Assessment of IPM HUB Strategy on the Dickinson College Farm

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Abstract

Increasing human health concerns, predicted growth of insect populations due to global warming, and increasing prevalence of pesticide resistance in insects have led to a recent surge of interest in alternatives to traditional, broad-spectrum chemical pesticides. One proposed alternative is the modification of agricultural landscapes to create habitat for beneficial insects, natural predators and parasites of pest insects. During the 2011-2012 academic year the Dickinson College Organic Farm created a series of six hubs, small ponds surrounded with native, flowering vegetation to attract and shelter insect predators and parasites. In order to assess the effectiveness of these hub habitats, a variety of tests were implemented including: comparison of families of insects found in hub vegetation with those targeted in planting; plotting of parasitized and non-parasitized tomato hornworms in tomato fields adjacent to ponds; and a series of transects, consisting of sweep net sampling, pitfall, and sticky traps, to determine the influence of ponds on spatial distribution of insects. Testing of hub vegetation showed goldenrod and cosmos to attract the greatest diversity and density of beneficial insects. Mapping of parasitized tomato hornworms showed no significant correlation ($F>0.05$) between distance from hub ponds and the presence of parasitic wasps. Results from cluster analysis, Shannon-Weaver Diversity index, and linear regressions of transect data do not suggest a pattern. From this research, it appears that further research and modifications will be necessary in order for these ponds to become an effective means of pest control.

Introduction

Background

Since the 1940s, intensive and industrialized agriculture has been becoming increasingly popular around the world (Javaid & Joshi 1995; Rodriguez & Wiegand 2009). The increasing scale of agriculture practice has generally led to the expansion of field sizes, thus simplifying landscapes and creating a loss of biodiversity that has affected most of the world (Rodriguez & Wiegand 2009). At this point, agriculture accounts for the greatest area of anthropogenic land-use on Earth (Tscharntke et al., 2005). This expansion has been driven by increasing human populations, developing technologies, and economic demand for cheap production of food (Burel et al. 1997,Tscharntke et al., 2005). As a result, many producers have switched to the production of large monocultures of high demand cash crops and an elimination of vegetated field borders to increase the efficiency of agricultural machinery (Burel et al. 1997; Lin 2011). This simplification of the agricultural landscape has led to a mass disappearance of remnant patches such as woodlots, hedgerows, ditches, and grass verges which previously provided food and shelter for a variety of beneficial insects (Le Coeur et al. 2002; Nicolls et al 1999). Among the species lost or reduced are many species of natural predators and parasites that have historically controlled pest species and have acted as pollinators (Nicolls et al 1999; Fields et al., 2008).

Instead of insect control by natural predators, modern agriculture has been hugely dependent upon synthetic pesticides (Javaid & Joshi 1995). The United States produces more than 600 million kilograms of pesticides a year, most of which is targeted at insect herbivores (Javaid & Joshi 1995). However, a number of complications in the use of pesticides have surfaced, beginning with the publication of Rachel Carson's *Silent Spring* in 1962 (Kogan, 1998). While the focus of *Silent Spring* was the influence of DDT on birds, today's agricultural concern is often centered on the increasing evolution of pesticide resistance in insects (Kogan, 1998; Vincent et al 2003). As of 2003, over 540 pest species were known to have developed resistance to at least one synthetic pesticide (Vincent et al 2003). This problem has led to widespread financial losses in the form of crop damage, increased consumption of pesticides, and the "pesticide treadmill" of attempts to develop new, effective pesticides (Hoy et al. 2000). Pest populations are also predicted to increase with global warming, because increased temperatures are likely to expand the ranges and breeding seasons of several key species (Lin 2011, Vincent 2003). Furthermore, there has been increased pressure to find alternatives to pesticides as concerns are raised about the mortality rates of non-target organisms and about increasing connections between pesticide contamination and human illness (Vincent 2003, Kogan 1998).

One proposed solution to these problems is the implementation of integrated pest management (IPM). IPM refers to the application of ecological knowledge to farm management, in order to reduce pesticide input (Kogan, 1998). Among the strategies covered by IPM is the manipulation of agricultural landscapes in order to alter the behaviors of target species (Zhender et al. 2007).

The Dickinson College Farm has adopted this approach, in the development of their IPM strategy. Specifically the farm is working to develop a conservation biological control (CBC) strategy. CBC refers to the strategy of bolstering colonization and health of natural enemies through modification of the environment (Zehnder et al., 2007; Jonsson, 2008). In this case, this has been initiated through the construction of "IPM hubs". Each "hub" consists of two main elements. The first of these elements is a 3m diameter pond that is intended to encourage colonization and act as breeding area for the American toad (*Anaxyrus americanus*) (Figure 1; Hoffman, 2011 & 2012). The second component of the hub design, which this study will focus on, is the establishment of insectaries, stands of native, flowering vegetation that are expected to attract beneficial insects by providing supplemental sources of habitat, prey, and pollen within the surrounding fields (Figure 1; Hoffman, 2011 & 2012; Norris & Kogan, 2005; Zehnder et al., 2007, Lavandero et al., 2006). These insectaries were planted in Spring of 2013.

Varieties of vegetation were chosen based on a literature search of previous CBC studies and suggestions made by local authorities (Hoffman, 2011 & 2012).

Although these hubs are fully constructed, the implementation of this program is far from over. The development of effective CBC strategy generally takes several years and requires an in-depth understanding of the local ecology of the implementation site (Landis et al., 2000; Zehnder et al., 2007; Jonsson et al., 2008). In order to maximize efficiency of the hubs, is essential to continue monitoring and adjusting the hub design. As a result, assessment of hub interactions with the farm landscape is slated to be an ongoing research project. However, for this study it is necessary to create a protocol that can be replicated in future years.

Considerations of Assessment

In their work, Landis et al.(2000) suggest five main issues that should be considered in the establishment of a successful ecosystem-manipulation based approach to pest control. These were used as the main criteria in the development of the research plan of this study.

1. ***Appropriate vegetation***

Appropriate vegetation is that which will be most effective in attracting and sustaining populations of beneficial insects (Lavendero et al., 2006; Landis et al., 2000; Fielder et al., 2008). Because many parasites and parasitoids feed on pollen and nectar, concentrations of flowering vegetation can reduce the amount of energy expended in finding food and increase food securiy, thus increasing their longevity and fecundity (Norris & Kogan, 2005; Lavendero et al., 2006). In the case of some species, such as Ladybird beetles, individuals were found to lay more eggs in patches with greater food availability (Dixon, 2000). Other factors that determine the attractiveness and utility of vegetation to parasites and predators include color, phenology of pollen production, odor, and the size of the insect's mouthparts relative to floral parts. Furtheremore, vegetation must be easy for colonizing insects to locate within a field (Lavandero et al., 2006). Stands of weeds also have benefits such as altering the microclimate of the field to make it more favorable to desired insects, creating concentrations of prey during times in the growing season when they may be scarce elsewhere, providing cover from disturbances within the agricultural field, and creating overwintering habitat (Norris & Kogan, 2005; Jonsson et al., 2008; Lavandero et al., 2006). In addition to considerations of insect interaction, it is important to avoid plant species that have the potential to become invasive or spread into production fields (Landis et al., 2000). To date there has been little research done on which plants are most attractive in insectary systems, and results would likely apply only to areas in which research was conducted (Lavandero et al., 2006).

2. *Influence of landscape modification on the behavior of predators and parasitoids*

A second issue for consideration in adding insectaries to landscape is the behavior of attracted insects. Preferably, insectary hubs should be bolstering populations of beneficial insects, which would cause a decline in the population of pests in the crops (Speight et al., 2008; Lavandero et al., 2006; Zehnder et al., 2007). However, Speight et al. (2008) have theorized that there is potential for increased populations to increase competition between beneficial insects, which may ultimately be counterproductive. As a result it is important to monitor not only the colonization of hubs by beneficials, but also their relationship with prey populations within the surrounding fields in order to determine impacts of landscape modification on predator/prey relationships as a whole (Speight et al., 2008; Landis et al., 2000).

In consideration of predator/ parasitoid behavior it is important to note that most insects have multiple natural enemies which may be in competition with one another, and that populations of many pests tend to be sporadic in both temporal and spatial occurrence (Debach & Rosen, 1991; Landis et al. 2000). However, observation of specialized parasite/prey pairs can provide a less complicated indicator of changes in behavior (Speight et al., 2008).

3. *Spatial scale of the implemented change*

While traditional pest management tends to focus at the field ecosystem level, ecological interactions take place over a variety of scales, depending on landscape composition and dispersal ability of species (Landis et al. 2000; Barret, 1992; Burel, 1997; Dauber, 2003). It has also been suggested that many of the interactions involved with CBC occur between patches, for example movement of insects from a grass strip to a field or between fields would be considered patch to patch transactions (Fielder et al., 2008). Therefore, interactions between attracted beneficials and pests must be analyzed on wider scale, as opposed to just the insectary or field level, because insect populations of the surrounding landscape, or metapopulations, determine what species will be available to colonize insectaries (Barret, 1992; Landis et al., 2000). Due to the nature of this project, spatial relationships are an important component of the success of the insectaries, which cannot be understood without multi-scale testing.

4. *Potential negative impacts of the introduced changes*

While the goal of building insectaries is to improve the health of the field ecosystem and crops, the introduction of vegetation patches into the agricultural landscape has the potential to cause damage (Norris& Kogan, 2005; Lavandero et al., 2006; Landis et al., 2000). If plants are inappropriate they may attract populations of pests, without attracting beneficials to predate them (Lavandero et al., 2006). Furthermore, there is potential for pests to establish themselves in refugia, then migrate to nearby crops (Norris& Kogan, 2005). These issues make assessment of vegetation suitability essential.

Vegetation should also be monitored to ensure that it does not disperse and become a weed elsewhere in the field and to ensure that the amount productive land being sacrificed to these habitats is within acceptable limits of the farm (Lavandero et al., 2006). Although the second issue is not a serious concern on the Dickinson College Farm, it may be a concern in getting other farms to adopt the practice.

5. ***Acceptance of the agricultural and social community into which management is introduced***

Because the strategy was willingly implemented by the Dickinson College farm, acceptance should not be a major consideration unless the strategy is found to be excessively cumbersome or counterproductive to its goal of reducing the insect population. Elements of CBC should be as unobtrusive to production and labor as possible.

Because the fifth consideration, acceptance, is likely to be best gauged verbally, this research focuses on the first four points. The goals of this research are 1) to determine whether planted vegetation is attracting insects, as predicted; the assessment of the potential negative impacts of the strategy should also be included in this investigation 2) to evaluate changes in natural enemy/prey interactions due to hub implementation 3) to assess insect populations relative to hubs at a variety of landscape scales, as insect populations and resources within the surrounding fields will determine which insects colonize the hubs (Barret, 1992; Dauber et al., 2003). Finally, this project aims to create a protocol and set a baseline for continuing assessment of CBC insectary success.

Methods and Materials

Study Site

Dickinson College Farm, is a small 50 acre, organic farm located just south of Boiling Springs, Pennsylvania (Figure 2; Dickinson College Farm, 2012). Currently, 18 acres are dedicated to livestock pasture, and 12 are under vegetable production (Dickinson College Farm, 2012). Six ponds are located among these fields, in addition to a better established irrigation pond and a children's pond (Hoffman, 2011 & 2012). Crops are rotated between fields with each season, and planting and harvesting are primarily done using tractors or human labor (Dickinson College Farm, 2012). Other IPM measures and measures for attracting pollinators found on the farm include beetle banks-corridors of unmowed vegetation-created to aid beetle movement, planted wind breaks, and a native pollinator garden (Hoffman, 2011 & 2012).

All sampling was done between September 11, 2012 and October 11, 2012, between the hours of 9am and 2pm. Each time that sampling was done between multiple ponds or along multiple transects, the sampling was completed on the same day, with exceptions as noted below for tomato hornworm transects, to mitigate potential differences caused by weather or disturbances caused by field management.

Assessment of Associations between Plants and Insects

In order to assess the influence of planted vegetation in attracting insects, insect populations were sampled at each of the hub ponds. All vegetation flowering at the time of study was identified and photographed. Insect interactions were observed and photographed. Each type of vegetation was then swept five times with a collapsible butterfly net to collect a sample of its associated insect population. A plastic cup was used to collect insects from the net and transfer them into envelopes for freezer storage.

Beneficial and pest insects found at each site were identified and compared to predictions based on Scott Hoffman's research to assess each plant's ability to attract target species, if applicable. Pests were also identified to test the potential of planted vegetation to attract unwanted species.

Tomato Hornworm (Manduca quinquemaculata (Haworth)*) Mapping*

Mapping of tomato hornworms *(Manduca quinquemaculata* (Haworth)*)* was done on the advice of Professor Betty Ferster. This test aims to examine the frequency and behavior of one of the hornworm caterpillar's parasitoids, which are several species of braconid wasp

(Braconidae spp.) and its relationship to the tomato hornworm. The braconid wasp lays 20 or more eggs in the caterpillar, and the larvae feed on the caterpillar until they are ready to pupate, at which point they form cocoons on the host's back (Altizer & Roode, 2010). This is one of the potential parasite/prey relationships that may be altered by implementation of the hub ponds. This process also serves as a test of the spatial influence of insect hubs on a field scale.

Both of the farm's tomato fields were tested and had similar compositions of tomato varieties in similar locations relative to field edges. Due to time constraints and cautions taken to prevent the potential spread of tomato blight, transects of both fields could not be conducted on the same day. Instead, tests were conducted over two days of similar weather during the last week of September.

Four transects were done in each field, at approximately the same positions in each. In the absence of a meter tape, a Garmin *e*trex GPS device was used to estimate 10m intervals (Figure 3). At each interval, GPS coordinates were recorded and the three nearest tomato plants were thoroughly searched for hornworms. Hornworms were characterized as parasitized if they were found to be hosting at least one braconid cocoon (Figure 4).

Numbers of parasitized and non-parasitized caterpillars were recorded against distance from the nearest hub pond in Microsoft Excel.

Transects

The spatial relationship between hubs and insect populations on a multi-field scale was measured through a series of transects, such as were used in landscape studies by Dauber et al. and

Burel et al. (1997,2003). Transects were placed along crop fields in three directions, moving away from hub pond 4 (Figure 5). This pond was chosen because it was the farthest pond from fields not managed by the Dickinson College Farm and was located among fields of relatively similar crops. Transects A and B were located along salad greens, while Transect C was bordered by sweet potato and cabbage. Although not completely alike these crops are all leafy and of similar height . Each transect was 70m long (half the distance to the second nearest hub pond), with samples being taken every 10m.

Data were collected from each point along the transect, using three sampling techniques, pitfall traps, sticky traps, and sweep net collection. To collect ground dwelling insects, pitfall traps were placed following the model of Dauber et al. (2003). Traps consisting of 0.5L plastic cups, buried to bring the rim level with the ground, were filled with 1cm of water and left for five days. Yellow sticky traps were placed based on the methods of Burel et al. (1997), and are of color that is highly attractive to many common agricultural pests. Each of the 30cm x10cm traps hung from a bamboo stake at 45cm from the ground and was left for a 5 day period. Traps were frozen and stored until identification over the winter. Sweep net collection was done following the same methods as the vegetation samples. Five sweeps were done at each site to examine the insects in the plant life.

Data Processing and Analysis

All insect identification was done during the winter following the study period. Frozen specimens were identified using a Nikon SMZ645 stereomicroscope and a variety of field guides, including Simon & Schuster's Guide to Insects, *The Audubon Society Field Guide to North American Butterflies* (Pyle, 2001) , *A Field Guide to the Beetles of North America* (White, 1983), *Kaufman Field Guide to Insects of North America* (Eaton & Kaufman, 2007), as well as the Butterflies and Moths of North America website (Opler et al., http://www.butterfliesandmoths.org).

Data were organized and graphed using Microsoft Excel. IBM SPSS was used to conduct a cluster analysis on transect data, and linear regressions of insect population distributions along transects were performed using Graphpad Prism.

Results

Vegetation Analysis

The composition of flora at each pond varied greatly (Table 1). Ponds 1, 5 and 6 were found to only have three species blooming each. Pond 5 had the largest amount of flowering vegetation, however it was dominated by cosmos (Figure 6). Ponds 2 and 3 had the greatest variety of blooming flora with six species each. Of the twelve species found in bloom during the study, in early October, only cosmos was found at all six ponds.

Of the flowering plants found at the hub ponds during the study period, many were not those for which Hoffman had predicted specific species relationships (Table 2). For those species that were listed as having target species (brown-eyed susan, cosmos, and goldenrod), only goldenrod was found to be attracting one of its beneficials, the tachinid fly. Cosmos were found to be attracting the highest diversity of beneficial insects. White aster was also found to be associated with a wide variety of beneficials. For both of these species, the majority of beneficials found were pollinators rather than predators and parasitoids, although tachinid flies, syrphid flies, braconid wasps, and a praying mantis were found. On the other hand, yarrow was found to be attracting a large variety of pest insects, but was only found to be attracting one beneficial, the tachinid fly.

Tomato Hornworm (Manduca quinquemaculata) Mapping

Mapping of the presence of wasp chrysalises based on distance from the nearest hub pond revealed a largely random pattern (Figure 7). For both fields there appears to be a peak population of parasitized hornworms around 60-70m from the nearest hub. However, statistics values for these trend lines did not suggest that this correlation was significant, and the two transects do not share patterns over changing distance.

Transects

To determine whether populations of individual families were displaying a spatial relationship with the pond, populations several key predator and pest species were graphed and analyzed with linear regression (Figure 9). Aphids (Aphidae), lady beetles (Coccinellidae), leaf hoppers (Cicadellidae), assassin bugs (Reduviidae), braconid wasps (Braconidae), and leaf beetles (Chrysomelidea) did not exhibit any perceivable spatial pattern.

Comparison of the population of lady beetles and aphids also showed no pattern between densities of predators and prey (Figure 9).

Miridae, tarnished plant bugs and other mirid, populations along Transects B and C were found to have a significant spatial relationship to the pond (Figure 10). Populations of Transect B were found to decrease with distance from pond. On the other hand, populations along Transect C followed an inverse pattern, increasing with increasing distance from the ponds. Although statistically insignificant, Transect A seemed to follow a similar pattern to Transect B, declining in population with increasing distance. Because the results Transect A are statistically insignificant and Transects B and C are opposing, there is some potential that these results are statistically significant only by chance.

Insect populations based on all three sampling methods were clustered based on insect population structure (Figure 11). Midges, *Chironomidae*, were excluded from analysis as they were not a group of interest, and their numbers were high enough to skew results. From the cluster analysis, it appears that distance from the pond has little effect on relationship. Very few sites demonstrated close levels of relationship. Of those, two were points from the same transect, but were not consecutive. Pairs with a lesser degree of relationship were occasionally found to be consecutive transect points, however these were often found to at the same level of relationship as points of different transects of and different relative distances. The first three points of Transect C were found to be less related than most sites and were loosely clustered together. A10m, A50m, and B30m were found to be the points least related to most other sites. As there was not a strong correlation between points on the same transects or between sites that are the same distance from the pond, it appears that populations of different families of insects are randomly distributed, at least in relation to the pond.

Diversity of the insects at each site was calculated using the Shannon-Weaver Index, which is based on number of families and the evenness of their occurrence (Figure 12, Table 3). Index values between the different sites varied by only 0.6. Diversity does not appear to follow a strong pattern based on distance from the hub. The point of highest diversity was located at A70m, while the point of lowest diversity was found at A10m, followed by B60m.

Discussion

From the results of the vegetation analysis it is not clear whether the current vegetation of the pond is appropriate. Vegetation sweeps showed that, while the insectary hubs were largely successful in attracting pollinators, many of the predicted natural enemies were not present on the planted vegetation. This could be caused by a variety of factors. Flowering vegetation was not found to be particularly dense, with the exception of cosmos. Likewise with the exception of cosmos, types of flowering vegetation were inconsistent between ponds. While this was done intentionally, a greater degree of flower density and variety repetition might be necessary to attract and support beneficial insects from the surrounding landscape (Hoffman 2012).

Another consideration is the short sample period of this study. Samples for this test were taken in early October, the end of the blooming season. While this is an important time period for the hubs, due to the decrease in available food in the surrounding landscape, it is possible that the hub flora was not sufficient enough to warrant high insect activity or that insect activity was slowing due to cooler temperatures and shortening photoperiods.

Furthermore the potential influence of the insectaries in the current year may have been influenced by the timing of their establishment (Zehnder et al., 2007). Final transplants of pond vegetation were completed in May of 2012. As a result, they had been in place for less than a growing season, reducing the amount of time in which they were available for colonization. Studies have suggested that it may take at least two years for hubs to establish themselves and become more attractive insect colonization after the first year (Zehnder et al., 2007: Fiedler & Landis, 2007). As vegetation matures, spreads, and becomes better established within the landscape, it will potentially increase in its suitability for attracting insects. The native pollinator garden, an established insectary approximately 75m from the end of Transect C, could potentially influence insect populations in the areas of transect farthest from the hub. Furthermore, this area has the potential to act as a source of colonizing insects, or conversely, act as a more appealing food source, attracting insects away from the hub.

Consistent with the relatively low numbers of natural enemies found on hub vegetation, analysis of parasites within tomato hornworms showed no significant or discernible spatial patterns. This suggests that the ponds are not yet influencing parasitic wasp populations or distributions. This relationship may, however, may change based on the season. Presence of parasite cocoons reflect the populations of adult wasps multiple weeks beforehand (Altizer & de Roode, 2010). Therefore, the results that were recorded reflect the hub's effectiveness from several weeks prior to sampling; however, in this case, hub ponds may have been inefficient even with the vegetation from earlier in the season. Furthermore, braconids and hornworms are present throughout the tomato season, so relationships from earlier in the season are not represented by this research.

As with the results of tomato hornworm mapping, results of transect sampling did not show a significant relationship between distance from the hub and distribution or diversity of insect populations. If the pond were having a strong influence over insect populations, one would expect to see shifts in the concentration of insect populations closer to ponds. Again, this is a pattern that may change as ponds become better established. However, it is also possible that vegetation will be found to be ineffective, and will require modification in order to influence insect distribution.

Results from the analysis of Myridae populations suggest some inconsistencies between Transect C and Transects A and B. Its Myridae populations followed an opposite distribution pattern to those of Transects A and B. As A and B were located along salad greens while C was located along sweet potatoes and cabbage, it is possible that the differences in Transect C are the result differences in the vegetation along transects. If this is the case it may suggest that crop type will have a greater influence over insect distribution within the landscape than relative location to hub ponds will. This is consistent with previous studies which have shown that CBC strategies are often less effective or ineffective in diverse agricultural landscapes (Jonsson et al, 2008).

Suggested Future Research

This project will require a great deal more research to create an effective IPM strategy. As mentioned earlier, this study covered a relatively small portion of the growing season. In order to gain a more complete understanding of the results of the implemented insectaries, it is necessary to track changes in insect dispersal, survival of planted species, and phenology of the insectaries over the course of several seasons, preferably from early spring to late autumn. It would also be useful to assess use of hubs for overwintering. This could potentially be done by counting egg cases, such as those left by praying mantis, or looking for insects buried in the soil.

Another means of strengthening assessment of the ponds would be to conduct multiple repetitions of hornworm mapping over the course of the season. This would make it possible to use mathematical models such as the Nicolson-Bailey Model to better represent and explore population dynamics between the tomato hornworms and their associated parasitoid wasps.

Other modifications that could be made to improve the quality of this study design would be experimentation and more extensive research on the dispersal abilities of target species. This information could then be used to set transects at a scale that would be most indicative of species dispersal. Also, closer study of the phenology and lifecycles of target species could be combined with knowledge of plant phenology to improve the utility insectaries as a site for egg deposition, acquisition supplemental food, and overwintering.

Conclusions

Based on results of vegetation analysis, mapping of braconid wasp cocoons on tomato hornworms, and analysis of populations along transects away from IPM hubs, it appears that, as of September and October 2012, this management strategy was not effective in altering composition of parasitoid and predatory insects within the fields of the Dickinson College Farm. It is possible that effectiveness will improve over time. However, it is more likely that the design will require a variety of changes in vegetation and composition in order to achieve its purpose of reducing pest insect populations. In order to make these modifications in an informed manner, future monitoring and research of plant and insect interactions are essential.

In many ways these results are consistent with IPM work being done around the world. Unlike chemical pesticides, these strategies are not broad spectrum. They are often highly specific to their landscape or region, and require a high level of ecological understanding to implement. There are a wide variety of variables ranging from insect vegetation preferences to the influence of landscape which must be considered, which remains an obstacle in the widescale establishment of such practices. However, as the ecological, economic, and human health impacts of traditional chemical pesticides gain attention, there if a potential that an increasing number of farmers will be willing to invest the time and resources into developing and perfecting these programs.

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Appendix

Tables

Table 1. Flowering Vegetation identified at hubs early October.

Pond	Common Name	Scientific Name
1	Cosmos	*Cosmos spp.*
	Goldenrod	*Solidago Canadensis* L./ *nemoralis* Aiton/*gramnifola*
	Yarrow	*Achillea millefolium* L.
2	Bee Balm	*Monarda didyma* L.
	Black-eyed Susan	*Rudbeckia laciniata* L.
	Cosmos	*Cosmos spp.*
	Lady's Thumb	*Polygonum persicaria* L.
	White Aster	*Aster ericoides* L.
	White Campien	*Silene latifolia* Poir.
3	Cosmos	*Cosmos spp.*
	Daisy	*Aster bellis*
	Goldenrod	*Solidago Canadensis* L./ *nemoralis* Aiton/*gramnifola*
	Hissop	*Agastache neptoides* (L.) Kuntze
	Lady's Thumb	*Polygonum persicaria* L.
	Yarrow	*Achillea millefolium* L.
4	Black-eyed Susan	*Rudbeckia laciniata* L.
	Boneset	*Eupatorium perfolatorium* L.
	Cosmos	*Cosmos spp.*
	Hissop	*Agastache neptoides* (L.) Kuntze
	Red Clover	*Trifolium pratense* L.
5	Cosmos	*Cosmos spp.*
	Hissop	*Agastache neptoides* (L.) Kuntze
	Yarrow	*Achillea millefolium* L.
6	Cosmos	*Cosmos spp.*
	Hissop	*Agastache neptoides*(L.) Kuntze
	Red Clover	*Trifolium pratense* L.

Table 2. Vegetation found at ponds and associated insects. Target beneficials are based on Hoffman 2012.

Common Name	Scientific Name	Target Beneficial	Beneficials Found	Pest Species Found
Beebalm	*Monarda didyma* L.		Bumble bee	leaf hopper, thrip
Boneset	*Eupatorium perfolatorium* L.		syriphid fly	
Brown-eyed susan	*Rudbeckia laciniata* L.	wasps, beetles	small milkweed bug	
Cosmos	*Cosmos spp.*	Lacewings, mantis, aranae,syrphid flies, chaclid wasps	braconid wasp, bumble bee, honey bee, milk weed tussuck moth, mound ant, tachinid fly	aphid, stink bug, flea beetle, leaf beetle, leaf hopper, tarnished plant bug,
Daisy	*Aster bellis* Krause		tachinid fly	
Golden-rod	*Solidago Canadensis* L./ *nemoralis* Aiton/*gramnifola*	lacewings, tachinid flies	tachinid fly, braconid wasp	green stink bug,slant faced grasshopper tarnished plant bug
Yellow giant hyssop	*Agastache neptoides* (L.) Kuntze		tachinid fly	
Lady's Thumb	*Polygonum persicaria* L.		braconid wasp, tachinid fly	aphid, shining leaf chafer beetle, tarnished plant bug
Red Clover	*Trifolium pratense* L.		syriphid fly	aphid, carpenter ant, gnat, green stink bug, leaf hopper
White Aster	*Aster ericoides* L.		tachinid fly, praying mantis, bumble bee, honey bee	three lined potato beetle
White campion	*Silene latifolia* Poir.		tachinid fly	aphid, gnat, tarnished plant bug, thrip
Yarrow	*Achillea millefolium* L.		tachinid fly	brown stink bug, flea beetle, gnat, leaf footed bug, leaf hopper, mosquito, spotted cucumber beetle, tarnished plant bug

Table 3. Shannon Weaver Diversity of insect family diversity based on distance from hub. Higher Shannon-Weaver values indicated that insect populations have more families and that individuals are more evenly distributed among families.

Shannon Weaver Diversity			
Site	A	B	C
0m	2.008308	2.160985	2.369425
10m	1.925659	2.221301	2.168259
20m	2.109573	2.375289	2.123175
30m	2.333596	1.941916	2.373731
40m	2.373181	2.260801	2.164259
50m	2.184107	2.104668	2.222781
60m	2.143491	1.928272	2.421022
70m	2.527377	2.377479	2.352102

Figures

Figure 1. Integrated pest management hubs composed of 3m diameter ponds and native, flowering vegetation. Photos taken in Mid-September.

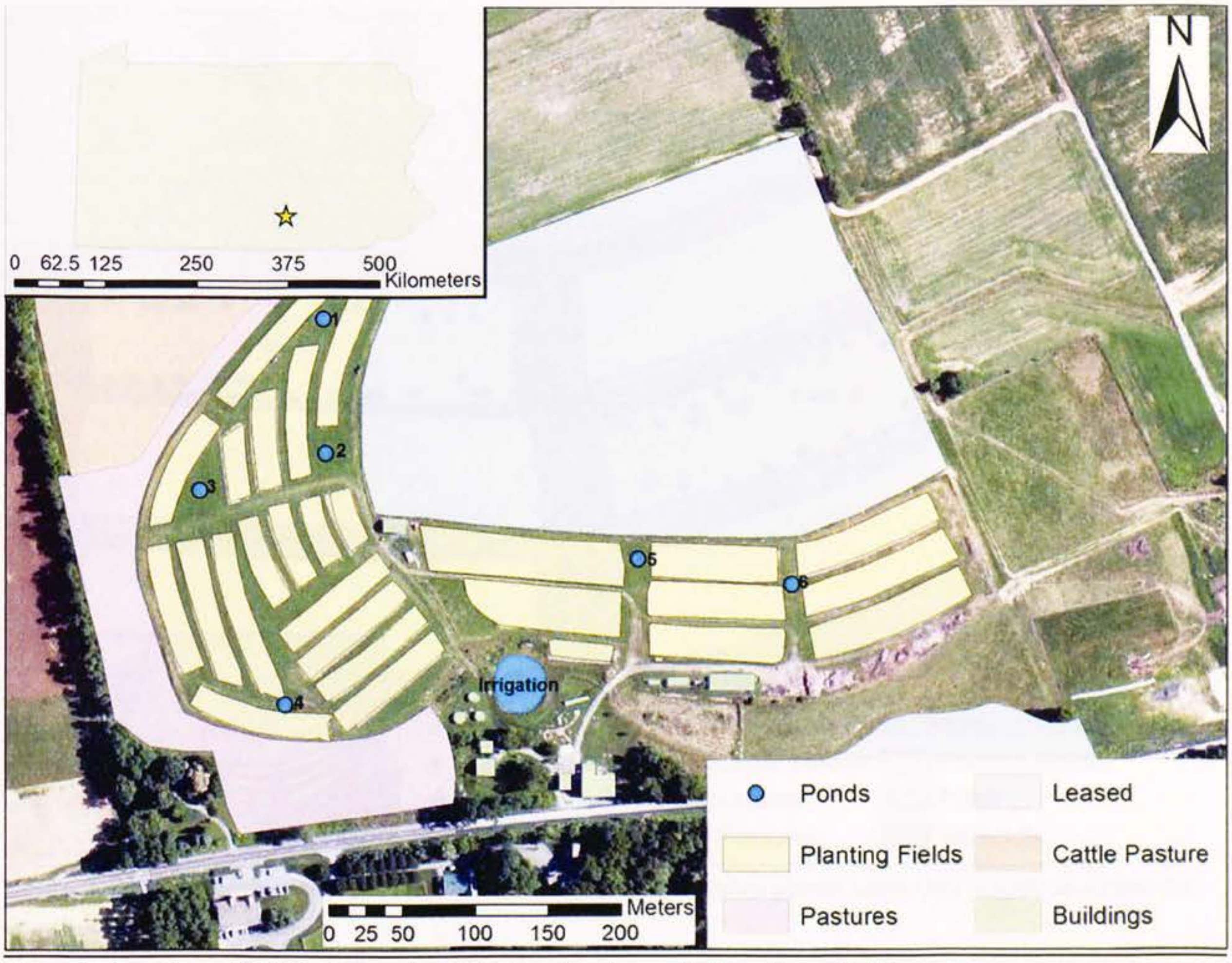


Figure 2. Location of IPM hub ponds within the Dickinson College Farm Fields.

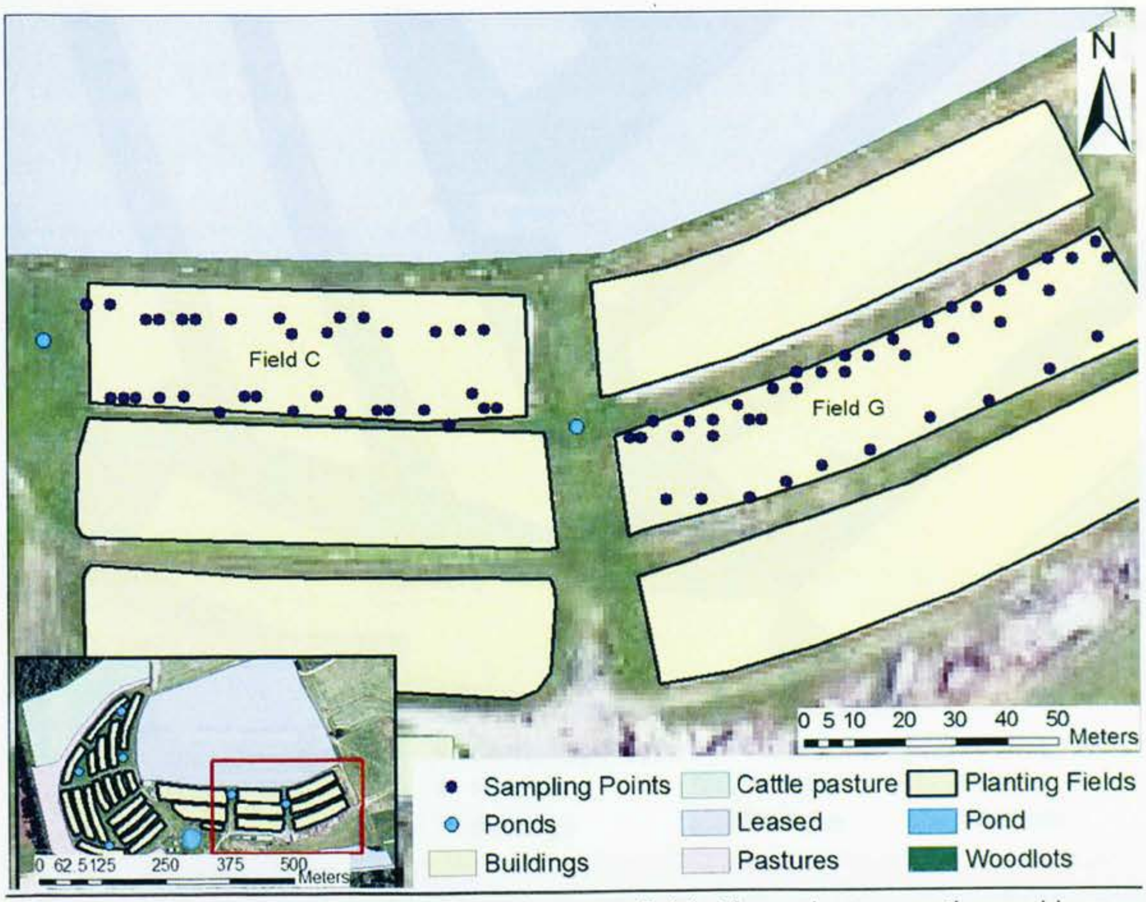


Figure 3. Data Collection points in the farm's tomato fields. Three plants were thoroughly searched for hornworms at each point.

Figure 4. Tomato hornworm with wasp cocoons.

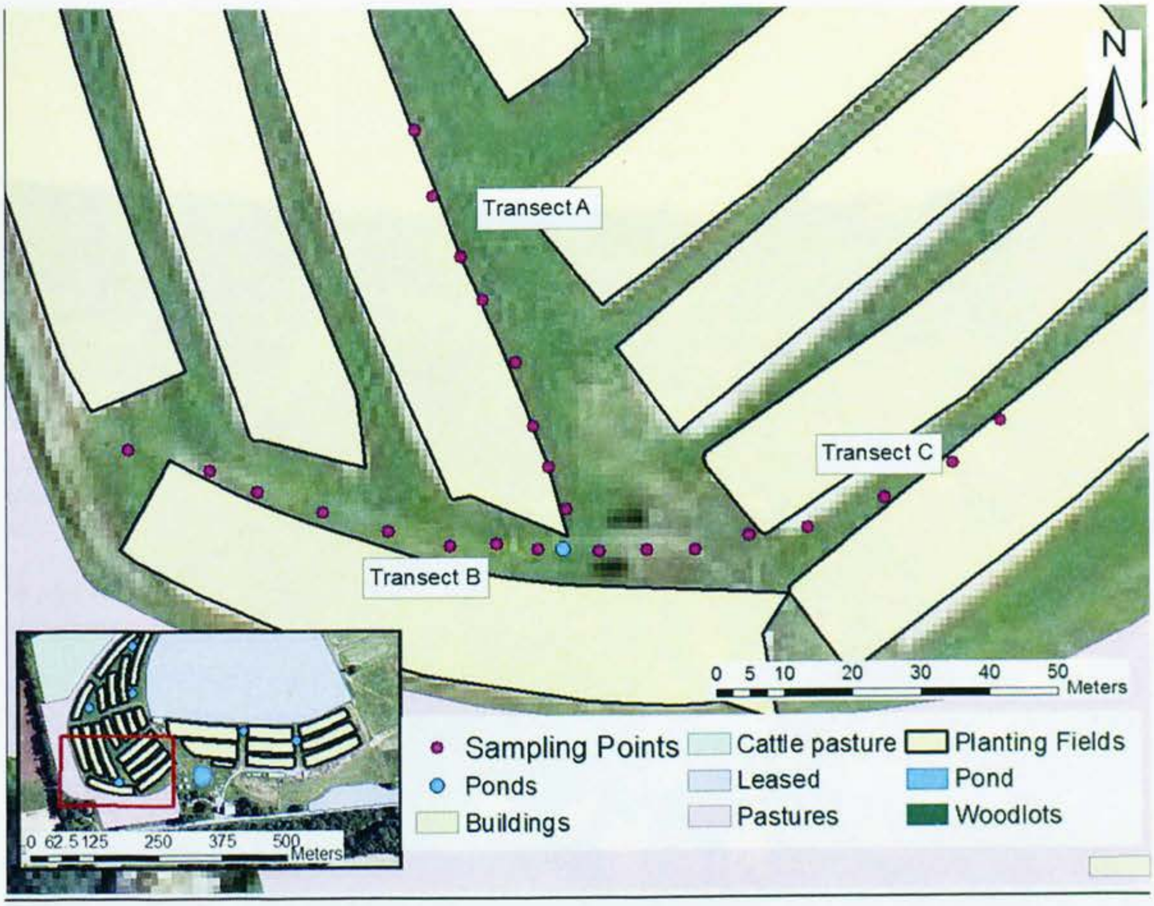
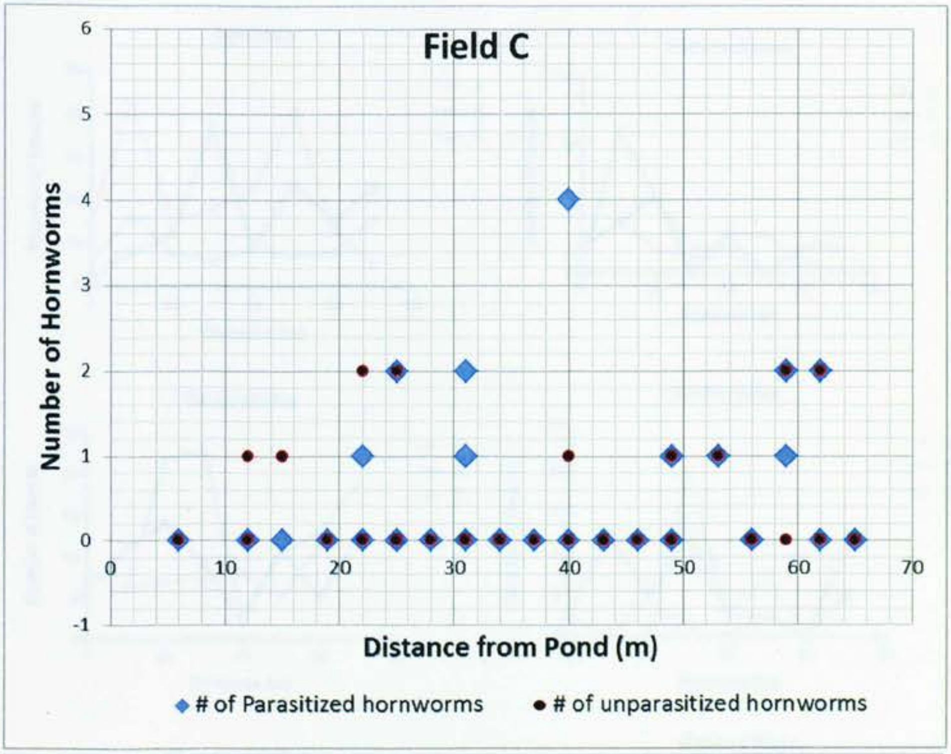


Figure 5. Data collection points along transects A, B, and C.

Figure 6. Large stand of cosmos at pond 5.



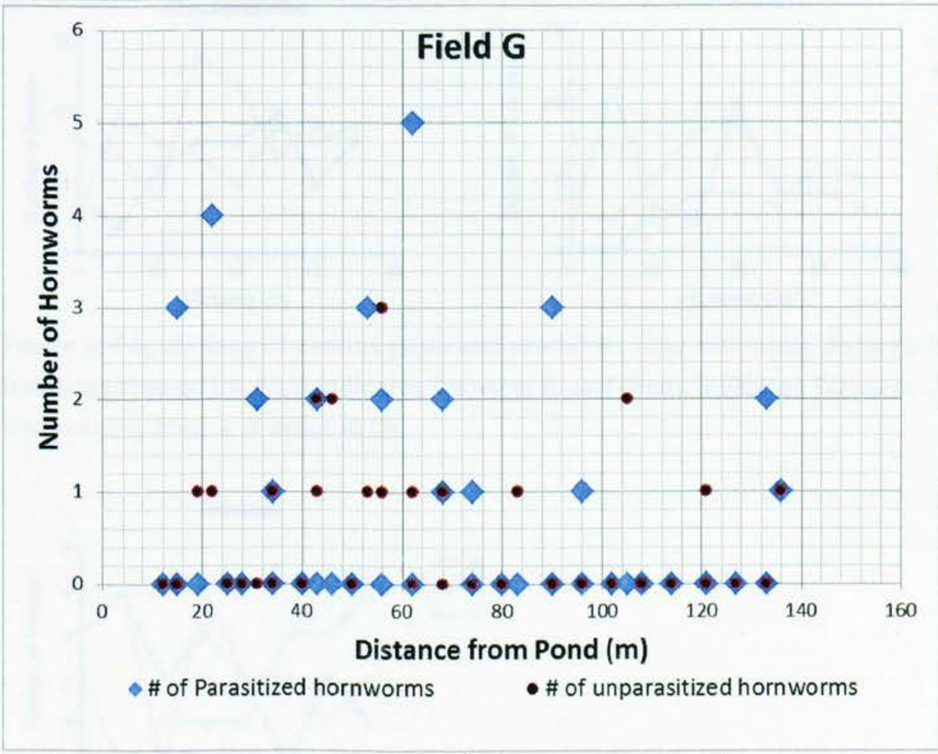


Figure 7. Comparison of presence of brachonid cocoons, based on distance from nearest hub. Patterns displayed a largely random. For all linear regressions: F Value>0.05, R^2<0.5, P Value>0.05.

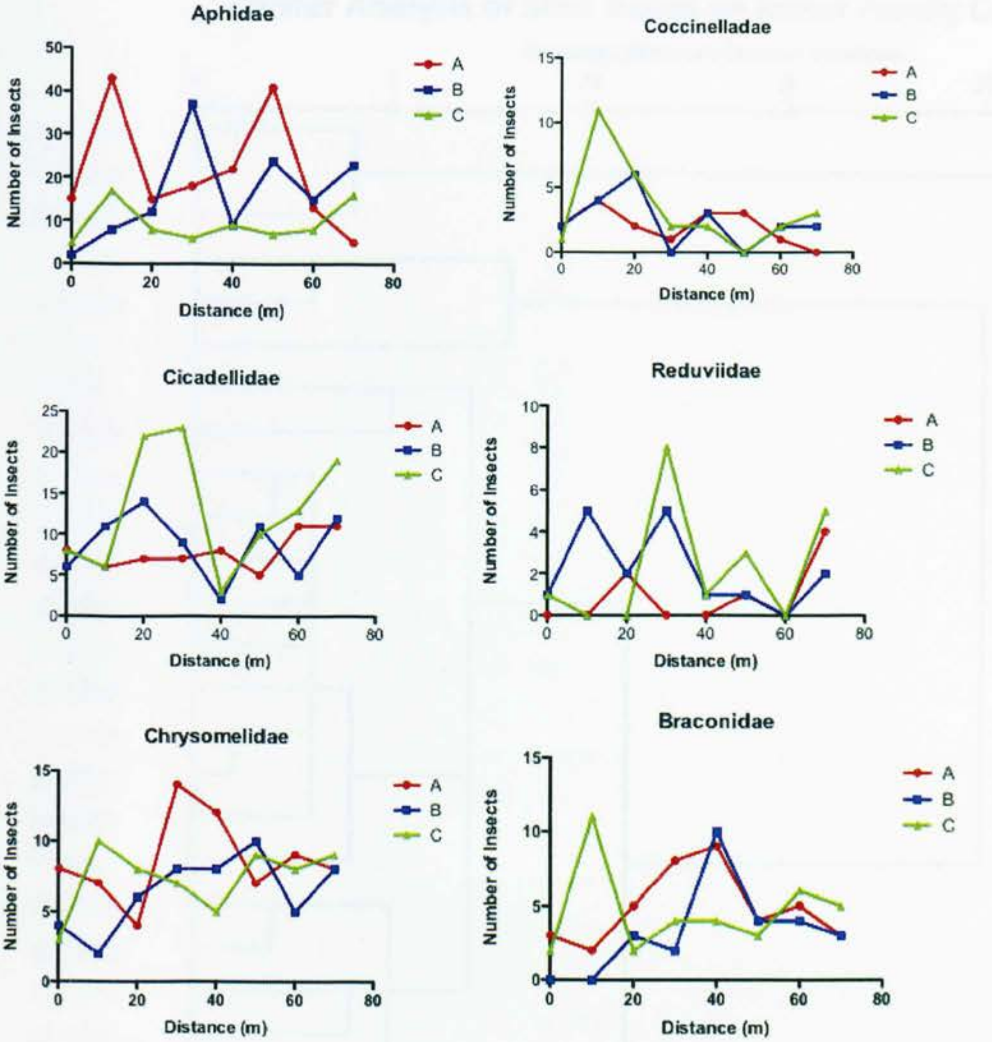


Figure 9. Populations of various pests and predators over increasing distance from hubs. The red line indicates Transect A, blue indicates Transect B, and green indicates Transect C. For all regressions, F Value>0.05, R^2<0.5, P Value>0.05.

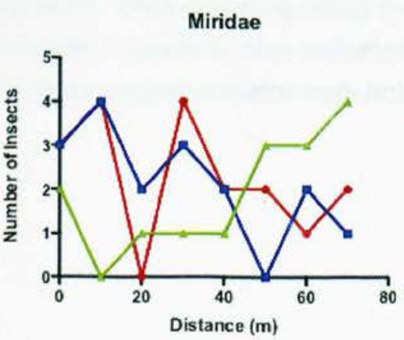


Figure 10. Miridae over increasing distance from hub. Transect A: F=1, P >0.05; Transect B: F =6.658, P=0.0417; Transect C F= 7.836, P=0.0312.

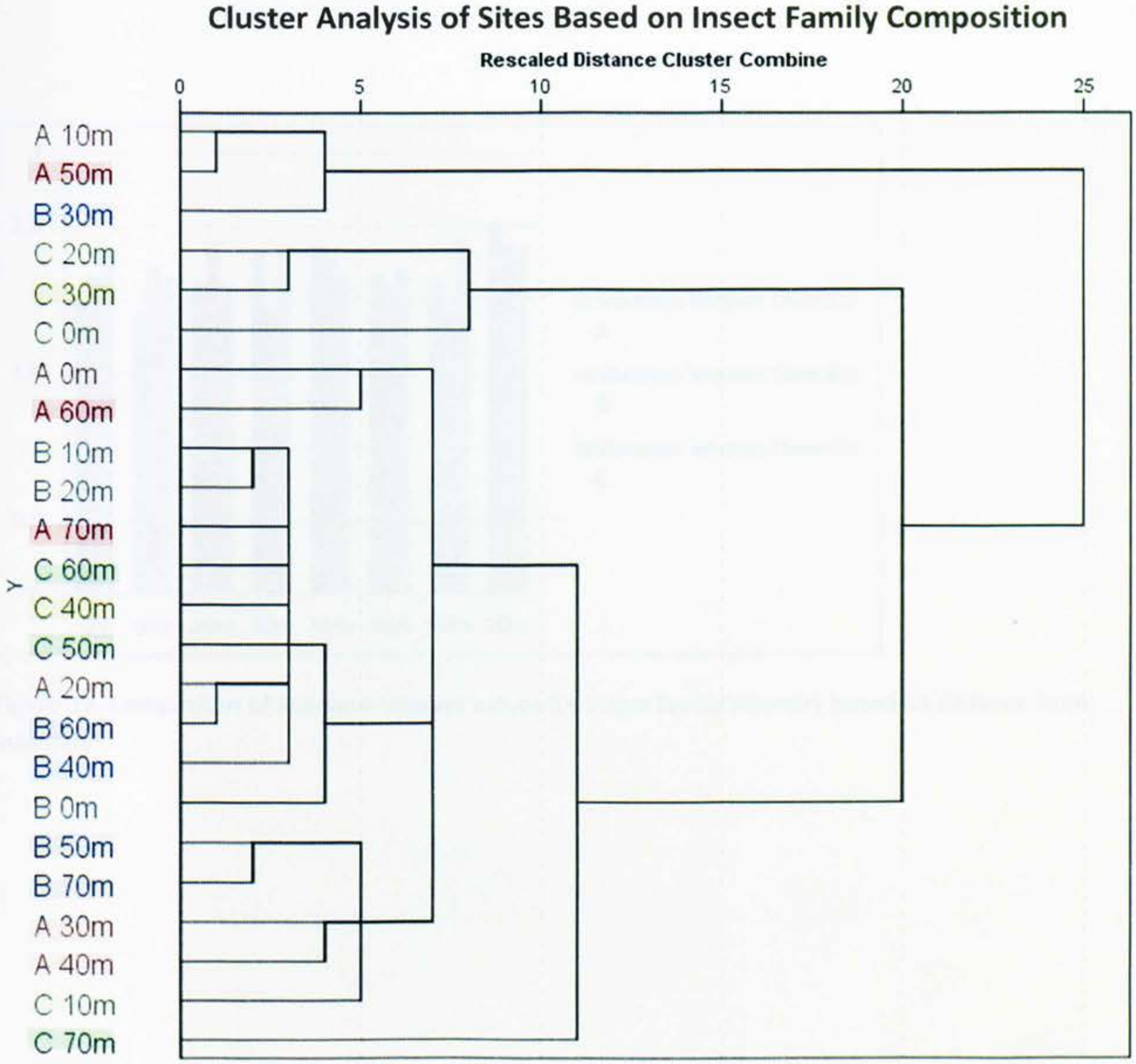


Figure 11. Cluster analysis of sites based on insect family composition (median cluster with Euclidean distance). Links occurring closer to the y-axis indicate a higher degree of relationship. Red highlighting indicates Transect A, blue indicates Transect B, and green indicates Transect C. Darker highlighting indicates greater distance from hub.

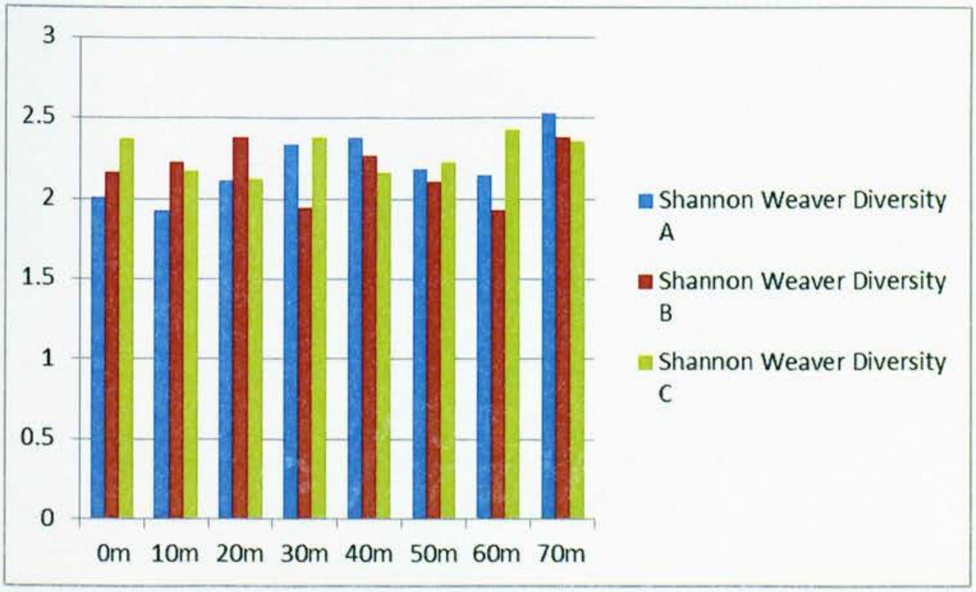


Figure 12. Comparison of Shannon-Weaver values for insect family diversity based on distance from insectary.