wolf spiders), on the other hand, appear to be more influenced by conditions in the immediate neighborhood of the traps, and so crop management might have a greater influence on their occurrence. (Note that we did not include any farms with heavy spraying regimes; pesticides, while an 'in-field' practice, could obviously radically affect residents and visitors.)
- Species-level data is important because only a subset of the cropfield beneficials are regularly caught in wilder habitats and hence might be reliant on them. Even within fields, correlations with field conditions may differ among species in the same taxonomic group.
- Bee, wasp and hoverfly abundance *in* cropfields was strongly related to the abundance of the respective taxa *outside* of the cropfields. This suggests (but hardly proves) that non-crop habitats may be important in supporting in-crop populations of these taxa.

- Bee abundance was not strongly related with total floral area or even with the total floral area of all flowers thought to be favored by bees. More particularly however, floral area of Wild Carrot and perhaps Annual Fleabane may have been associated with higher bee numbers.
- At least in the cropfields, wolf spider abundance appeared to be most strongly correlated with habitat structure around the traps, rather than floral areas or potential pest abundances.
- Ground beetles appeared to respond to both habitat physical conditions and, especially when species-level data were considered, the abundance of certain potential prey items such as caterpillars and flea beetles.
- Flying insects/facultative visitors, especially beneficials, appeared to be more abundant around wilder areas, and this may have influenced their populations along field margins. It was unclear how far into the fields the effect existed, although for some groups it may still have been apparent 300' into the field.
- Corresponding to the earlier results suggesting their correlation with habitat structure right around the traps, our transect data hinted that proximity to wilder margins was less relevant for the ground dwellers/cropfield residents such as ground beetles and ground-active spiders.
- The service of a particular group of predators, as measured by its visits to Armyworm bait, was loosely correlated with the abundance of the respective creatures. However, the relationship was not constant across taxa and some groups, e.g., daddy longlegs and slugs, visited the bait at a disproportionately high rate relative to their abundances.
- Total predatory services measured in this way in the cropefields were roughly equal across three farms, although the actors contributing to that service differed across the farms.
- Because the relative importance of the activities of the two aforementioned groups (i.e., cropfield residents and facultative visitors) contributed different proportions of the total apparent predation activity across the different farms, the relative impact of local landscape-scale management vs in-field management on the 'services' of beneficials will likely differ among farms.
- Habitat use outside of the growing season may differ from habitat use during the growing season, and we know relatively little about habitat use at that time.

***Potential Future Work - Three Evident Questions*:**

<u>Agronomically, what, if anything, are beneficials actually doing?</u> Our camera data were our only indicators of beneficial activity. Future work should expand our measures of services in order to get a better indication of whether or not beneficial abundance translated into services.

<u>Some habitats were associated with increased populations of **both** beneficials and pests, what is net effect of pests and beneficials in terms of production quantity/quality?</u> We had no measures of crop pest damage nor of pollination importance. This seems crucial if we are to evaluate the consequences of habitat management.

<u>What is the scale of the habitat correlations and so what is the relative role of habitat conservation/managment at the larger landscape scale, vs. nook and cranny improvements around the farm fields?</u> Our small number of farms made it impractical to test for large-scale landscape effects; nevertheless, our past studies and the work of others (Martin et al. 2016, Schmidt et al. 2008) have suggested such effects are potentially important. Furthermore, while trap-level and local landscape-scale effects appeared to exist in our data, they were not always strong, perhaps, as has been suggested by others (Winfree et al. 2007), because the general landscape is already quite diverse in our area.

Acknowledgments.

We are grateful for the major funding provided to this project by the New World Foundation through the Hudson Valley Farm Hub. We also thank the farmers and staff of the Hudson Valley Farm Hub, Hawthorne Valley Farm, Hearty Roots

Community Farm and Ironwood Farm for their assistance and patience. Thanks to Rosa Villegas for helping to check and dig traps. Aaron Iverson and Katja Andrea Poveda of Cornell provided important advice and encouragement. David Foster of Harvard Forest facilitated very handy library and software access. Jeff Skevington gave prepublication access to their tremendous hoverfly field guide. Kyle Bradford identified a sub-sample of our ants. Rory Schiafo pinch-hit for Claudia during one set of vegetation sampling. Kelly Gill of Xerces shared helpful information and technical assistance.

Literature Cited.

Bell, R.T. 2015. Carabidae of Vermont and New Hampshire. 2nd edition. Shires Press, Manchester Center, VT. 385 pp.

Choate, B., and F. Drummond. 2011. Ants as biological control agents in agricultural cropping systems. Terrestrial Arthropod Reviews 4:157–180. Available online at http://booksandjournals.brillonline.com/content/journals/10.1163/187498311x571979.

Hendrickx, F., J.P. Maelfait, W. Van Wingerden, O. Schweiger, M. Speelmans, S. Aviron, I. Augenstein, R. Billeter, D. Bailey, R. Bukacek, F. Burel, T. Diekötter, J. Dirksen, F. Herzog, J. Liira, M. Roubalova, V. Vandomme, and R. Bugter. 2007. How landscape structure, land-use intensity and habitat diversity affect components of total arthropod diversity in agricultural landscapes. Journal of Applied Ecology 44:340–351. Available online at http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2006.01270.x/abstract.

Marc, P., A. Canard, and F. Ysnel. 1999. Spiders (Araneae) useful for pest limitation and bioindication. Agriculture, Ecosystems & Environment 74:229–273. Available online at http://www.sciencedirect.com/science/article/pii/S0167880999000389. Accessed July 23, 2011.

Martin, E.A., B. Seo, C.R. Park, B. Reineking, and I. Steffan-Dewenter. 2016. Scale-dependent effects of landscape composition and configuration on natural enemy diversity, crop herbivory, and yields. Ecological Applications 26:448–462.

Offenberg, J. 2015. Ants as tools in sustainable agriculture. Journal of Applied Ecology 52:1197–1205.

Quick, D.L.J. 2016. The Braconid and Ichneumonid Parasitoid Wasps. John Wiley & Sons, Ltd., Chichester, UK.

Schmaedick, M., and A. Shelton. 2000. Arthropod Predators in Cabbage (Cruciferae) and their Poteintial as Naturally Ocurring Biological Control Agents for Pieris rapae (Leidoptrea: Pieridae). The Canadian Entomologist 132:655–675.

Schmidt, M.H., C. Thies, W. Nentwig, and T. Tscharntke. 2008. Contrasting responses of arable spiders to the landscape matrix at different spatial scales. Journal of Biogeography 35:157–166. Available online at http://onlinelibrary.wiley.com.proxy.library.cornell.edu/doi/10.1111/j.1365-2699.2007.01774.x/abstract. Accessed October 19, 2011.

Wäckers, F.L., and P.C.J. van Rijn. 2012. Pick and Mix : Selecting Flowering Plants to Meet the Requirements of Target Biological Control Insects. Pp. 139–165, *In* G.M. Gurr, S.D. Wratten, W.E. Snyder, and D.M.Y. Read (Eds.). Biodiversity and Insect Pests: Key Issues for Sustainable Management. John Wiley & Sons, Ltd., Oxford.

Wagner, D.L., J.S. Ascher, and N.K. Bricker. 2014. A Transmission Right-of-Way as Habitat for Wild Bees (Hymenoptera: Apoidea: Anthophila) in Connecticut. Annals of the Entomological Society of America 107:1110–1120. Available online at http://openurl.ingenta.com/content/xref?genre=article&issn=0013-8746&volume=107&issue=6&spage=1110.

Winfree, R., N.M. Williams, H. Gaines, J.S. Ascher, and C. Kremen. 2007. Wild bee pollinators provide the majority of crop visitation across land-use gradients in New Jersey and Pennsylvania, USA. Journal of Applied Ecology 45:793–802. Blackwell Publishing Ltd. Available online at http://doi.wiley.com/10.1111/j.1365-2664.2007.01418.x. Accessed March 13, 2018.