Data-based Reflections on Five Years Monitoring Above-ground Macroinvertebrates in Experimental Wildflower Meadows.

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Introduction: Why study wildflower plantings?

Cropfields can be stark environments for many invertebrates. Even without pesticide use, their low plant diversity, regular disturbance, and exposed conditions reduce the suitability of cropfields as habitat for many species other than those which feed on the particular crops themselves. Many such herbivorous species are considered 'pests'. Conversely, beneficials species (i.e., those that pollinate the crops or kill the pests) often have habitat requirements that may involve semi-natural lands in addition to cropfields. These might include nesting sites (such as for ground-nesting bees) and food sources (such as the flowers where parasitoid wasps gather nectar). It has thus been hypothesized and, in at least some cases, shown that increasing the semi-natural habitat on a farm (such as by creating wildflower meadows or planting diverse, native hedgerows) may enhance beneficials relative to pests. However, these effects seem to be somewhat inconsistent, being more prominent in some situations than others.

From a conservation perspective, cropland can be extensive, but it often supports relatively few species of conservation interest. In highly agricultural landscapes, increasing semi-natural habitat where practical (e.g., along field edges or in other nooks) can enhance the land's biodiversity conservation value.

Our previous work looking at the insect communities of naturally-occurring, semi-wild habitats on farms had suggested that, in terms of supporting groups of beneficials, one size did not fit all (Vispo et al. 2018). Spiders, for example, were more common in wetlands, while lady beetles might have preferred old fields. Nonetheless, on-farm semi-natural habitat creation often focuses on wildflower meadow installation, and, through its Conservation Stewardship Program, NRCS/USDA provides cost-share to farmers interested in creating such habitat. Xerces (a national invertebrate conservation society) collaborates with NRCS in the hopes of not only enhancing production but also supporting biodiversity conservation. Off of farms, wildflower meadows are a popular ingredient of landscaping and are sometimes included in solar fields and other developed settings.

The work reported here was conducted to test whether, in the mid Hudson Valley landscape, wildflower meadows were really so all-encompassing in the creatures they support and, relatedly, whether they enhance on-farm conservation and adjacent crop production. Few studies of this type have been undertaken in the Hudson Valley and, in general, most wildflower meadow studies are limited in their duration. Because it has been shown that the apparent agroecological value of wildflower areas differs with landscape context, a lack of regional studies is problematic. Likewise, given that wildflower meadows are not stable in their plant species composition and invertebrate populations can be slow to respond, short duration studies may not adequately describe the impact of wildflower plantings on invertebrate ecology.

The work presented here follows the logic outlined in Fig. 1, which indicates that on-farm habitats, be they intentionally created or not, determine the composition of species communities, which, in turn, helps determine both the conservation value and the crop production value of such habitats. While assessment of conservation value can be relatively straightforward (for example, which regionally rare species are supported by the given habitat?), the assessment of a habitat's contribution to crop production is more complex and can be approached in three different ways: first, what is the abundance of pests and beneficials in a given habitat?; second, what evidence is there that

'beneficial services' are associated with the habitat's creatures?; and, third, is there direct evidence that the habitat is benefitting adjacent crops? Ultimately, what is learned about the biodiversity conservation and agronomic value of these on-farm habitats can feed back into future management recommendations.
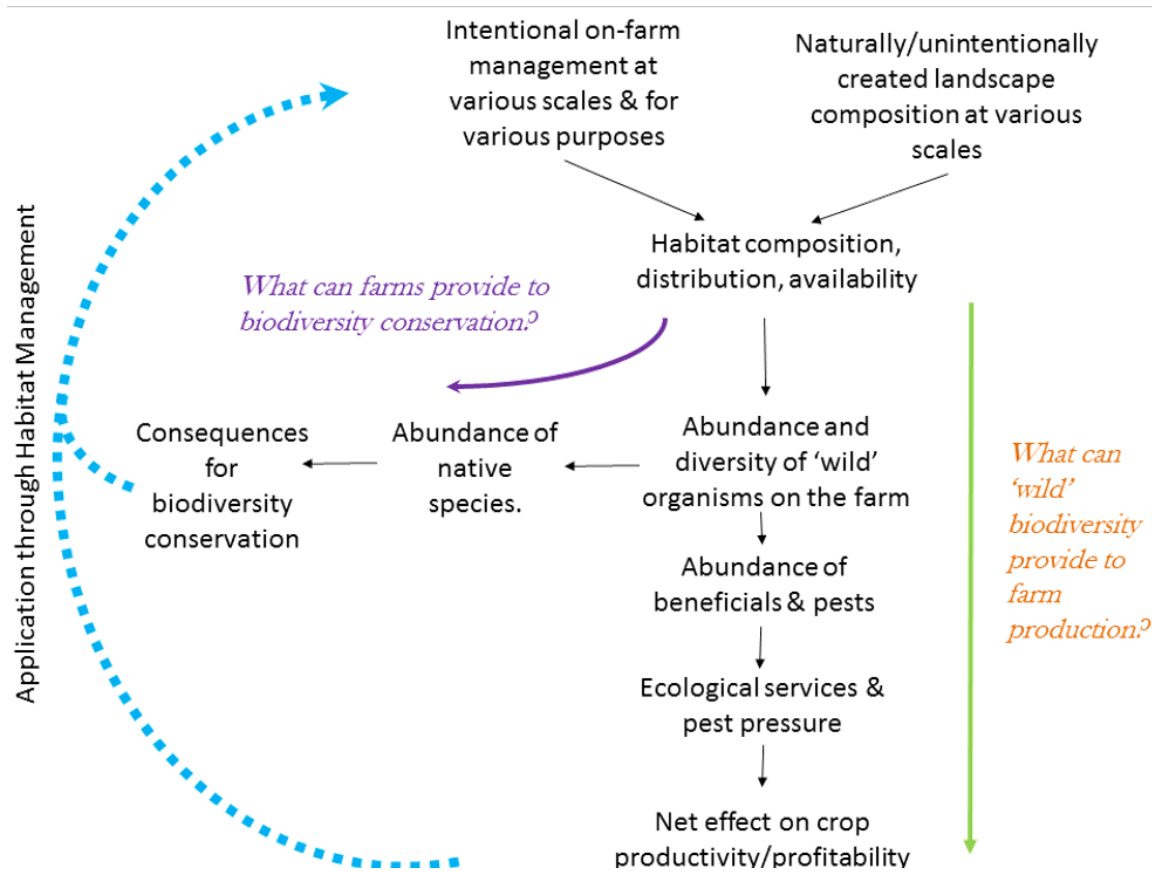

Figure 1. A diagram outlining the logic of the work described in this report.

Each of the approaches to assessing a habitat's impacts on food production has its strengths and weaknesses. Abundance assessment is relatively easy, and crop pests are fairly well known and beneficial groups widely described. Abundance is regularly used as surrogate for beneficial services. Unfortunately, translating abundance assessments of "pests" and "beneficials" into crop production impacts is difficult for several reasons which we will outline in this report; as a result, this is perhaps the weakest of the three approaches. Assessment of beneficial services seems tempting because one is avoiding assumptions about species' roles and directly assessing beneficial activities. However, such assessment is not easy and often requires that one focus on a limited set of potential services, which may or may not be representative of overall pest control (Doug Landis, pers. comm.). Finally, crop production would seem to be the most straightforward approach because it is getting at the bottom line so to speak. Nonetheless, growing an adequate variety of crops and understanding the best scale at which to evaluate them is hardly trivial. Long-term data are again needed because ambient "pest" and "beneficial" numbers can vary dramatically from year to year and evolve over time.

There is no standardized floral definition of a wildflower meadow – the species composition will vary depending upon what is planted, soils, management, climate and time. It has been shown that this variation can influence which invertebrates the planting supports. The floral composition of our wildflower plots is detailed in the accompanying botanical report (Knab-Vispo et al. 2022). Likewise, plot size can affect outcomes. It should thus be acknowledged that our results are most applicable to similar meadows of similar size and should not be over-generalized.

In this report, we will summarize up to five years of above-ground invertebrate abundance data gathered from wildflower meadows and comparison treatments seeded to native grasses, maintained as an unseeded fallow, and

managed as a perennial hayfield. We will assess these invertebrate communities from the perspective of their biodiversity conservation value and their populations of purported pests and beneficials. We will then summarize our data on services by reporting on one particular technique for assessing pest predation (using time-lapse cameras to record predation on Fall Army Worm eggs) and on two indirect measures of services: bee abundance on/near adjacent crop flowers and damage observed on those crops. We will go on to summarize production from squash and corn growouts adjacent to each of our treatments. We will continue by considering what might explain the inconsistencies in the results from our different approaches and by asking, given these results, which growers might find wildflower plantings most fitting. We close by summarizing our future plans.

What others have found: See Thies et al. (2003), Bianchi et al. (2006), and Chaplin-Kramer et al. (2011) for the differential response of pests and beneficials to landscape complexity. Xerces (https://xerces.org/sites/default/files/2018-05/16-020_01_XercesSoc_Habitat-Planning-for-Beneficial-Insects_web.pdf) and USDA/NRCS promote wildflower plantings (https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download/?cid=nrcseprd1431518&ext=pdf). Discussion of wildflowers and solar installations can be found in Blaydes et al (2022), while Weaner and Christopher's book (2016) exemplifies the use of wildflowers in Northeast landscaping. Holland et al (2016) provides a nice review of evidence on the agronomic significance of wildflowers, including a summary of the different types of evidence usually gathered and see Dicks et al. 2020 (available here https://www.conservationevidence.com/actions/442) . A recent review of results from Europe and North America concluded that wildflower plantings provided pest control, and, albeit less clearly, pollination benefits to adjacent crops (Albrecht et al. 2020). This paper also concluded that pollination benefits increased with age of the planting, but an experimental study by some of the same authors (Albrecht et al. 2021) found that pollinators declined markedly in older plantings. The authors explained the discrepancy in part by noting that few of the studies in their review lasted more than three years. Fountain (2022) noted that in more than 130 of the studies considered in their review of the impacts of wild flowers on orchard production and conservation values, fewer than 30 lasted from more than three years. Frank and Künzle (2006) and Buhk et al. (2018) likewise found that meadows and invertebrate communities change with time. Habitat management or conservation to enhance biocontrol is often termed 'conservation biological control' (Landis et al. 2000).

> ...Because they are commonly prescribed as a way of enhancing a land's conservation and/or food-production value, and yet those roles have been little studied in our region or in the long term.

Methods: How did we do our study?

Experimental Planting. This work was conducted at the Hudson Valley Farm Hub in Hurley, NY, USA. 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 on former cropland in the Spring of 2017. Each set included .5 acre of a flower-rich/grass-light seed mix, of a flower-light/grass-rich mix, 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. Seed mixes, management details and the botanical evolution of these plots is described in the accompanying botanical report (Knab-Vispo et al. 2022).

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 2017, partial sampling occurred in mid August and September; 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 2020, sampling happened in mid June, early July, early August and early September; and in 2021, we sallied forth in mid June, July, August and September. In all cases, sampling was scheduled to avoid appreciable rain, high winds or unseasonable cold during the sampling period. During the initial years, three vane traps (two blue, one yellow) also accompanied the sampling. This was discontinued, but reference is made to some of those early results.

In 2019 and 2021, one emergence trap (Bugdorm Black Soil Emergence Trap, covering ca. 484 in^2) was placed in each of our 12 plots. The exact dates when these were set depended on how the Spring developed but in general emergence traps were installed in early to mid April and removed three or four weeks later. The flaps along the edges of the traps were buried to discourage comings and goings. ETOH was placed in the traps' collecting jars, and traps were checked roughly every week.

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].

Experimental Crop Beds. Starting in 2019, a 50' row of Waltham butternut squash was established from starts next to each of the nine initial .5 acre experimental plots (no crops were planted directly adjacent to the hay). These were managed without pesticides and herbicides, although, as is done commercially, a fine fabric ("Remay") was placed over the squash starts for approximately the first two weeks. They received a hand scattering of poultry pellets as an initial fertilizer. Damage and growth parameters were visually assessed periodically. In 2020, a single of row of Sweet Corn was interspersed with the squash plantings, but this seemed to result in reduced pollination. In 2021 we therefore planted four rows of Sweet Corn adjacent to the opposite ends of our beds. These were seeded and managed according to the commercial organic practices elsewhere on the farm, except there was no spraying of organic pesticides and no releases of beneficial wasps. Weeding and watering occurred in both crops on an 'as-needed' basis.

Insect visitors were tallied by sweep netting in 2019 and vacuuming subsequently (to reduce the damage associated with sweep netting). Squash growth (estimated length and width of the plant, leaf number) and damage (% of leaves with various forms of damage) was noted periodically. At harvest, the squash were counted and individually weighed. The length of the Sweet Corn cobs were measured and the cobs were weighed. Tip fill and cob fill (indices of fertilization) were estimated and any insect damage was noted.

Invertebrate Identification. We could not practically identify all captured invertebrates to species. Both in the field and in the lab, we tried to identify captured bees and ground beetles to species and captured parasitoid wasps primarily to family or genus. In some years, wolf spiders, ants and hover flies were also identified to species. Otherwise, aside from a few distinct creatures, family or even order was the lowest level of identification used.

Statistics. General linear models with a negative binomial distribution were used to evaluate for treatment effects after taking into account date, site and interaction effects. Results are presented as "estimated marginal means", these are essentially the mean captures that can be associated with treatment – they are what is 'left over' after accounting for the effects of the other factors in the model. The R statistical program was used.

For the most part, the taxa identified are those for which there were adequate data in the captures. The major exception is unidentified flies. These were often our most abundant captures but are not presented here due to uncertainty about their identities and ecological roles. Given that some flies are known to be parasitoids, obtaining more information on this group could be important.

> *…We used an array of capture techniques to survey the invertebrates associated with each of our treatments. Using crop growouts and baited time-lapse cameras, we then assessed select aspects of invertebrate activity and attempted to measure the influences of our treatments on crop production.*

What did our trapping reveal about how invertebrates responded to our plantings?

As described in the methods, during the course of this study, invertebrate abundances during the growing season were evaluated using three different sampling techniques: malaise traps, sweep netting and pit traps. Each of these methods samples a different component of the invertebrate community and, while certain creatures are definitely left unsampled, the variety of techniques provides a more complete picture of that community.

Sweep netting (Fig. 2) involves brushing the tops of the vegetation with a sweep net. In doing so, it captures creatures that are easily knocked from leaves and stalks and, to some degree, insects flying in the same neighborhood. Most of the leafhoppers, Tarnished Plant Bugs, caterpillars (most Lepidoptera), lady beetles, ants, spiders and flea beetles were probably caught off of the plants themselves, whereas the bees, wasps and hover flies may have been either perched or in flight nearby.

The most evident sweep netting results were the marked relative abundance of bees, and, to a lesser degree, of Lepidoptera, hover flies and ants in the wildflowers; the relative abundance of parasitoid wasps, leafhoppers (although not significantly different), weevils, Tarnished Plant Bugs, micro flies, and flea beetles in the fallow; and the relative dearth of spiders, bees, and ants in the Hay, but the abundance of lady beetles therein. It is notable that the grass treatment did not excel in any taxon and seemed to be especially low in ants, hover flies and Lepidoptera.

Malaise traps (Fig. 3) are passive in that creatures walk or fly into them. They seemed to capture more parasitoid wasps, hover flies and Lepidoptera than the sweep netting. Notable results are the relatively high numbers of bees, hover flies and long-legged flies in the wild flowers; of parasitoids in the fallow and hay; of aphids and nymph/adult true bugs in the fallow; and of ants, small flies, and leafhoppers in the hay. No taxon seemed particularly abundant or rare in the grass treatment.

Pit traps capture a distinct group of creatures – the invertebrates active on the ground surface. The salient results (Fig. 4) were the relative abundance of wolf spiders and slugs in the hay, of ants and ground beetles in the fallow and of rove beetles in the wildflowers. Again the grass treatment seemed to be neither particularly high nor particularly low in any of the taxa we considered. While these pits were not baited, it is possible that previous captures attracted (or deterred) later ones.
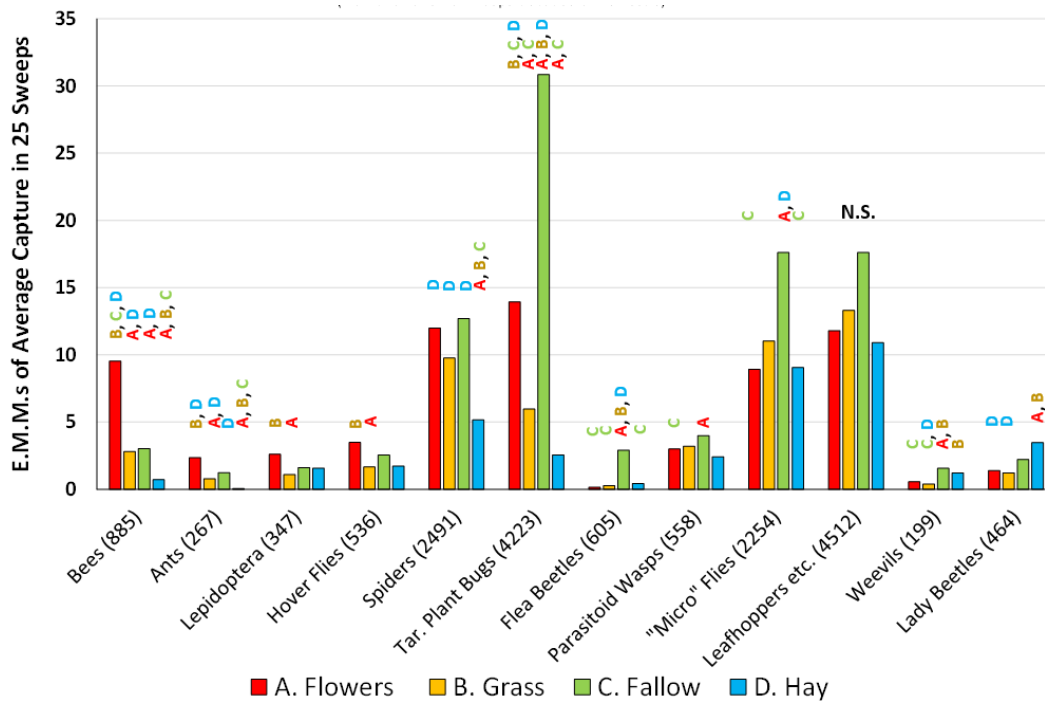
Figure 2. The estimated marginal means for sweep net captures classified by treatment. These are data from 2017 through 2021, although 2019 data for parasitoid wasps was excluded due to an issue of net mesh size which we believe did not affect the other, larger groups. The letters above each bar describe the results of taxon-specific analysis for treatment effects; a letter indicates which other treatments differed significantly from that represented by the given bar. For example, the "B" above the red bar in hover flies signifies that the number of hover flies in the flower plots differed significantly from that in the grasses; of course, as indicated by the "A" above the orange bar, the number in the grasses also differed significantly from that in the flowers.
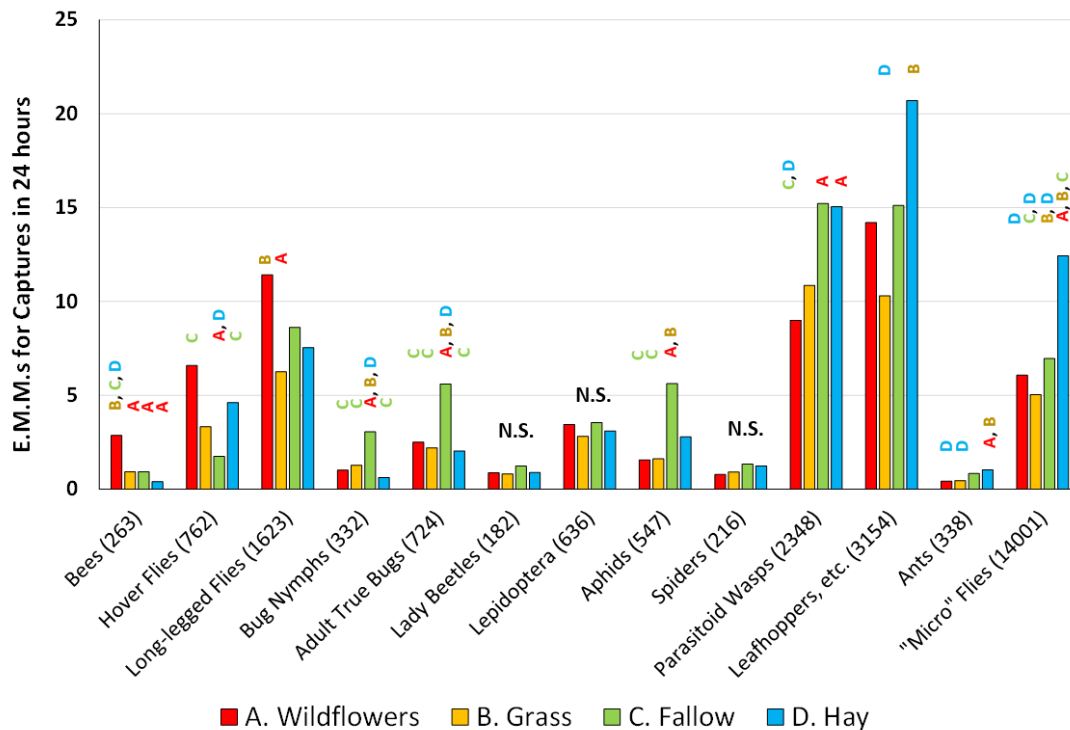

Figure 3. The estimated marginal means for malaise trap captures classified by treatment. These are data from 2018 through 2021. The letters above each bar describe the results of taxon-specific analysis for treatment effects; a letter indicates which other treatments differed significantly from that represented by the given bar. For example, the "B" above the red bar of long-legged flies signifies that the number of such flies in the flower plots differed significantly from that in the grasses; of course, as indicated by the "A" above the orange bar, the number in the grasses also differed significantly from that in the flowers.
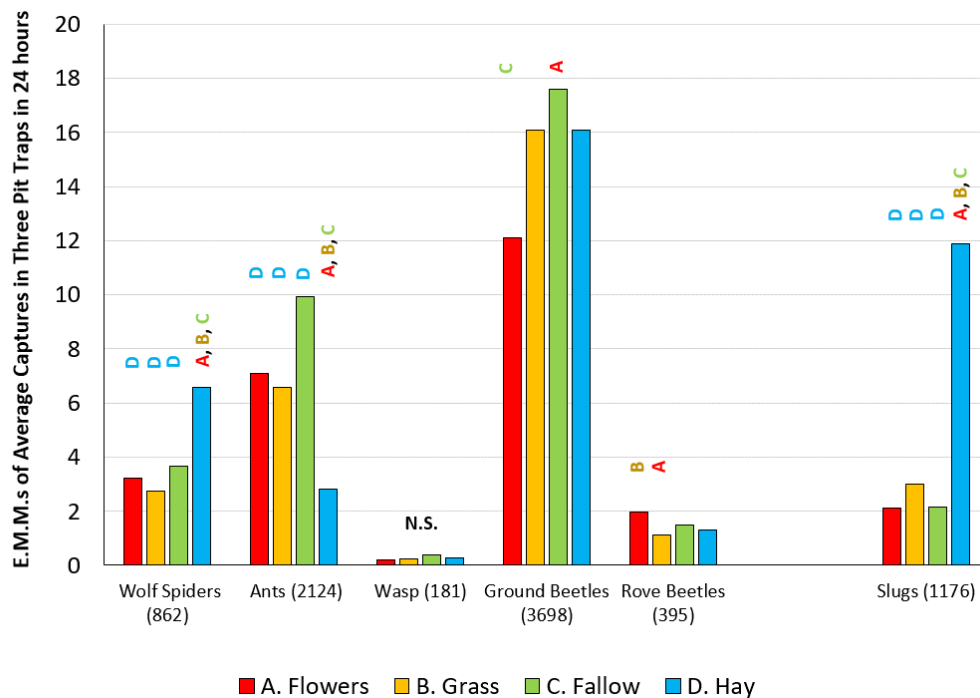
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Figure 4. The estimated marginal means for pit trap captures classified by treatment. These are data from 2018 through 2021. Groups to the left of the gap are generally considered "beneficials", while those to the right are commonly classified as pests. The letters above each bar describe the results of taxon-specific analysis for treatment effects; a letter indicates which other treatments differed significantly from that represented by the given bar. For example, the "B" above the red bar in rove beetles signifies that the number of these beetles in the flower plots differed significantly from that in the grasses; of course, as indicated by the "A" above the orange bar, the number in the grasses also differed significantly from that in the flowers.
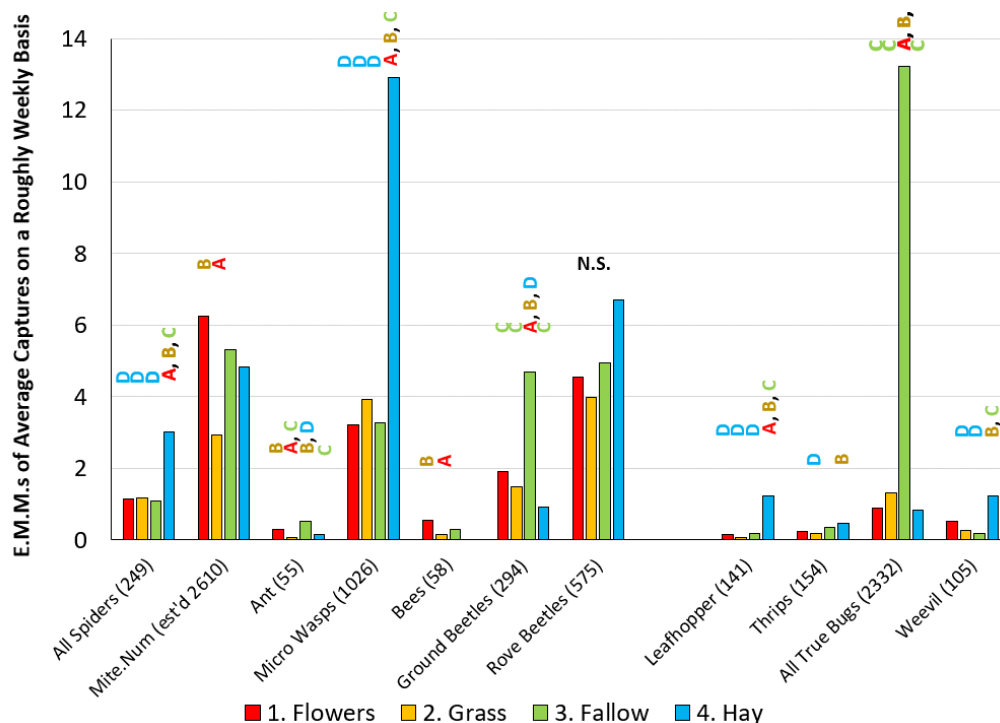

Figure 5. The estimated marginal means for emergence trap captures classified by treatment. These are data from 2019 and 2021. Groups to the left of the gap are generally considered "beneficials", while those to the right are commonly classified as pests. The letters above each bar describe the results of taxon-specific analysis for treatment effects; a letter indicates which other treatments differed significantly from that represented by the given bar. For example, the "B" above the red bar for bees signifies that the number of bees in the flower plots differed significantly from that in the grasses; of course, as indicated by the "A" above the orange bar, the number in the grasses also differed significantly from that in the flowers.

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Finally, we used emergence traps to capture overwintering creatures emerging in the Spring. This technique (Fig. 5) produced relatively high numbers of spiders, parasitoid wasps, leafhoppers and weevils in the hay; of mites and bees in the wildflowers; and of ants, ground beetles and true bugs in the fallow. Yet again, no taxon was particularly common in the grass, while ants, bees and thrips were noticeably low.

In some ways each of these techniques shows a different aspect of the invertebrate ecology in our treatments, and they provide a rather confusing amount of information. The following table (Tab. 1) seeks to summarize those data by indicating which groups were most abundant in each treatment. A group was assigned to a treatment if multiple techniques indicated a consistent pattern or if the given creatures were only well sampled with one technique but within that technique, there was a strong pattern.

In preparation for the discussion that follows, the different taxa have been designated as of mixed or unknown relevance for agriculture, as being a "beneficial", or as being a "pest". The beneficial designation is derived from the popular literature, while pest designation comes from that literature and Anne Bloomfield's records from the Farm Hub (pers. comm.). This table suggests that our treatments are having a significant effect on some invertebrate groups and, at least in that sense, we have been successful in manipulating invertebrate habitat. Simply in terms of the most abundant invertebrate groups in each respective treatments, the wildflower treatment would appear to host the highest ratio of beneficials to pests.

Table 1. A table summarizing the statistically significant results from our various capture methods. The groups indicated were significantly more common in the treatments below which they are listed. They have been classified as "pests" or "beneficials" based on the popular literature and farm records.

	Wildflowers	Grass	Fallow	Hay
Unknown or Variable	Ants		Other True Bugs Micro flies	
"Beneficials"	Bees Hover Flies Long-legged Flies Rove Beetles		Ground Beetles Parasitoid Wasps	Lady Beetles Wolf Spiders
"Pests"	Lepidoptera		Aphids Flea Beetles Tarnished Plant Bug	Leafhoppers Slugs

What others have found: Our observation that the wildflowers attract bees, hover flies and Lepidoptera echoes that of other workers (Pollier et al 2019). Like us, Middleton et al. (2021) found both that bees were favored by wildflower plantings but lady beetles were not clearly favored. Albrecht et al. (2021) found that wildflower strips hosted enhanced bee populations but that this effect declined substantially with time.

...Not surprisingly, different techniques produced somewhat different results, and yet, as reflected in our colored table, there did seem to be certain generalities, with the wildflower plantings hosting the most beneficial groups.

Given our captures, what could we say about the apparent biodiversity conservation value of our plantings?

In its crudest form, biodiversity conservation value could be assessed based on species richness or some related biodiversity index. Unfortunately, we have not been able to get to lower-level identification for all taxa.
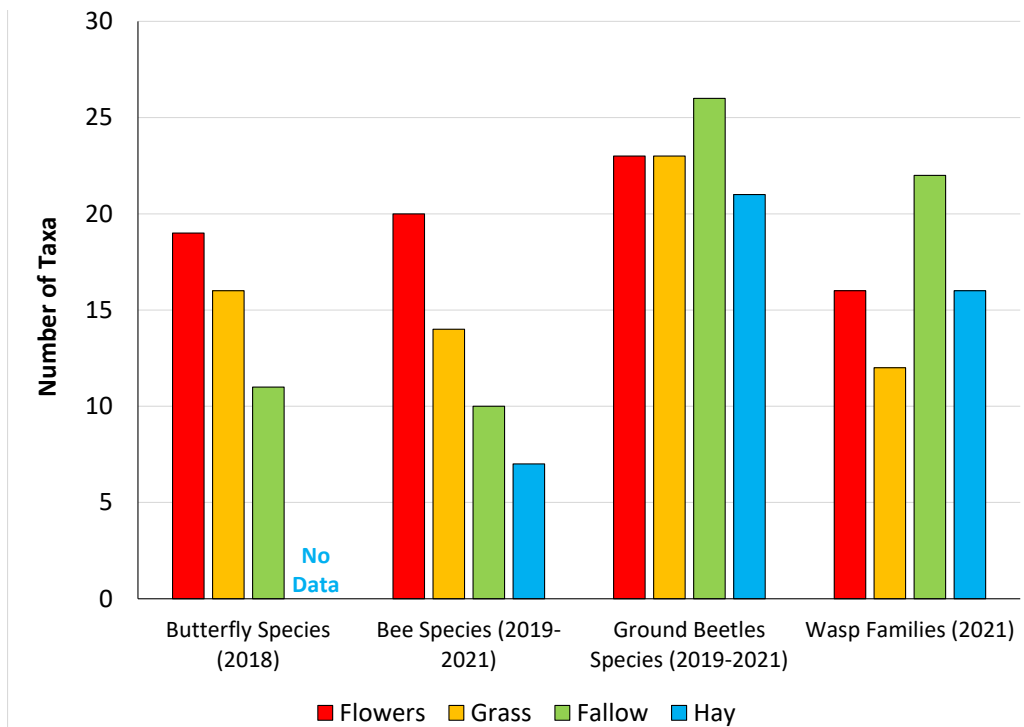
Figure 6. Species numbers by treatment for butterflies, bees and ground beetles and family numbers for wasps. The butterfly data are from visual surveys done by Erin Allen as part of her masters dissertation, all other results derive from our standardized sampling.

What information we do have (Fig. 6) suggests, not unsurprisingly, that diversity is probably proportional to abundance. For each of the groups for which greater taxonomic detail is available, the group was most taxa-rich in the same treatment where it was most abundant.

However, from a regional conservation perspective, absolute species numbers may not be the most relevant metric. Those values can include non-native species and widespread, common generalists. As would be expected in relatively young and small habitat patches on a highly worked farm, we observed few rare species, and, for the most part, there seemed to be no obvious pattern across our treatments in their occurrence nor in the occurrence of non-native species. Relative to our other treatments, our hay treatment (the treatment that was most similar to crop field) did tend to be home to a more common and disturbance-favored set of ground beetles. However, more than treatment, soil texture seemed to be important for ground beetle diversity, with our sandiest site having 20-60% more species than our less sandy sites; this included some regionally rare species.

Given their small size, there is little reason to expect our treatments to draw particularly rare species unless those species are already in the landscape adjacent to our plots and we are providing them with resources of interest. One such group of rare species might be herbivores tied to the native grasses that are now well established in our grass plots (such as some of the 'Little Bluestem Skippers'), however, given the lack of such native grasslands nearby, such establishment may be unlikely. More likely might be visits from rarer forest insects, such as the Tawny and Hackberry Emperors of the adjacent floodplain forests, which are tempted to visit the meadows for nectaring. Conservation effects would presumably become more likely with larger plantings. As has been said by others, part of conservation is keeping the common species common, and, from this perspective, we support the creation of such habitat wherever it replaces lawn or other landscaping that has low food production and conservation value.

What others have found: Lepidopterists in Europe have similarly found that wildflower plantings seem to predominantly but not solely favor the common species (Haaland et al. 2011). Korpela et al. (2013) reported that wildflower benefits to specialist butterflies (which tend to be rare) developed more slowly than pollinator abundance or overall biodiversity. In another European study, Scheper et al. (2015) reported that wildflower plantings were associated with increased bee diversity and abundance, including for rare species.

What can we say about the agronomic relevance of our plantings based upon the occurrence of designated "pests" and "beneficials"?

Another way to view our results is through the lens provided in Table 1 – where are 'pests' and 'beneficals' found? By this basic rubric, we might tout our wildflower mix given the relatively high number of beneficial invertebrate groups it seems to support and the relatively low number of pest groups. This could be misleading for a variety of reasons.

If we define a "pest" as a creature who damages human crops and a "beneficial" as a creature who supports such crops, either through direct benefits like pollination and soil improvement or by helping to control "pests", then it is clear that pests and beneficials exist. However, this does not mean that blanket characterizations are always appropriate.

There are several reasons why our categories might be overgeneralizations. First, relatively few species within a particular group might actually be a pest or beneficial. For example, we have recorded almost 300 genera of wasps from the Farm Hub and these may represent at least 500 species. Most of these are parasitoids but for any given crop the number of relevant parasitoids is small. For instance, there may only be five or fewer wasp species who parasitize pests of the Butternut Squash we planted adjacent to our beds. The same logic probably holds for parasitic flies. In this case, who is a beneficial is strongly dependent on the crop system you are concerned about. Similarly, those butterfly and moth species which interact with crops are usually considered pests, but they make up a small proportion of the roughly 750 regional Lepidoptera species we have tallied.

Second, "pests" and "beneficials" are human constructs rather than attempts to identify inherent ecological roles. As such, species are in no way beholden to these designations. Within ground beetles, for example, of 86 known ground beetle species at the Farm Hub, 46 are recorded in the literature as sometimes eating pests, 17 are recorded as eating weed seeds, and 21 are recorded as eating crops (that is, being 'pests' themselves). Eighteen species eat both pests and crops! Eight are described as potentially of beneficial economic importance, while ten are documented as agronomically relevant pests. Similarly, while we have not yet quantified spider predation patterns, our photo documentation of regional spider activity reveals multiple examples of spiders eating bees, and we have also photographed them eating praying mantis, dragonflies, and lady beetles. As a generalist predator, they do not confine their diets to pests. Even "pest" status is not immutable. Slugs are widely perceived as pests and, unquestionably, can consume crops and yet, as we will document below, they were also the most frequent consumers of the Fall Armyworm eggs we used to bait our timelapse cameras.

Even the justification for calling all bees "beneficial" is somewhat less clear than one might hope. As is widely recognized, for instance, one species (the Eastern Cucurbit Bee aka Squash Bee), is responsible for much regional squash pollination. Our gross-level work looking at pollination of other regional crops also suggests ample variation – the observed role of Honey Bees varied from over 80% of observed pollinator visits to less than 10% depending on the crop; and it is likely that even within the native bee pollinators of crops, there is also some differentiation. Furthermore, for our numerous wind-pollinated crops or whose leaves rather than fruits are harvested, bees are largely unimportant (seed production of leafy vegetables being the exception). Thus, bee beneficiality is context dependent.

Some of these observations would be less problematic if the species within our gross categories responded in a uniform way to habitats. For example, if all parasitoid wasps responded identically, then we might hope that, while there would be lots of 'extras', the wasps of agronomic interest would be most frequent wherever parasitoids as a whole were most common. Likewise, if all bee species had identical occurrence patterns, then we could assume whatever pollinator a crop favored would occur wherever bees were most abundant. Unfortunately, such is not the case.
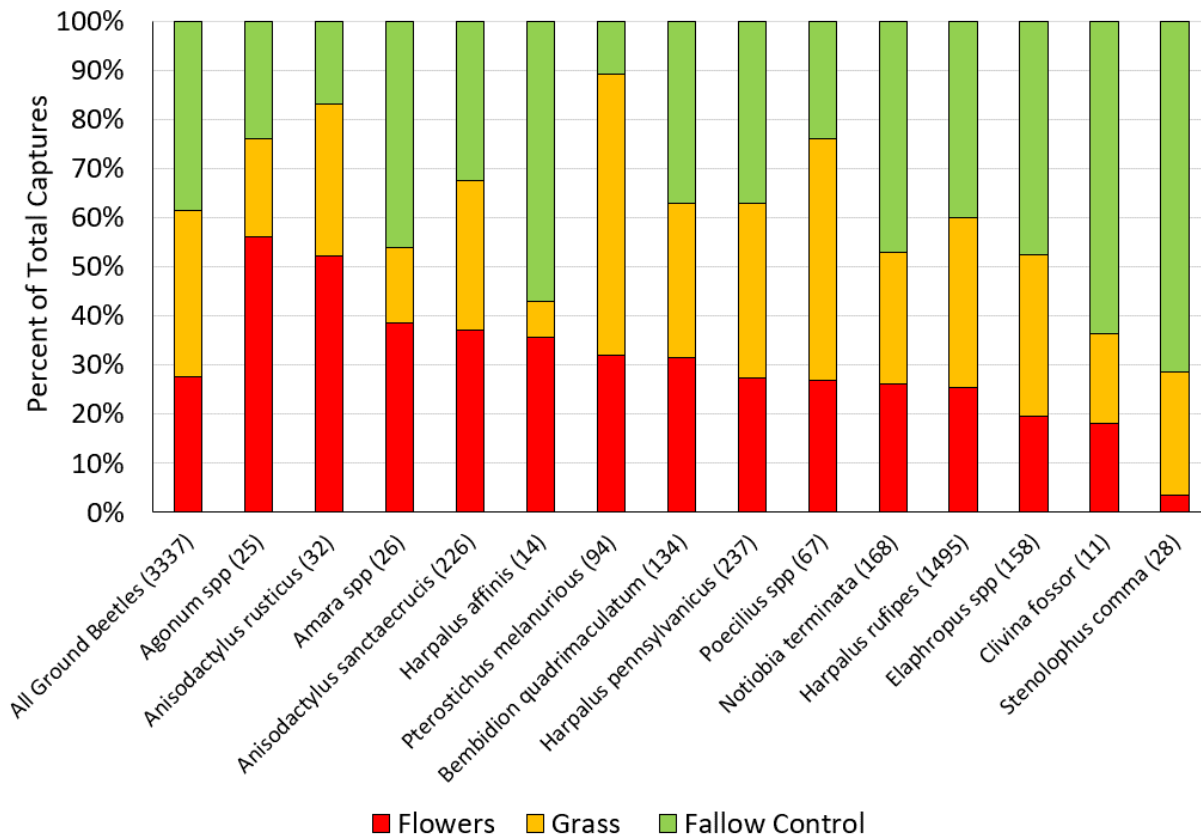
Figure 7. The proportional representation of all ground beetles across treatments in 2017-2021 pit trap captures (left bar), together with that of various lower ground beetle taxa. Note that the occurrence pattern of some species differs markedly from that of ground beetles as a whole.
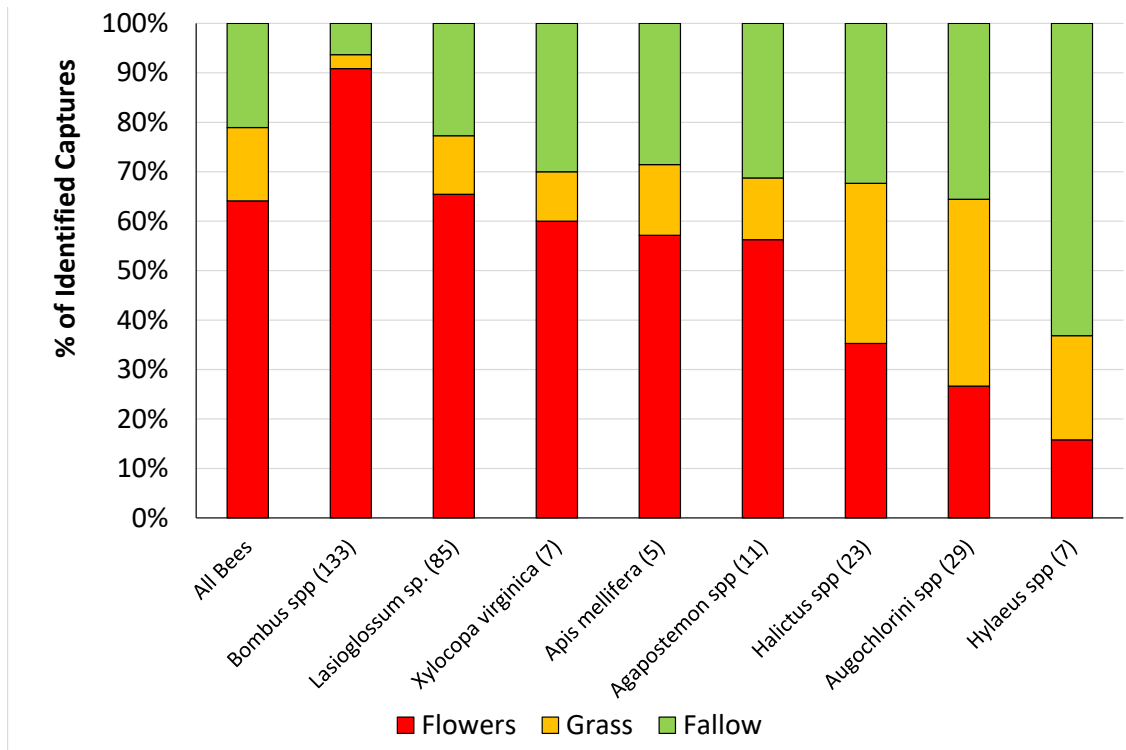

Figure 8. The proportional representation of all bees across treatments and capture methods for 2017-2021 (left bar), together with that of various lower bee taxa. Note that the occurrence pattern of some species differs markedly from that of bees as a whole.

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While total ground beetle captures (Fig. 7) were divided roughly evenly across our treatments (leftmost bar), there was substantial variation amongst lower-level taxa with , for example, more than two thirds of the *Stenolophus comma* captures coming in the fallows and more than half of the *Anisodactylus rusticus* captures being reported from the wildflowers. Given simple mathematics, the apparent treatment preferences of the group as whole reflect those of the most common species (i.e., *Harpalus rufipes, H. pensylvanicus*, and *Anisodactylus sanctaecrucis*).
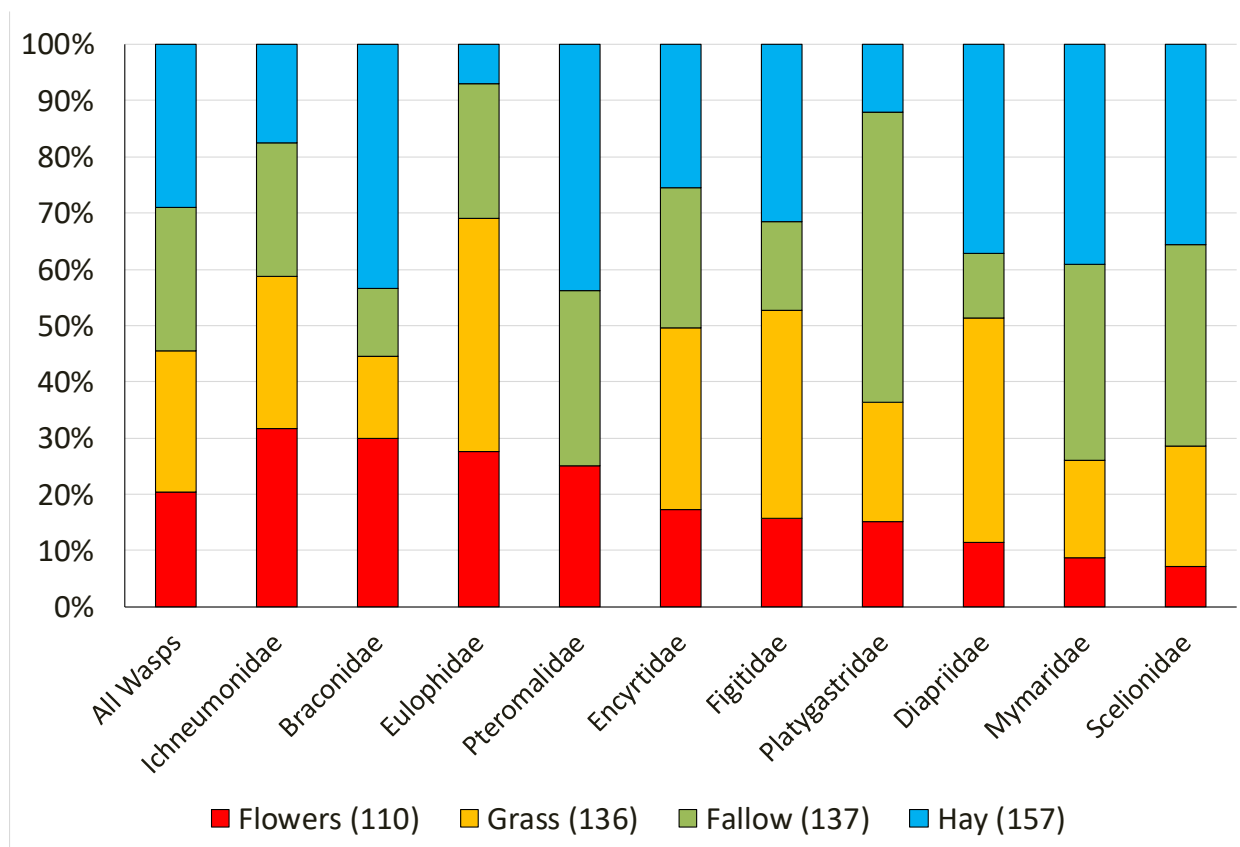

Figure 9*. The proportional representation of all wasps across treatments and methods in 2021 (left bar), together with that of various wasp families. Note that the occurrence pattern of some families differs markedly from that of bees as a whole. These tallies are only for identified wasps from 2021 as assessed by all methods, for this reason the leftmost bar differs from the proportions shown in the multi-year, single-method results shown earlier.*

Bee distributions (Fig. 8) show a similar pattern: while nearly two thirds of all bee captures occurred in the wildflower plots, this percentage was about 90% for bumblebees (*Bombus spp.*), but only about 15% for species of *Hyleaus*. If crops differ in their most effective pollinators, then this variation can be agronomically relevant. (Of course, which bees are where spatially is not the only piece of the puzzle, one must also understand which bees are present at the same time as the crop is flowering!)

The distribution of parasitoid wasp families (Fig. 9) is no different. (Because these data are all from 2021 unlike the longer term data shown for the previous two groups, we have included the hay treatment, which was not present in the earliest years.) Yet again, the pattern for all wasps (left bar) masks substantial variation amongst lower-level taxa. Depending on the family, proportional captures in fallow varied from more than 40% to near 0%, while fallow captures varied from more than 50% to about 10%.

Our gross classifications might be somewhat more applicable to certain groups with more uniform behavior. For instance, aphid consumption is rampant amongst the hover fly species we captured (dominated by *Toxomerus* spp) and amongst the lady beetles. Of course, not all the aphids being consumed might be considered pests and if those aphids were feeding on weeds, then the complexity returns. However, this generalized behavior means that our categories "hover flies" and "lady beetles" may be more agronomically relevant that some of our other general groups.

In sum, while it is often not practical to obtain lower-level taxonomic information for all invertebrate groups captured and, even with that information in hand, it is not always possible to translate those identifications into agronomic relevance, we should question placing too much weight on the occurrence patterns of larger taxa broadly described as "beneficial" or "pest" in the popular literature.

What others have found: The 'go-to' source for ground beetle ecology and the citation for much of our diet information is the North American ground beetle ecology review by Larochelle and Lariviere (2003); supplemented in some cases by Bell's (2015) more regional work. Middleton and others working in Europe have found, like us, that *Bombus* is especially attracted by wildflower plantings (Middleton et al. 2021). Garibaldi et al (2015) discuss the links between crop flower morphology and pollinators. MacLeod et al. (2020) documented the major pollinators of some important Northeastern crops, noting that there was some variation amongst crops.

..."Pest" and "Beneficial", when broadly applied, may be overgeneralizations that do not let us predict the relevance of a given habitat and associated insect community for production.

Even if our plantings do influence invertebrate communities, are those creatures shared with adjacent crops?

Even if we felt confident of our pest and beneficial assessments for the invertebrates associated with each treatment, these results could still be misleading if the creatures found within each plot were not, in fact, shared with the adjacent crops. Cropfields and wildflower meadows, for example, are very different habitats, and the invertebrates in the latter may not regularly wander into the former. Indeed, following the same logic that has led to the use of trap crops (i.e., the planting of crops that are more attractive to a pest than the focal commercial crop, plantings like wildflowers could actually attract beneficials that might otherwise be in the crops.

For three of the general taxonomic groups for which we had finer identifications, we took advantage of our experimental hay treatment (our nearest analog to a cropfield) to ask 'what percent of the taxa found in the wildflowers also occurred in the hay field?'. Less than 30% of the bee species found in the wildflowers were also found, given equal sampling, in the hay fields. That proportion increased to 75% for wasps, although that rise may have partially reflected the fact that for bees and ground beetles we are working at the species level, while for wasps we were dealing with families.

Work with another of our Farm Hub data sets, in which we compared bee and ground beetle species, and wasp genera between field and forest (Tab. 2), also indicated that substantial numbers of species were not shared amongst the habitats and that overlap was highest for wasps. The key point is that a substantial proportion of the species in some semi-wild habitats may not even venture into adjacent crops.
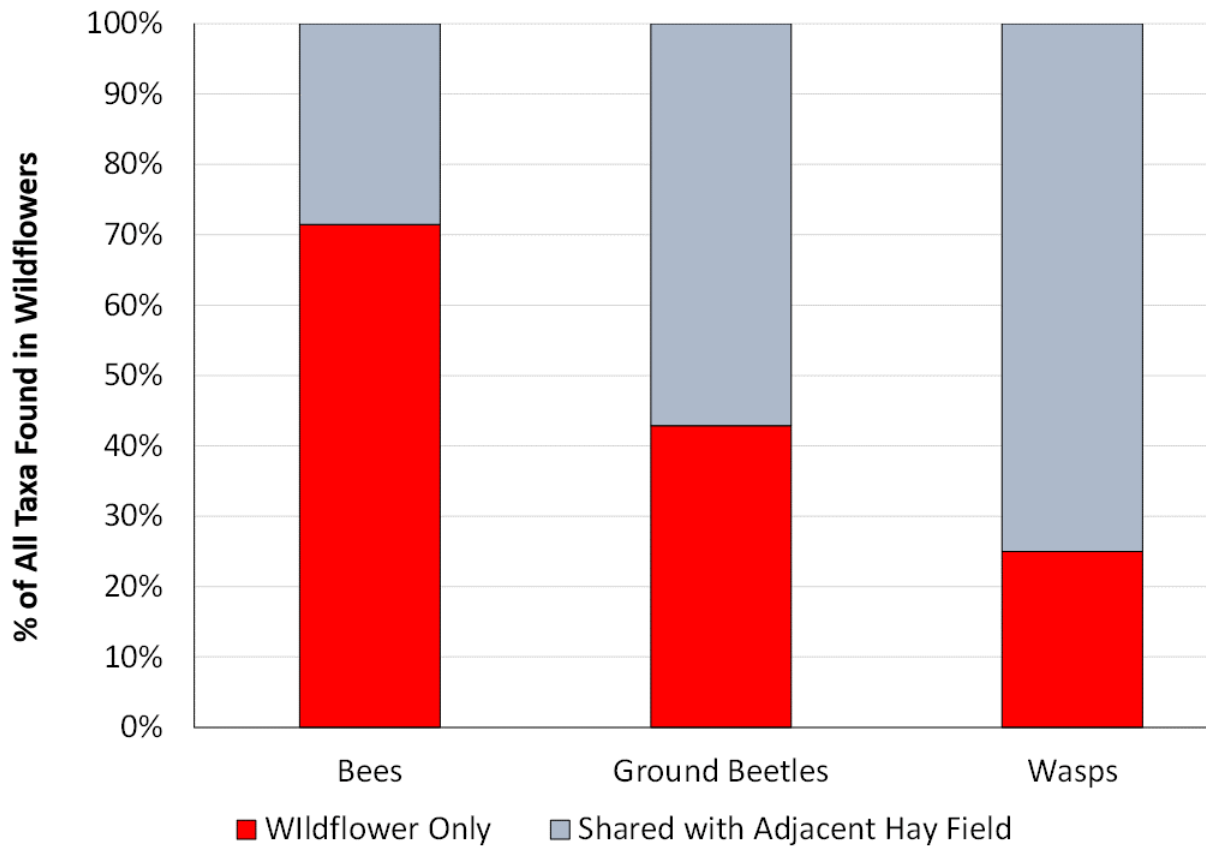
Figure 10. The percentage of wildflower-occurring taxa that were confined to the wildflowers or were shared with the adjacent hay fields.

Table 2. The percentage of captured bee, ground beetle and wasp taxa from along an independent set of sampling transects at the same farm, showing the proportional occurrence of taxa found in one or both habitats. Although sampling intensity was not equal between woods and fields (and so direct comparisons of the diversity in those two habitats is not appropriate), these data provide evidence that while some species do occur in both habitats, a substantial portion do not.

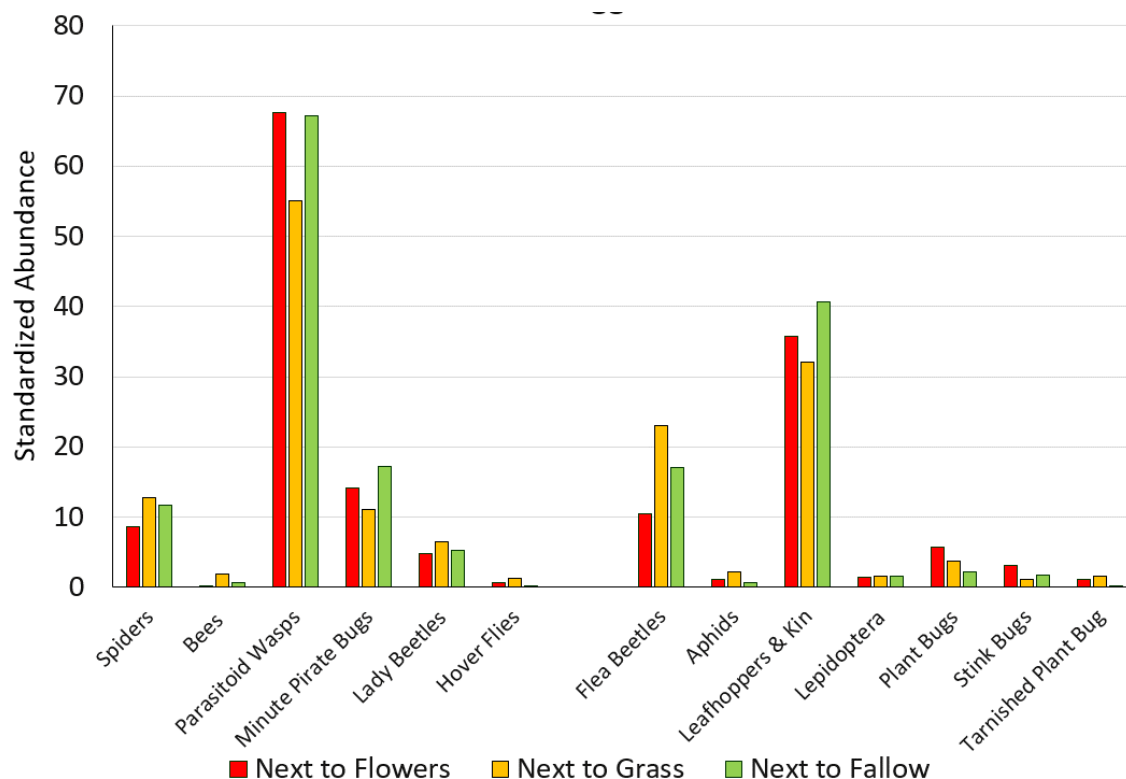|	Woods Only	Woods & Fields	Fields Only
Bees	13%	20%	67%
Ground Beetles	13%	22%	65%
Wasp	43%	37%	20%

Figure 11. Results from vacuuming conducted in the experimental crop plots in 2020 and 2021. No statistics have yet been applied to these results.
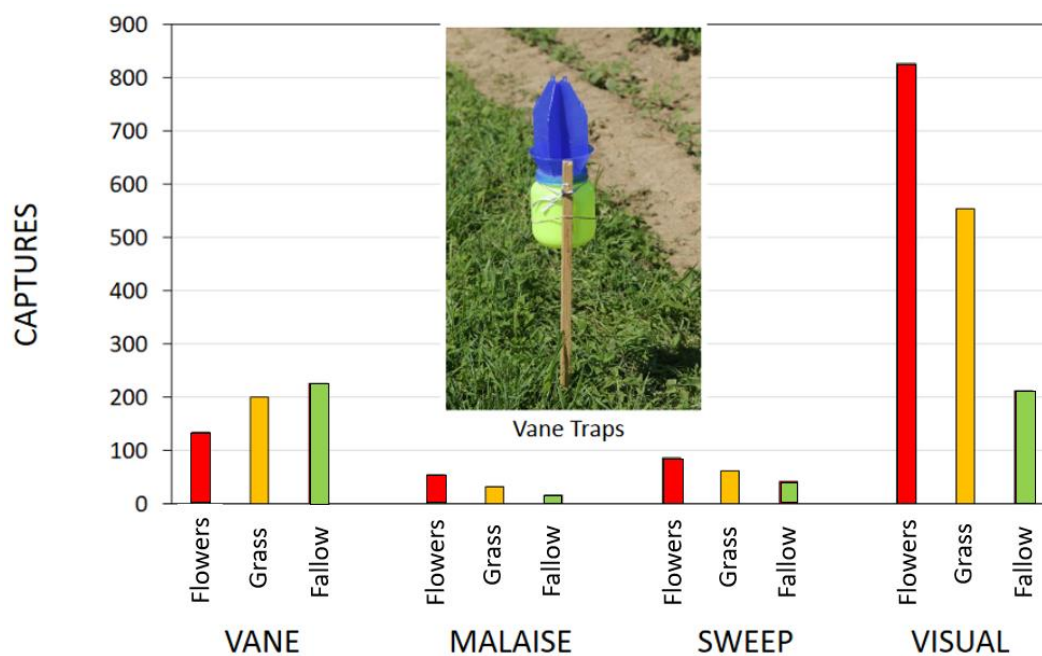

Figure 12. A comparison of 2018 bee captures (bumble bees were excluded) using colored vane traps (pictured). Notice how bee abundance as measured by malaise and, sweep trapping and by visual surveys (Erin Allen's thesis data) all indicated that bees were most common in the wildflower plots while vane trapping from the same sites and, at least in the case of the other traps, the same dates indicated the reverse pattern.

This point is further illustrated by comparing the creatures vacuumed from the crops (Fig. 11) with those reported for the adjacent treatment plots (Table 1). In most cases, there seem to be few parallels, and treatment effects seem modest. This shouldn't be surprising - the communities of the plowed corn and squash growouts would be predicted to

be more similar to themselves than to the variable experimental habitats next door; any effects from adjacent habitats would be expected to be subtle.

The possibility that adjacent habitats were not only not sharing but might have been hoarding individuals is suggested by our earlier data on bees as assessed by different methods (Fig. 12). We initially used blue and yellow vane traps to evaluate bee populations in our treatments; we also obtained bee data from sweep and malaise trapping and, during one year, from visual surveys. All techniques except the vane traps pointed to the notably higher populations of bees in the wildflowers, while vane traps suggested bees were most numerous in our fallows. Discussing this result with experienced bee biologists, the likely explanation became apparent – the colorful vane traps are most attractive in landscapes with few distracting flowers. We believe that bees are actually most numerous in the wildflower treatment, but that the plethora of flowers reduced the relative attractiveness of the vane traps in that setting. Similarly, crop flowers adjacent to our wildflowers might suffer from lack of bee attention.

What others have found: Our results to date seem somewhat atypical. Blaauw and Isaacs (2015) reported greater abundance of natural enemies in blueberries adjacent to wildflower plantings. Like us, McCabe et al. (2017) found that, in vacuum sampling, predatory insects did not increase in strawberries adjacent to wildflower plantings, although certain pests (such as Tarnished plant bug) responded positively. Their pit trapping (which we have not yet conducted in the vegetable beds) did suggest an increase in predators. Studying the effects of landscape context, Albrecht et al. (2021) found that adjacent semi-natural habitat which was open resulted in enhanced wild bee abundance in planted wildflower strips whereas adjacent *forested* habitat had a negative effect, presumably because forested areas shared fewer bee species with the strips.

…There does appear to be some overlap between the communities of our plantings and of adjacent farmland, but it's not necessarily extensive and one should not automatically assume the sharing of taxa between sharply distinct cover types.

The habitats we created with our management look distinct to us, but is that misleading in terms of their relevance to other creatures?

We are large, visual animals and it's easy for us to subconsciously assume that what looks very distinct to us must also be very distinct for all other organisms. Clearly, that is not the case. Our four habitat types, while sporting markedly distinct surface vegetation, apparently have not yet produced clear differentiation in soil qualities (see the accompanying botanical report, Knab-Vispo et al. 2022). Indeed, temporal trends seem to be more conspicuous than treatment effects. It should thus not be surprising that our pit trap results (Fig. 4) have suggested relatively little differentiation in the ground-dwelling invertebrates among the treatments.

One of the most marked patterns in the pit trap results occurred across years rather than treatments: figure 13 shows how ground beetles in the native meadow test plots have declined dramatically since 2017, while ants have increased. Lest one wonder if some of this reflects climatic changes or other global effects, in 2021, during pit trapping in nearby ploughed ground on the same farm, we captured 497 ground beetles and no ants! We hypothesize that, from the perspective of the ants and ground beetles, one of the most dramatic changes in our experimental plots has been the cessation of plowing, an activity that makes life of the ground-nesting ants difficult but for which a group of plowed-soil ground beetles are clearly adapted. This result is relevant as we start to explore the consequences of beetle banks. Based on these results, we predict that ground beetle abundance in the unplowed beetle bank will drift lower than that of plowed fields and, based on the species composition work described earlier, the ground beetle community in the bank may diverge from that of the plowed ground. Both of these are tendencies that would tend to reduce the agronomic benefits of beetle banks, at least in terms of any services that those beetles might provide. Creating perennial wildflower habitat in formerly plowed land changes more than just the surficial vegetation. Cessation of plowing can have profound effects on soil ecology, which is likely to alter the communities of ground-dwelling insects.

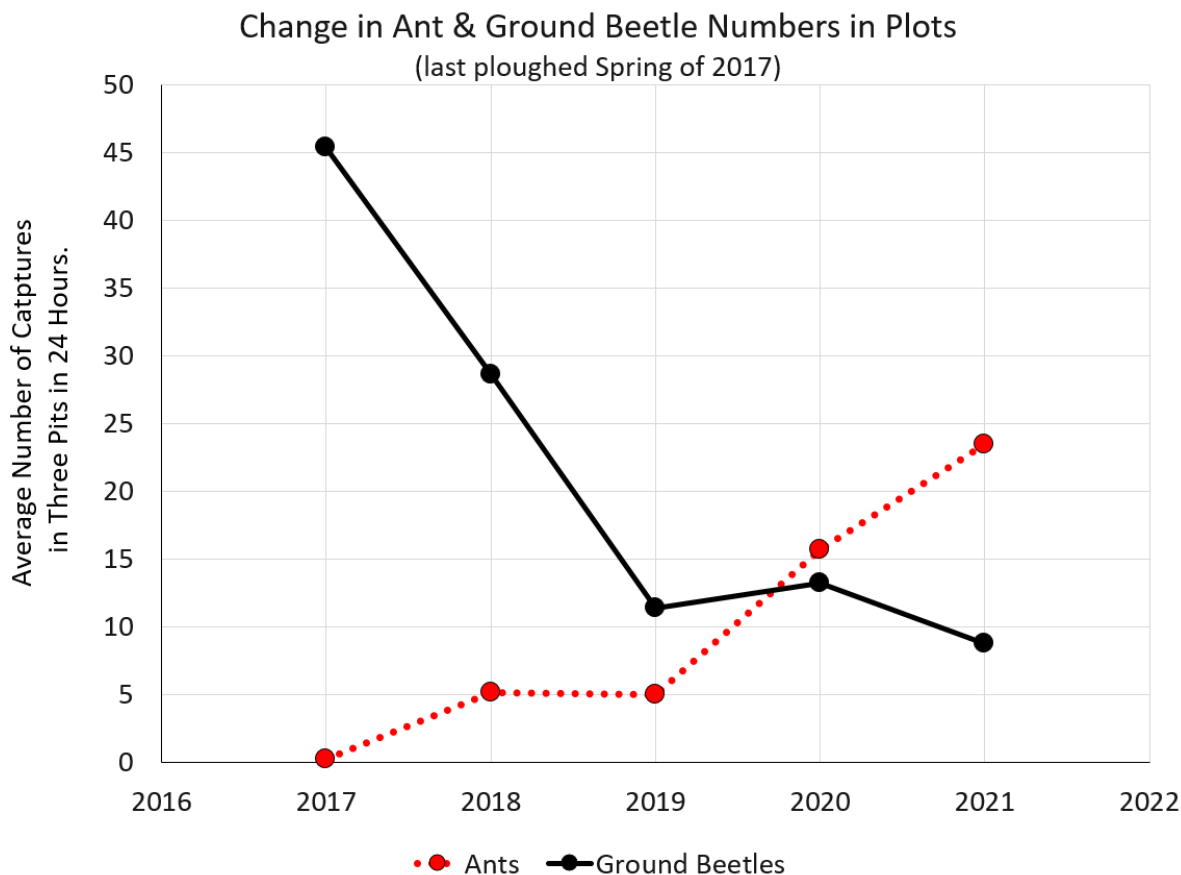Change in Ant & Ground Beetle Numbers in Plots
(last ploughed Spring of 2017)

Figure 13. The development of ant and ground beetle pit trap captures across five years. During this period, ants and ground beetles switched places in terms of abundance.

What others have found: Harmon-Threatt (2020) describes some of the effects that plowing might have on ground-nesting bees, and Albrecht et al. (2021) suggested that the reduction in bee use that they observed in aging wildflower plantings might have been due to a decrease in the bare ground sought after by ground-nesting bees. In other words, it's important to realize that even bees have habitat needs beyond flower availability.

…At least in the short term, surface vegetation may only be marginally relevant to certain organisms such as ground dwellers; other factors, such as the cessation of plowing might be more influential.

A mini case study: What do wasps look for in a habitat?

By considering the captures of other invertebrate groups and by joining our invertebrate capture results with data on floral abundance (Knab-Vispo et al. 2022), we can dig a little bit deeper into the factors affecting wasp and bee occurrence. We can also look for evidence of wasp and bee habitat preference based on flower functional traits such as color and nectar locations. This can help predict how seed mixes can be tailored to better attract particular beneficials. While this section won't get beyond correlations, these analyses might suggest some hypotheses for further exploration.

We ran a series of general liner models (glm) to identify the best predictors of bee and wasp occurrence across our samples (Appendix Tables 1-4). While there are disconcerting statistical differences between the results from our sweep netting and malaise trapping, the most consistent results across our methods were the higher wasp numbers associated with the fallow treatment and their positive association with the abundance of beetles and Lepidoptera and of white flowers. Other aspects of flower morphology and flower species identity drifted in and out of significance. The

correlation with Lepidoptera and beetles should not be surprising given that these are common parasitoid hosts, however certain other common host groups, such as aphids and leafhoppers, were not as clearly correlated with wasp abundance. Furthermore, the causative nature of these apparent host correlations is called into question by our results for bees. If one repeats similar analysis for bees, then, while the wildflower treatment and a variety of flowers (especially Early Goldenrod) do come out as being positively correlated with bee abundance, so too do Lepidoptera and beetles. Possibly there is some combination of weather and time-of-year effects that make Lepidoptera and beetles good correlates of bee (and perhaps wasp) abundance even though there is no direct cause and effect.

Our visual surveys suggest that bees and wasps do indeed differ in their flower choice (Figs. 10 and 11 in Vispo 2019). Wasps seemed to favor some of the weedier, less showy flowers that, at least initially, were associated with the our fallow treatments. These included fleabanes and Horseweed, both white-flowering species. In subsequent seed mixes we have included more of these species in the hopes of attracting more parasitoids to our wildflower plantings.

What others have found: There has been substantial work done in Europe exploring the relationships between flower functional traits and insect visitors. For example, Campbell et al. (2017) used consideration of flower functional traits to tailor multi-purpose flower mixes for attracting both pollinators and other beneficials. Hatt et al. (2018) and Hatt et al. (2020) report on the flower functional traits favoring parasitoids and generalist predators, respectively. Doug Landis and colleagues have explored multi-purpose wildflower mixes in the Midwest (https://www.canr.msu.edu/nativeplants/#native%20plants, Rowe et al. 2021). Wäckers and van Rijn (2012) review past work and present an accessible overview of these considerations. While not expressly analyzing floral functional traits, Sutter et al. (2017) reported that the abundance of certain key flower species, rather than overall floral abundance, was a key determinant of the abundance of both crop-pollinating and rare bees.

…Our understanding of the factors influencing habitat choice by wasps (and bees) is clearly still incomplete, both floral composition and the co-occurrence of other invertebrate taxa may have been influential.

Rather than assess abundance, can we index what "services" communities are providing?

One way that ecologists have worked around some of the complexities outlined above is by focusing on direct measures of services. Can we index pollination rates, parasitism, or pest predation directly, thereby avoiding assumptions based just on the presence of purported pests and beneficials? This is not simple and does not necessarily enable broad conclusions, but it does get us closer to our ultimate aim of assessing relevance for crop production.

We tried to assess consumption of pest eggs by using time-lapse cameras to record visitation to freeze-killed (to avoid pest introductions) Fall Armyworm eggs. Fall Armyworm is a major pest of corn at the Farm Hub (Anne Bloomfield pers. comm) and elsewhere in the region.
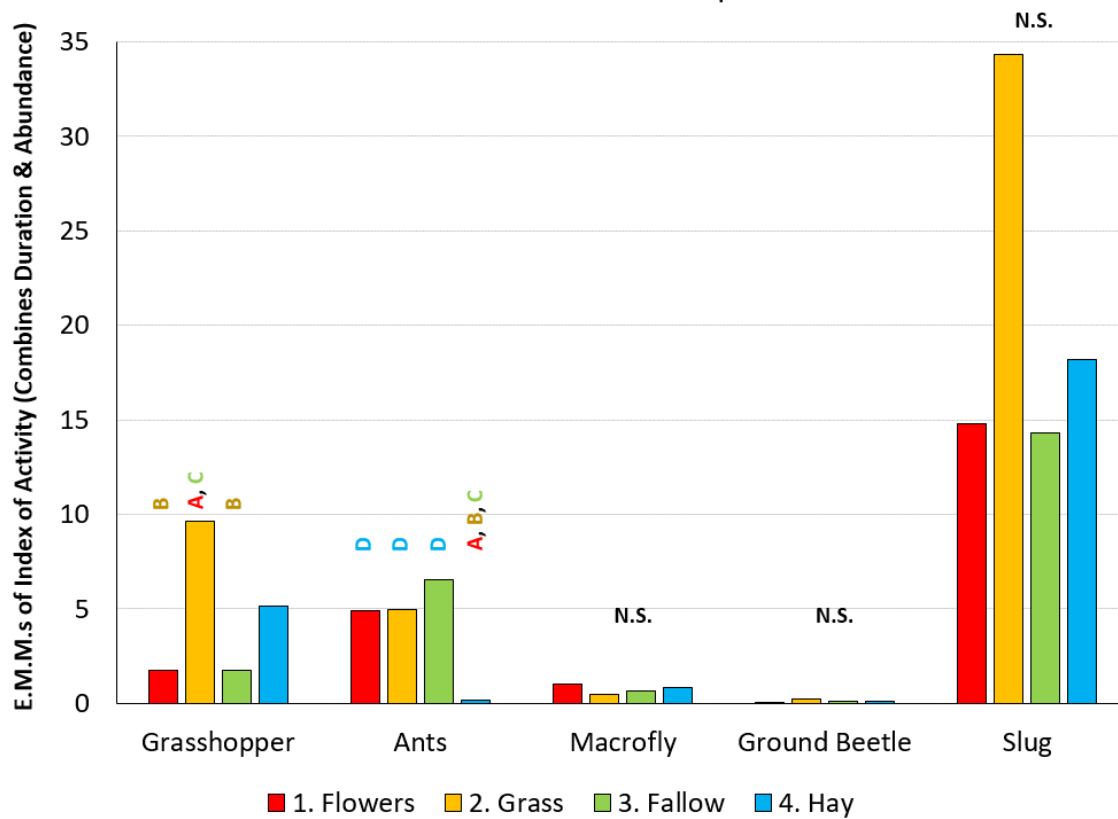
Figure 14. 2019 and 2021 visitations during 24 hours at bait stations of freeze-killed Fall Army Worm eggs presented by taxon, statistical notation as in previous bar graphs.
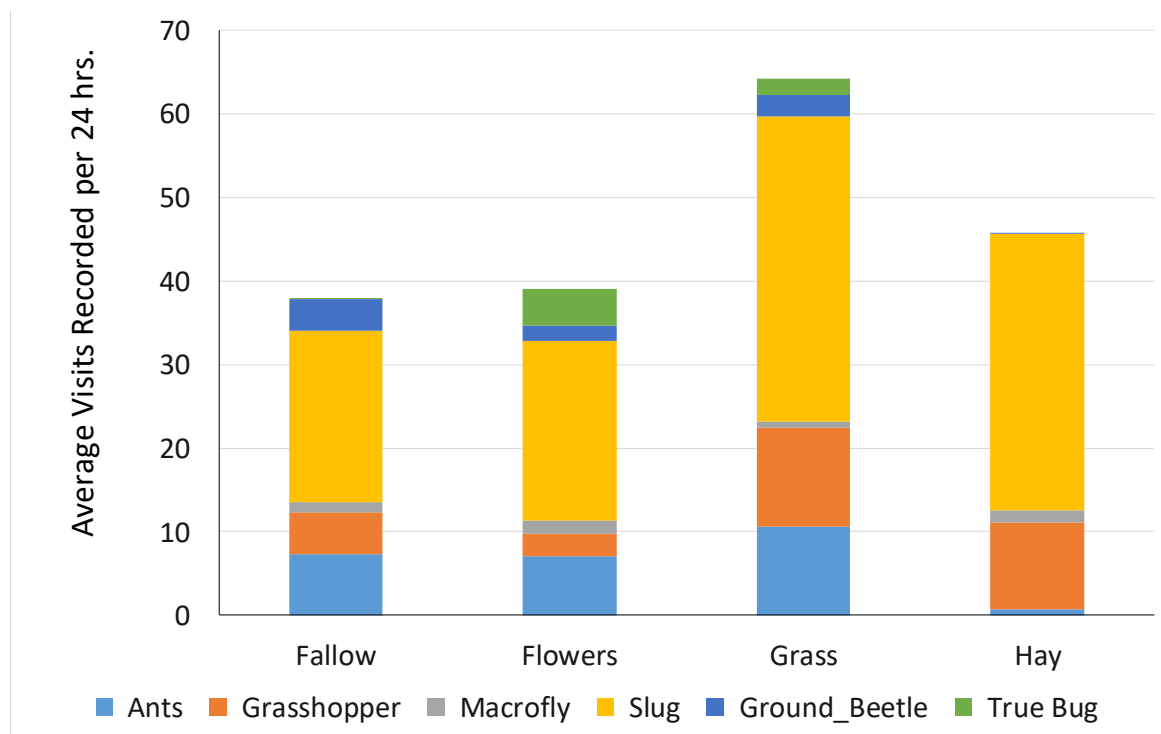

Figure 15. Proportional captures by treatment, emphasizing the high activity of slugs across all treatments.

Our results (Fig. 14 and 15) suggested that grasshopper and slug activity was highest in the grass treatment, although the latter was not statistically significant. The grasshoppers may have been more interested in the paper and cardboard that the eggs were presented on than in the eggs themselves. In general, these results seem to suggest little in terms of treatment effects, other than that ant activity was low in the hay (which parallels the low ant activity in the hay indicated by our pit trapping; Fig. 4). Perhaps more interesting is the overall composition of apparent egg predators.

Tallied across all treatments, slugs accounted for more than 50% of the observed invertebrate activity at Fall Armyworm eggs during 2019 and 2021, with ants and grasshoppers roughly tied for second place and ground beetles surprisingly absent given their abundance at the site.

Our other forms of service assessment involved our crop growouts adjacent to each treatment. First, we assessed leaf damage on corn and squash during their growth period (Fig. 16). These results still need to be analyzed statistically, but do suggest that, if anything, leaf damage was highest on crops planted next to our fallow treatments.

We also attempted to index squash pollination activity by tallying bee visitations to squash flowers (Fig. 17). Variation was large but these results suggest higher visitation to squash flowers adjacent to our wildflower plantings. This contradicts our squash weight results presented below and the vane trap results mentioned earlier, and we hope to repeat these observations in the upcoming year to see if the results hold.

Our very limited service assessments are somewhat equivocal. While leaf damage may have been lowest and flower visits highest in crops adjacent to our wildflower plots, differences were slight and our time-lapse camera work showed no clear egg-predation benefits associated with this treatment.
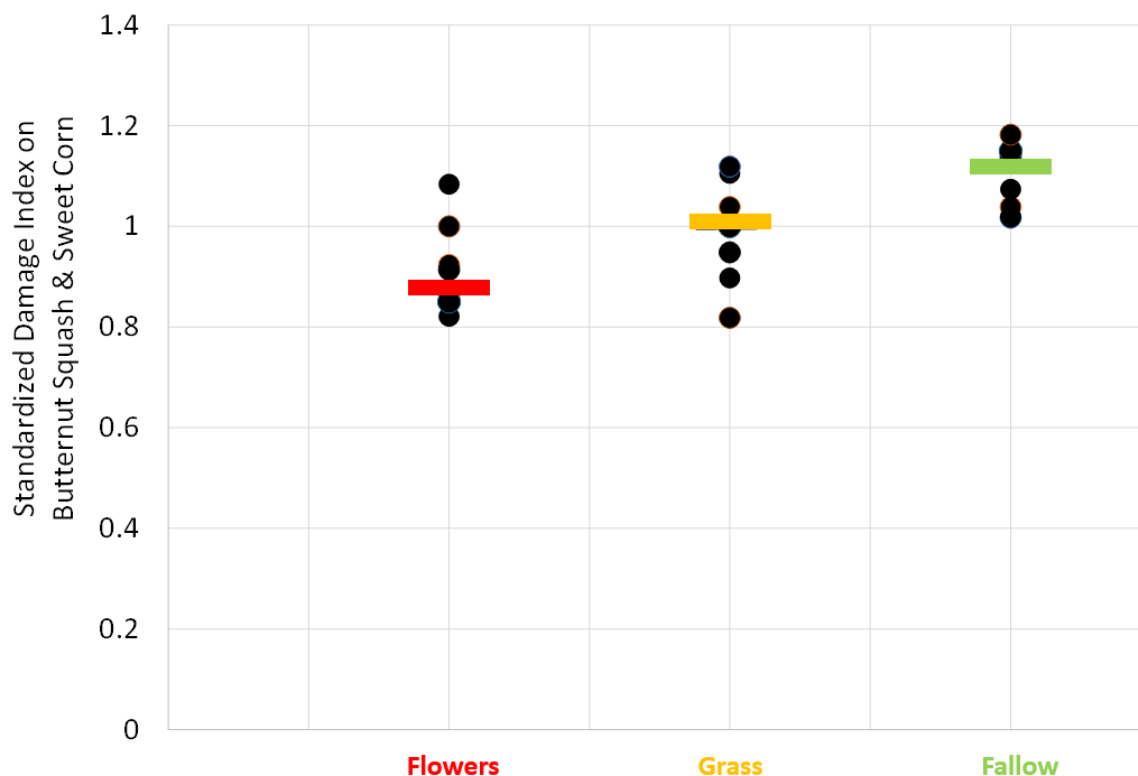

Figure 16. Average leaf damage in Butternut Squash and Sweet Corn plots adjacent to the indicated treatments. The colored bar indicates the mean for each treatment.
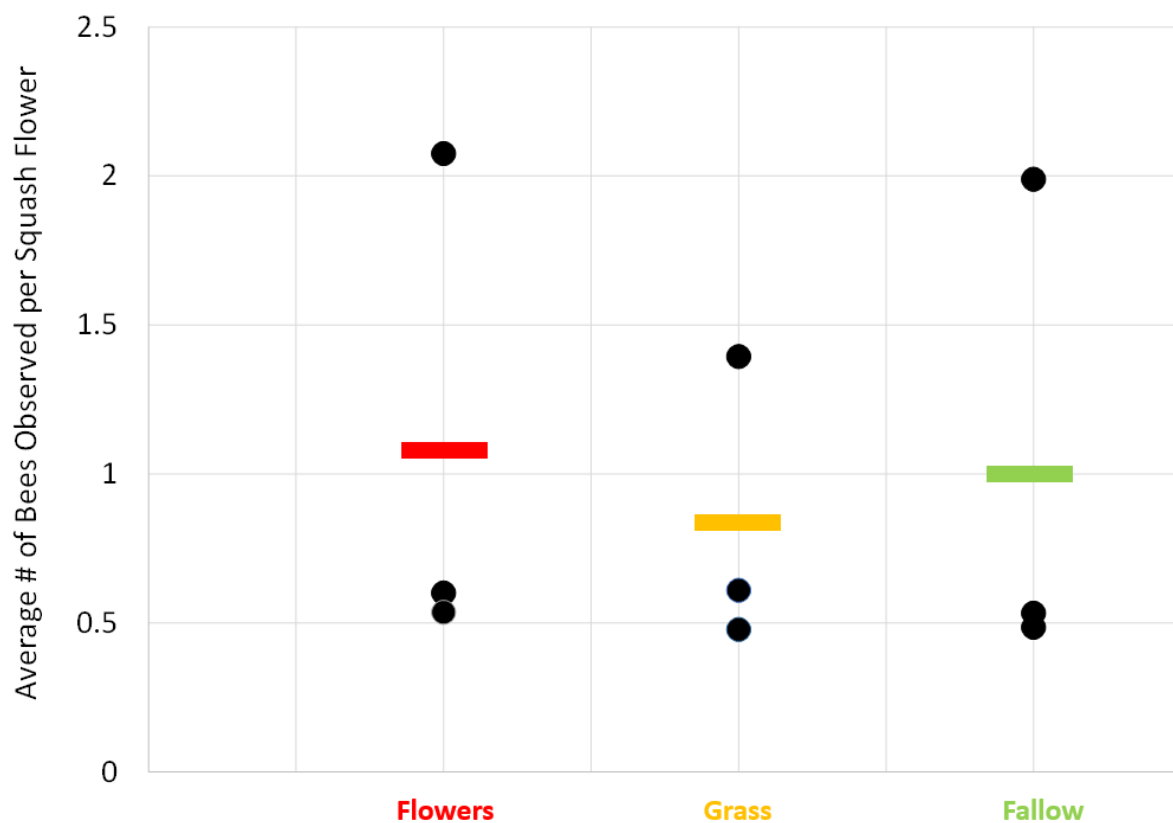
Figure 17. 2020 counts of bees observed per squash flower in beds planted next to the indicated treatments.

What others have found: Other researchers have found that wildflower plantings can increase invertebrate-mediated agroecological services and/or production in adjacent crops, at least in certain landscapes, see for example, Blaauw and Isaacs (2015) working with blueberries and Grab et al. (2018) with strawberries. Lövei and Ferrante (2017) review the use of sentinel prey as a way of measuring services. Evidence of how choice of sentinel bait affects one's results is presented by McHugh et al. (2019). The apparently beneficial role of slugs has been documented by others using time-lapse photography (Grieshop et al. 2012).

...No consistent patterns emerged as we looked at "services" from the perspective of visits to pest eggs, crop damage and crop-flower visitation.

What's the agronomic bottom line – how did crop production vary adjacent to our plantings?

Assessing crop production itself seems like the most direct way of determining the agronomic significance of our different treatments. However, this method too has its drawbacks.

For one, we cannot possibly grow all types of crops adjacent to our plots but, as we have already noted, each crop is likely to have a very particular subset of pests and beneficials that are relevant to its production. Thus, conclusions based on any one crop are really only applicable to that particular crop.

Even within crops, production techniques (e.g., scale, till/no till, spray/no spray, mono- vs poly-cropping) will also influence which pests and beneficials are most relevant to production. Simulating commercial production techniques during the growouts next to our experimental beds was not straightforward. Our squash plantings – while we used commercial organic procedures (minus any pesticide applications) – were of a substantially smaller scale than the typical

commercial undertaking; their pest conditions might therefore be expected to differ somewhat from that of large plantings. Likewise, our initial sweet corn planting involved interspersing corn and squash in a single bed. However, the corn was too sparse to allow effective pollination and, during the second year of such plantings, the corn was seeded in four rows following standard production protocols (except for pesticide use and beneficial wasp releases). Nonetheless, four rows does not a cornfield make, and pest dynamics in these relatively isolated patches might be expected to differ from those of larger fields.

Additionally, even if our plantings were able to approximately replicate production crop conditions, where, relative to our treatment plots, should we seek a result? For example, is it reasonable to expect a positive effect on plants immediately adjacent to wildflowers, given bee and hover fly abundances therein? As alluded to earlier, might wildflowers instead serve as magnates which actually create a desert of bee and hover fly activity in their immediate surroundings although, at the same time, their provisioning of these creatures might augment their overall populations and, at a larger scale, enhance crop pollination?

Finally, crop production is affected by a wide variety of factors other than the presence or absence of pests and beneficials. Disease, microclimate and soils are amongst the conditions that can have dramatic effects. In a given year, any modest effects of invertebrate activities, might be swamped by more dramatic effects due to a wide variety of independent factors. The effects of invertebrate activities might only be apparent during certain years and under certain conditions.

With these caveats in mind, we can look at our results.

Almost all corn plants produced a single harvestable cob and so cob weight (Fig. 18) was a stand-in for total production. In 2020, when relatively few corn plants were interspersed amongst squash plants, cob weight was highest next to our wildflower treatment. In 2021, when four rows were planted next to our plots, the pattern reversed, with the largest cobs occurring adjacent to the fallows. The results in table 3 suggest that tip and cob fill (indicators of pollination) have been important in determining cob weight. In 2021, when there was appreciable caterpillar damage to cobs, such damage was highest adjacent to the wildflowers.
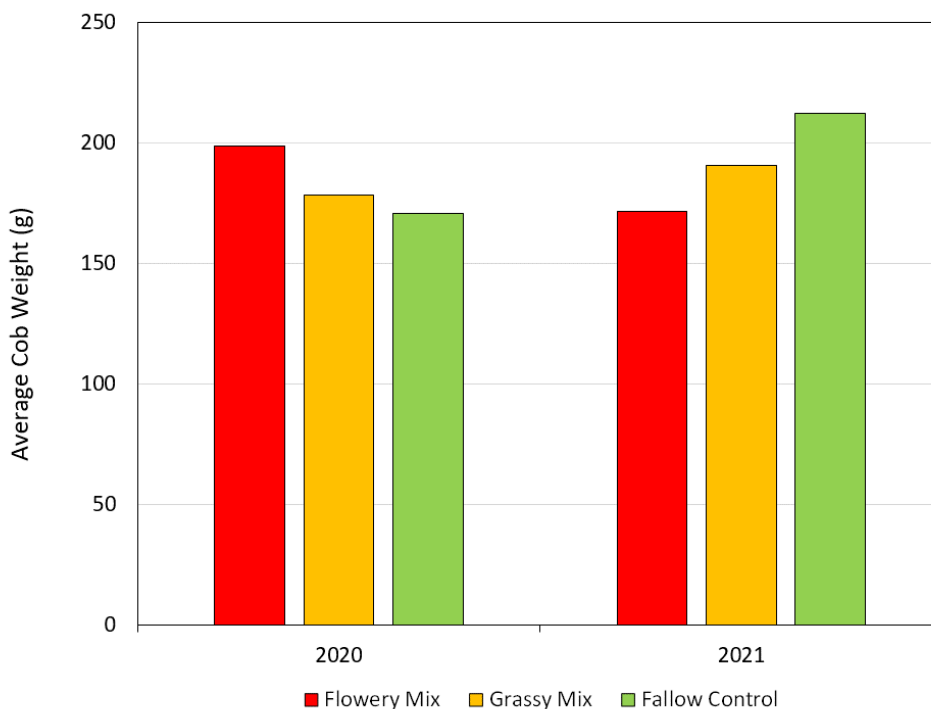

Figure 18. Average Sweet Corn cob weight in growouts adjacent to each of the indicated treatments.

Table 3. A tabular view of cob weight together with cob length, % kernel fill (at the tip and throughout), and percentage of cobs with caterpillar damage.

	Average of Lgt (mm)		Average of Wgt (g)		Average of % tip fill		Average of % cob fill		Average % Cobs showing caterpillar damage	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Flowers (A)	192.5	151.5	198.6	171.8	40	41	84	73		42
Grass (B)	192.8	164.8	178.3	190.8	30	57	77	77	negligible	39
Fallow Control (C)	190.6	158.7	170.9	212.5	39	63	69	86		29

In 2021, we also assessed cobs from commercial harvests on the same farm. Average length was 186mm, with an average weight of 243g. Tip fill averaged 79% and cob fill 94%. Only one cob in 50 had caterpillar damage. The better 'vital signs' are probably attributable to better pollination because of the larger field and to lower pest pressure due to the spraying of organic pesticides.

We weighed total butternut squash harvest from beds adjacent to each of our three core treatments (Fig. 19). Across all three years, squash harvest was highest next to the fallows. In 2021, the harvest was very low, perhaps due to a fertilizing mistake, but nonetheless, the pattern persisted. Analyzed across the three years, the treatment effect was statistically significant. The greater total harvest was attributable to both larger and more squash – in each of the years, the plots next to the wildflowers produced fewer and smaller squash than the other two treatments. Insect damage to the squash fruits did not appear to be major; most damage was from mammals.

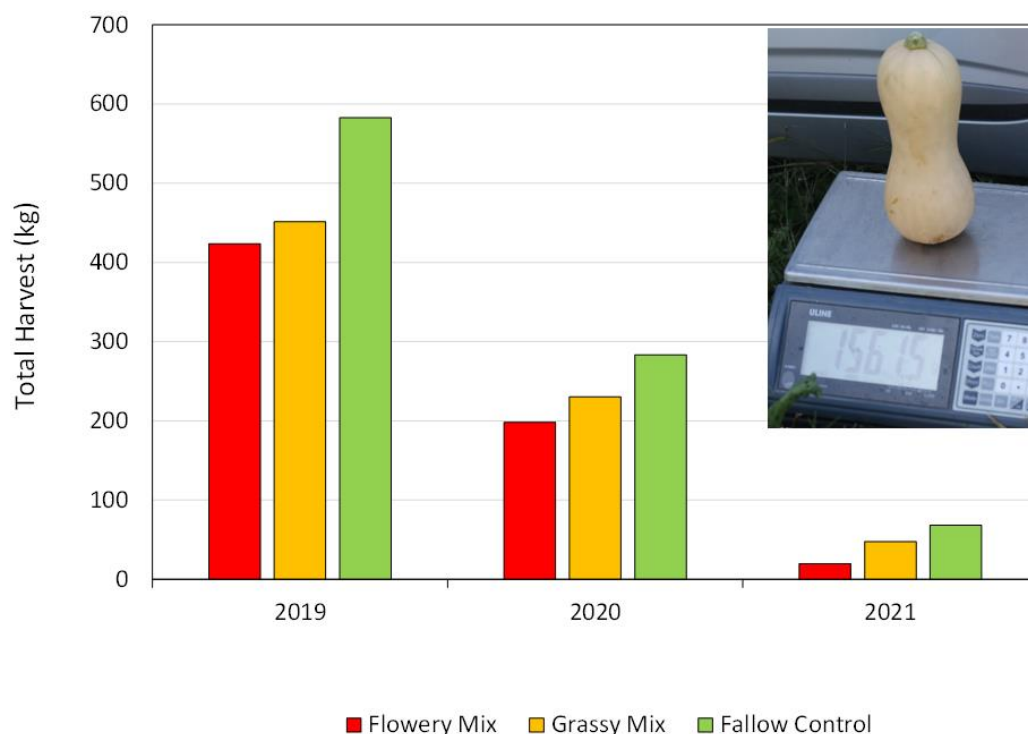Figure 19. Total Waltham butternut squash harvest in beds adjacent to the indicated treatments. In general, the higher harvests were associated with squash that were both heavier and more numerous.

It seems apparent that, at least for these two crops, managed and planted as they were, our wildflower meadows were not obviously benefiting production. This might have occurred because our wildflower treatment did not actually favor

beneficials and/or did favor pests, because the effects of these creatures on production was minimal, because we were not adequately assessing beneficial and pest activities (e.g., we should have used other crops or assessed flavor), and/or because the insect communities occurring in our meadows were not being shared with the adjacent crops.

What others have found: Similar to us, Albrecht et al. (2021), in a multi-continent review of the effects of wildflower plantings on crop production in, found no clear evidence of an effect on production, even if, as in Sutter et al. (2018), there were appreciable positive effects on measures of pollination and predation. Angelella et al. (2021) found that wildlife flower plantings increased crop set in strawberries and winter squash, but that these benefits were decreased in the presence of Honey Bees. Grab et al. (2018) noted improved strawberry production adjacent to wildflower plantings, but only in landscapes with intermediate levels of natural habitat. Intriguingly, Pywell et al. (2015) found that crop yields (wheat, rape, and field beans) improved relatively slowly with the most dramatic results only apparent five or more years after edge management (including wildflower additions).

…. There was no clear patterns in crop production adjacent to our plantings as assessed by corn growouts; if anything, butternut squash production was highest next to our fallows.

How relevant were our plantings in the overall landscape context?

At least one additional explanation for our equivocal results seems likely – our habitat installations were trivial in effect relative to the general insect abundance caused by the large amounts of semi-wild habitat in the surroundings.

As our own previous work (Vispo et al. 2015) and that of others has documented, landscape composition within 1-2 km can have an appreciable effect on a site's invertebrate community. Even this effect is likely nested within a larger one having to do with the landscape's general ability to harbor insect populations. Compared to much of the Midwest, California's Central Valley, and much of western Europe's agricultural lands, the Hudson Valley abounds in forest, edge and old field. As such, our treatment plots may have been a drop in the habitat bucket. If invertebrate communities were already relatively abundant, then the influence of our plots, even when they were adjacent to the crops, may have been minor. Our abundance results may represent very localized impacts on invertebrate distribution patterns rather than any agronomically relevant change in their populations.

Crop production is influenced by a wide variety of site factors in addition to invertebrate abundances, for example, microclimate, soil conditions, and disease pressure can all be influential, and these factors may, in our situation, dominate in determining crop growth. This is not because beneficials are irrelevant, but rather because we've already got it about as good as one is going to get it. In the All-Star Game, the outcome may not be determined by player quality (because they are all so good), but rather by the way the wind happens to blow in the 7th inning or the location of a left-field puddle. Perhaps for historical reasons, potassium averaged 20% higher in the squash plots adjacent to our fallows; this slight nutrient edge may have been enough to tip squash production in favor of those patches.

What others have found: Various authors have predicted and/or documented that habitat additions, such through wildflower planting, have the largest effect in landscapes with intermediate levels of semi-natural habitat (e.g., Tscharntke et al. 2005, Isaacs et al. 2009, Jonsson et al. 2015, Grab et al. 2018). Schmidt et al. (2008) and Martin et al. (2016) report estimates of the scale at which landscape composition affects various invertebrates. Redhead et al. (2016) noted that bumble bee foraging distances (and hence, presumably, willingness to service crops at some distance from the wildflower plantings) *decreased* as semi-natural habitat increased in the farm surroundings, presumably because the bees had less motivation to range widely. In a pan-European study, Scheper at al. (2015) found that wildflower planting impacts were significantly tied to floral characteristics of the surrounding landscape, although the effects varied amongst pollinators considered. Liere et al. (2017) described the various scales at which landscape may influence on-farm ecologies. Haan et al. (2021) try to bring the pieces together and propose design principles for landscape that favor invertebrate-mediated agroecological services.

…While wildflower plantings are concrete, localized undertakings, it is important not to lose sight of the overall value of the landscape beyond the farm fences.

Based on these considerations, which growers would we recommend perennial Wildflower Meadows to?

- Those willing to devote some time to land preparation, seeding and subsequent management. It is clear from the botanical report (Knab-Vispo et al., 2022) that if one wishes to create and maintain wildflower habitats, then substantial time needs to be devoted to site preparation and to meadow maintenance, at least during the early years. Those looking for something quick and easy had best look elsewhere.

- Those who value the wildflowers not just (or perhaps even primarily) for potential crop benefits. It is not clear that, in our landscape, modest wildflower installations will produce appreciable benefits to the crops. This does not mean that they shouldn't be planted for their aesthetic benefits nor for their ability to draw a greater diversity of life onto a particular farm. (Both effects that, for farms with on-site marketing, might benefit the customer base.) Furthermore, use of wildflower plantings to replace *extensive* but ecologically depauperate habitats (such as, the lawns of multiple back yards, of large businesses or institutions, and of solar installations) may allow such habitat to reach a scale that has an ecologically relevant impact on overall regional habitat composition and thus on regional invertebrate populations.

- Those who like watching habitats change. Related to the above two considerations, it is important to realize that, even with assiduous management, the composition of wildflower meadows does not stay constant. This can be a pleasure or headache depending on one's perspectives. If you are somebody who celebrates year-to-year variation, then wildflower meadows will add to that enjoyment; if you view change as something to be reined in, then perhaps wildflower meadows will only add to your concerns.

- Those in areas with somewhat limited semi-wild habitat in the surroundings. In Europe and North America, the case for wildflower installations seems mixed, probably in part because their relative benefits may be highest in areas where semi-natural habitat is substantially reduced but still existent. In such situations, there are still resident insect populations, but their numbers can be appreciably augmented by even relatively small installations.

- Those with pollination or aphid problems that the insects of wildflower meadows might help address. Bees and hover flies appear to increase markedly in our wildflower meadows. These creatures can benefit pollination and help control aphids, respectively. In this and other conceivable cases, farmers in our areas who are facing particular growing issues might consider wildflower plantings as a way not of increasing overall beneficial populations but of 'piping' particular beneficials to their crops. For example, springtime pollination of orchards can be an issue regionally. Increasing the abundance of in-orchard wildflowers that flower outside of fruit flowering time, but that support bees who fly during fruit flowering, might be advantageous.

- Those in systems where increasing semi-wild habitat is unlikely to markedly increase hard-to-manage weed problems or vertebrate pests. Unfortunately, 'beneficial habitat' doesn't just support beneficials, some pests also take advantage of such patches. In our experience, mammalian herbivores such as Ground Hogs and voles may be the most destructive of such newcomers. Thick thatch and undisturbed ground provide good habitat for these crop consumers. Thus, the locations of any installations should be evaluated relative to the farming system within which they're located. For example, a farmer whose crops don't attract Ground Hogs and/or who has effective Ground Hog control might consider planting wildflower meadows, either at some distance from crops (voles don't travel far) or nearer crops unlikely to be affected by vole herbivory.

….We recommend wildflower meadow plantings to those with the time, patience, and suitable aspirations, especially if they're located in landscapes with somewhat less semi-wild habitat than what we have here in the Hudson Valley.

What's next?

- Continue our monitoring of the plantings because some effects are relatively subtle and year-to-year variation due to climate and other factors is high. Few other wildflower plantings have been followed in detail for such long periods of time but, based on the few literature reports, there do appear to be important changes with time.

- Expand the variety of crops we attempt to grow next to our treatments – each crop provides a different perspective on the effects of our plantings and no one crop provides the entire picture.

- Directly explore the mortality of pests by parasitism studies and through studies of the diets of purported predators. Understanding these trophic links can help clarify what is happening in ways that 'simple' correlations cannot. This can also help link our work to that of some of the other AFERC collaborators.

- Renew our flower watches in order to get additional data on the flower preferences of wasps and bees and so improve our understanding of the factors influencing the abundances of these insects.

- Use moth lights to assess nighttime invertebrate activity in and around our plots.

- Continue to develop the multi-researcher data sets. This year we worked through important aspects of the data unification and analyses; unfortunately, we did not yet have sufficient data to say much. However, this layering of research projects has the potential to reveal patterns that none of us would see on our own.

- Undertake visual surveys for bees in squash flowers and for butterflies in all treatments. These cannot be adequately assessed by any of our current methods and yet are important for assessing pollination on the one hand and conservation value on the other.

- Use film and other media to create appealing outreach material illustrating the ecological interactions occurring in and around crop fields. Share the idea that if you favor local, ecological farming, then you should favor an ecologically intact landscape around those farms; develop ways of illustrating that idea through research.

…The analysis in this report has both indicated the value of standardized long-term data sets and the limitations imposed by such methodology. While we plan to continue our standardized monitoring, we're also hoping to explore other ecological aspects that will let us better understand the results of that monitoring and share it in more inspiring ways.

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Appendix 1. GLM models looking at the factors affecting wasp and bee occurrences in our sweep and malaise trapping. These are 'best models' based on AIC numbers.

Appendix table 1. GLM results for wasp abundance in our sweep samples. Treatment 2, 3 and 4 refer to our grass, fallow and hay treatments respectively. Treatment 1, our wildflower planting, was the reference condition. RUHI and RUTRT are the floral abundances of Black-eyed and Brown-eyed Susan. "WH" and "YE" refer to the abundances of white and yellow colored flowers. Nect_1, Nect_2 and Nect_3 are floral abundances and indicate flowers with varying exposure of their nectaries, from shallow (1) to deep (3). "All Beetles" and "All Lep" signify the abundance of all beetle and Lepidoptera captures. Details of floral abundance assessments can be found in the accompanying botanical report (Knab-Vispo et al. 2022).

```
Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)  1.447e+00  2.243e-01   6.451 1.11e-10 ***
TmtCode2    -2.243e-01  2.461e-01  -0.912 0.361989
TmtCode3     5.198e-01  2.559e-01   2.031 0.042257 *
TmtCode4    -1.873e+00  4.817e-01  -3.888 0.000101 ***
RUHI2        7.519e-05  1.816e-05   4.141 3.45e-05 ***
RUTRT        5.015e-05  1.841e-05   2.723 0.006464 **
WH           6.276e-05  1.727e-05   3.635 0.000278 ***
YE          -9.771e-06  3.721e-06  -2.626 0.008631 **
Nect_1      -6.528e-05  1.723e-05  -3.789 0.000152 ***
Nect_2       1.038e-05  4.021e-06   2.581 0.009850 **
Nect_3      -4.787e-07  1.377e-06  -0.348 0.728044
All_Beetles  4.287e-02  1.517e-02   2.826 0.004719 **
All_Lep      1.737e-01  5.515e-02   3.150 0.001635 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(0.9405) family taken to be 1)

    Null deviance: 250.93  on 164  degrees of freedom
Residual deviance: 177.67  on 152  degrees of freedom
  (33 observations deleted due to missingness)
AIC: 959.7
```

Appendix table 2. GLM results for wasp abundance in our malaise samples. See Appendix table 1 for abbreviations. In addition, "Aphid" and "Hopper" refer to all aphid and leafhopper captures. "YR" and "Month" refer to the year and month of the sampling.

```
Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)  4.126e+03  7.964e+02   5.181 2.21e-07 ***
TmtCode2     3.526e-01  1.645e-01   2.143  0.03213 *
TmtCode3     5.685e-01  1.681e-01   3.382  0.00072 ***
TmtCode4     7.593e-01  2.634e-01   2.883  0.00394 **
WH           6.428e-06  2.718e-06   2.365  0.01803 *
Aphid       -1.783e-02  8.362e-03  -2.133  0.03293 *
All_Lep      5.702e-02  2.136e-02   2.670  0.00759 **
Hopper       5.619e-03  2.803e-03   2.004  0.04503 *
Oth_Beetle   4.307e-02  9.146e-03   4.709 2.49e-06 ***
YR          -2.042e+00  3.943e-01  -5.178 2.24e-07 ***
Month       -5.340e+02  1.051e+02  -5.083 3.72e-07 ***
YR:Month     2.644e-01  5.203e-02   5.082 3.74e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(2.1319) family taken to be 1)

    Null deviance: 258.72  on 146  degrees of freedom
Residual deviance: 164.83  on 135  degrees of freedom
  (33 observations deleted due to missingness)
AIC: 1004.7
```

Appendix table 3. GLM results for bee abundance in our sweep samples. Abbreviations as described for previous tables. In addition, MOFI, ECPU, SOJU, DACA6, ERIGE2, and SOSPS4 refer to the floral abundances of Monarda, Purple Coneflower, Early Goldenrod, Wild Carrot, Fleabane species, and Showy Goldenrod, respectively. "RED_PU_PK" is the combined abundances of red, purple and pink flowers, and Tot_Flor_Abund refers to total floral abundance of all flowers.

```
Coefficients:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)    9.852e-01  1.863e-01   5.287 1.24e-07 ***
TmtCode2      -5.562e-01  2.324e-01  -2.394 0.016677 *
TmtCode3      -1.191e-01  2.257e-01  -0.528 0.597826
TmtCode4      -3.662e+00  1.035e+00  -3.537 0.000404 ***
All_Beetles    4.209e-02  1.158e-02   3.635 0.000278 ***
MOFI           1.556e-04  7.304e-05   2.130 0.033179 *
ECPU           1.563e-04  7.310e-05   2.138 0.032531 *
SOJU           7.604e-05  1.319e-05   5.766 8.10e-09 ***
DACA6          2.938e-05  1.516e-05   1.938 0.052649 .
ERIGE2         3.929e-05  2.192e-05   1.792 0.073148 .
SOSPS4         9.469e-05  2.519e-05   3.759 0.000170 ***
RED_PU_PK     -1.543e-04  7.311e-05  -2.111 0.034777 *
Tot_Flor_Abund 7.001e-07  1.394e-07   5.022 5.11e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(1.8411) family taken to be 1)

    Null deviance: 408.22  on 146  degrees of freedom
Residual deviance: 163.16  on 134  degrees of freedom
  (33 observations deleted due to missingness)
AIC: 687.03
```

Appendix table 4. GLM results for bee abundance in our malaise samples. Abbreviations are as described for previous tables. In addition, "Plot.Code" refers to which of our three replicates the sampling was done in. COLA5, CHFA2 and TRRE3 indicate the floral abundances of Lance-leaved Coreopsis, Partridge Pea and White Clover, respectively.

```
Coefficients:
                        Estimate Std. Error z value Pr(>|z|)
(Intercept)           -3.263e-01  3.777e-01  -0.864  0.38761
Plot.Code2            -5.490e-01  4.127e-01  -1.330  0.18338
Plot.Code3            -9.442e-01  4.442e-01  -2.126  0.03353 *
TmtCode2              -1.497e+00  5.587e-01  -2.680  0.00736 **
TmtCode3              -1.367e+00  5.237e-01  -2.611  0.00903 **
TmtCode4              -3.695e+01  3.355e+07   0.000  1.00000
RUHI2                  5.244e-05  1.907e-05   2.750  0.00596 **
COLA5                  5.794e-05  1.917e-05   3.022  0.00251 **
CHFA2                  5.537e-05  2.035e-05   2.720  0.00653 **
SOJU                   1.126e-04  2.252e-05   5.001 5.70e-07 ***
TRRE3                  7.411e-05  2.389e-05   3.102  0.00192 **
YE                    -5.170e-05  1.908e-05  -2.710  0.00674 **
All_Lep                1.217e-01  3.433e-02   3.547  0.00039 ***
Oth_Beetle             6.498e-02  1.564e-02   4.155 3.25e-05 ***
Plot.Code2:TmtCode2    1.437e+00  6.891e-01   2.085  0.03706 *
Plot.Code3:TmtCode2    1.067e+00  7.527e-01   1.417  0.15635
Plot.Code2:TmtCode3    1.297e+00  6.629e-01   1.957  0.05032 .
Plot.Code3:TmtCode3    1.643e+00  6.894e-01   2.383  0.01716 *
Plot.Code2:TmtCode4    3.547e+01  3.355e+07   0.000  1.00000
Plot.Code3:TmtCode4    3.457e-01  4.745e+07   0.000  1.00000
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(1.7269) family taken to be 1)

    Null deviance: 311.03  on 146  degrees of freedom
Residual deviance: 130.66  on 127  degrees of freedom
  (33 observations deleted due to missingness)
AIC: 420.25
```