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Fall 2019

# Effectiveness of Different Agricultural Management Styles as Insect Biological Corridors: A comparison of insect populations in fragmented Chocó cloud forest, Ecuador

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## Recommended Citation

**Effectiveness of Different Agricultural Management Styles as Insect Biological Corridors**
*A comparison of insect populations in fragmented Chocó cloud forest, Ecuador*



*The community garden in Yunguilla, EC dedicated to providing organic produce to the community restaurant, grown using western organic agriculture practices. Tara Krantz.*

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## Abstract

Insects are part of the most diverse class of animals on the planet and are essential to various ecological functions such as pollination, nutrient cycling, providing a food source for other taxa, and more. The diversity and ecological services of insects are necessary to the operation of agriculture because of pest control and pollination of crops. However, the diversity of insects is severely reduced due to fragmentation. It is currently not well understood if certain types of agriculture can lessen the impact of fragmentation on natural and crop-based insect communities. In this study, insect populations in four different agricultural management styles and their borders were analyzed to understand the difference in insect populations not only within different cultivated areas, but to also understand the potential for different agricultural management styles to function as biological corridors for insects. Two types of sampling were done to observe the soil insect population as well as the winged insect population found in each study area. A $20cm^3$ sample of soil was taken from each quadrant to collect the soil insects present. Additionally, within a 10m by 5m quadrant a netting collection was done for two hours. All insects were persevered and identified to family level with a microscope. It was found that the traditional organic polyculture contained the highest diversity of both soil and winged insects and had the most similar insect community to its border according to β diversity calculations. Agricultural systems that focus on mimicking components of natural ecosystems such as increased biodiversity, absence of pesticides, and minimum soil disturbance are most likely to function as relatively effective biological corridors for insects between forest fragments.

*Keywords: agroecology, insects, biodiversity, entomology, fragmentation, Chocó cloud forest, Yunguilla*

## Resumen

Insectos son una parte de la clase más diversa de animales en el planeta y son esenciales a varias funciones ecológicas, por ejemplo, polinización, el ciclo de nutrientes, provenir una fuente de comida para otros taxones y más. La diversidad y los servicios ecológicos de insectos son necesarios a la operación del sistema agrícola a causa de control de las plagas y la polinización de los cultivos. Sin embargo, la diversidad de insectos es reducida severamente debido a la fragmentación. En este momento, no se entiende bien si algunos tipos de agricultura pueden reducir el impacto de fragmentación en comunidades de insectos naturales y en cultivos. En esta investigación, poblaciones de insectos de cuatro estilos diferentes del manejo agrícola y sus bordes fueron analizados para entender la diferencia en poblaciones de insectos no solo dentro de las áreas cultivadas, sino entender la potencial para estilos diferentes del manejo agrícola para funcionar como corredores biológicos por insectos también. Dos tipos diferentes de muestras fueron tomados para observar la población de los insectos del suelo además de la población de los insectos alados encontrados en cada área de investigación. Una muestra de $20cm^3$ fue tomada de cada cuadrante para colectar los insectos de suelo presentes. Además, dentro de un cuadrante de 10m por 5m una colección de la red fue hecha por dos horas. Todos de los insectos fueron preservados e identificados al nivel de familia con un microscopio. Fue encontrado que el policultivo orgánico tradicional contuvo la diversidad más alta de insectos del suelo y alados y tuvo la comunidad de insectos más similar a su borde según calculaciones de diversidad β. Los sistemas de agricultura que enfocan en el mimetismo de los componentes de ecosistemas naturales como biodiversidad aumentada, ausencia de las pesticidas, y la perturbación mínima

del suelo son más probable que funcionar como corredores biológicos efectivos relativamente para insectos entre fragmentos del bosque.

*Palabras claves: agroecología, insectos, biodiversidad, entomología, fragmentación, Chocó bosque nublado, Yunguilla*

**Statement of Ethics**

All work was conducted in the Area of Conservation and Sustainable Use: Yunguilla, and all necessary permissions for conducting research were attained by academic advisor, Xavier Silva and project advisor, Ana Maria Ortega. All insects captured for purpose of identification were killed with 70% proof alcohol to minimize suffering. This sample represents an insignificant amount of the local insect community in the area and is therefore unlikely to make a significant ecological impact.

**Introduction**

The class *Insecta* is considered to be the most diverse classification of animal taxon on the planet, with over 1 million described species (Weisser & Siemann, 2008). There are estimated to be between 2 million and 50 million species of insects worldwide (Stork, 1993). Insect diversity is dependent on its environment including surrounding plant diversity and abiotic factors such as climate and elevation (Scherber et al., 2014; Cuartas-Hernández & Gómez-Murillo, 2015). These factors extend to insect diversity in agricultural systems. Much lower species richness has been found in monoculture fields, or fields that have been intensely managed with pesticides than more organic and traditional management styles that mimic components of natural ecosystems (Sonoda et al., 2011; Letourneau et al., 2011; Nicholls & Altieri, 2004).

Based on the diversity and number of insects, there are an immense amount of ecological interactions between insects and other terrestrial organisms (Grimaldi & Engel, 2005). These interactions include but are not limited to herbivory, pollination, nutrient cycling, providing a food source for other taxa, disease transmission, and more (Foottit & Adler, 2009). The ecological roles of insects have a large impact on human life. Insects are essential to the modern agricultural system and can be devastating to crop yield at the same time (Foottit & Adler, 2009). Insect pests can decimate the agricultural community through herbivory or disease infestation. For example, the brown planthopper *Nilaparvata lugens* causes $1.23 billion in rice crop losses in southeast Asia annually through infection and herbivory (Nault, 1994). However, there are many more beneficial insects in agriculture. Approximately 85% of all angiosperms are pollinated by insects (Grimaldi & Engel, 2005). The estimated economic values of honeybees to the United States' agricultural system is between $1.6-8.3 billion (Southwick & Southwick 1992). Natural pest control is an undervalued ecological service in the agriculture industry. Up to 99% of potential pests are naturally controlled (DeBach 1974), with an added value of $54 billion to the industry as an ecosystem service (Naylor & Ehrlich 1997). While these interactions are essential to the biological functioning of modern agriculture, they are under threat by a variety of human activities including pesticides, introduced species, and habitat destruction and fragmentation (Foottit & Adler, 2009).

One of the largest issues in ecological conservation is habitat destruction and fragmentation (Leimu, Vergeer, Angeloni, Ouborg, 2010). Fragmentation can lead to species isolation and extinction and an inability to adapt to climate change. With fragmentation,

individuals cannot travel between fragments to their ideal ecosystem that will change elevation or composition with climate change. Additionally, species that are separated have less access to genetic variation, lowering the overall genetic fitness of a species and making it less likely to adapt to changes in its environment (Leimu et al., 2010). All species are effected by fragmentation, including insects. A study by Marcelo Aizen addresses how fragmentation effects the insect-plant relationship in dry tropical forest. There are two major ways fragmentation effects this relationship; changing abiotic factors in microclimates as well as affecting biotic population fluctuations of insects (Aizen & Feinsinger, 1994). Fragmentation has many possible effects on insect population abundance and species richness and can "also disrupt plant-herbivore, herbivore-enemy, and plant-pollinator interactions" (Tscharntke & Brandl, 2004), according to a compilation study on the changing plant-insect relationship due to fragmentation.

In terms of direct agricultural fragmentation, over 13 million ha of tropical forests are deforested yearly for agricultural purposes (Jha, Dick, Dirzo, 2010). Agriculture is classified as a type of fragmentation because the use of land for pasture or crops disrupts continuous natural ecosystems. This disruption makes it difficult for species to travel between pockets of land (Jha et al, 2010). Pollination is hugely important to agriculture and "has been shown to be directly affected by fragmentation through a reduction in the abundance and species richness of pollinators, and also indirectly by the alteration of their behaviour and flight patterns" (Didham, Ghazoul, Stork, Davis, 1996). The entire agricultural system is dependent on pollinators, pest control, and other types of plant-insect interactions. The extent of these fragmentation effects can change depending on the types of crops and methods used in cultivated areas (Tscharntke & Brandl, 2004), as well as the ecosystem that is being fragmented for agricultural purposes.

One ecosystem that has been particularly devastated by deforestation and fragmentation is the Chocó cloud forest region. The Chocó cloud forest region in Ecuador is located on the western side of the Andean mountain range between 1500 to 3000 m with rainfall between 500-10,000 mm/yr (Cayuela, Golicher, Rey-Benayas, 2006). The cloud forest is one of the most biodiverse ecosystems on the planet (Fagua & Ramsey, 2019). Signature characteristics of the Chocó cloud forest are a high biomass density due to many epiphytes, wet soil with high organic content, and high local endemism (Cayuela et al., 2006). It is essential for hydrological regulation, which contributes to how plants grow in the area and the creation of microclimates, and the protection of biodiversity by providing habitat to many rare and endemic species (Cayuela et al., 2006). A high rate of local endemism and biodiversity is partly created by natural cloud forest fragmentation in Central and South America due to its geological location situated on mountain ranges (Martínez-Morales, 2004). This fragmentation is only exacerbated by human activities. It is estimated in Ecuador that most of the cloud forest in the central and western regions has disappeared completely (Dodson & Gentry, 1991). Due to increased fragmentation in the cloud forest, many species and ecological services will suffer if proper measures are not taken to preserve and protect this diminishing ecosystem (Hermes, Segelbacher, Shaefer, 2018). Therefore, reserves that protect the cloud forest and encourage restoring connectivity are essential to the conservation of the region (Hermes et al., 2018).

There are multiple government and private organizations in Ecuador working to protect and connect the Chocó cloud forest. Yunguilla is a rural town in Ecuador dedicated to community living that has three main pillars to supporting their community economically; conservation, ecotourism, and agriculture. (www.yunguilla.org.ec, 2016). The community is in the Chocó cloud forest region, and Yunguilla protects a reserve of 3000 ha which is used for conservation, agriculture, scientific research, reforestation, and ecotourism. The largest monetary

source for Yunguilla is ranching and agriculture. The community is committed to mainly practicing sustainable and organic agriculture, without the use of pesticides or herbicides (www.yunguilla.org.ec, 2016). While the community has over 3000 ha of protected land, it is fragmented by various farms and pastures used by the community members. Under the environmental protection of the Quito municipal government Yunguilla is classified as an Area of Conservation and Sustainable Use (ACSU). An ACSU signifies that the area is predominantly natural ecosystem, but a local population still inhabits the area. The village must adopt conservation practices and reforestation efforts to increase the functionally of the environment, and to preserve biodiversity and ecosystem services (Carrera, Bustamante, Sáenz, 2016). The ACSU does not prohibit development, but rather encourages the use of land in terms of sustainable production. This stipulation allows Yunguilla to rely on ranching and agriculture and contributes to cloud forest fragmentation within the overall reserve (Carrera et al., 2016).

The goal of this study is to assess the similarities and differences in insect populations that exist in different forms of managed agriculture and their borders in and around Yunguilla, Ecuador. This assessment is in terms of abundance, family diversity, and assemblage composition for each of the agricultural areas studied. This data will also help to understand whether different forms of agricultural management can serve as biological corridors for insect populations. Similar studies have been done that focus on using different types of agroecology for bird biological corridors. One example looked at different types of seeds found in soils and bird observations in shaded coffee plantations in the Ecuadorian coast to determine bird movement and if they could use the plantations as steppingstones between their natural forest habitat (Lozada et al., 2005). There is less of an understanding surrounding the use of agriculture as biological corridors for insects, especially in neotropical environments (Hill, 1994). It is important to understand how insect populations are effected by fragmentation to minimize the ramifications fragmentation has on the ecological services insects provide in agriculture.

**Methods**
*Location and Study Area*

Yunguilla, Ecuador is located at 0.15° N, 78.67° W, at 2650 m in altitude, about an hour north of Quito, Ecuador (Google Earth, 2019; www.yunguilla.org.ec, 2016). The town exists in both the Chocó cloud forest and Andean montane region of Ecuador depending on the elevation of different fields and sections of the protected reserve. The study was conducted in the Chocó cloud forest section. The community practices a variety of management strategies for their crops, making Yunguilla an ideal location for this study. The study was conducted during the beginning of the rainy season in the region which ranges from November to May (Castellanos, 2011).

Four different testing locations were chosen to compare insect populations that exist in four different crop management styles. One location uses westernized organic agricultural practices in a polyculture setting (referred to as Q1, border quadrant Q2). The second location uses conventional agricultural strategies such as fumigation and synthetic fertilizers (referred to as Q3, border quadrant Q4). The third location practices traditional organic polyculture (referred to as Q5, border quadrant Q6). Traditional organic agriculture refers to the combination of polyculture and other organic farming methods with cultural practices such as planting crops during certain seasons (Appendix X). The fourth location uses westernized organic agricultural practices in a monoculture setting (referred to as Q7, border quadrant Q8). More detailed descriptions and designations are found in Table 1 and Appendix A. One quadrant was built in each of the four agricultural systems, as well as one quadrant built on the border of each

agricultural system (Figure 1, Table 1). All areas were chosen to include borders that were not currently being cultivated such as pasture or another type of crop.

Field data was collected over three weeks between November 10 and November 29, with an average of three to four days spent at each testing site.
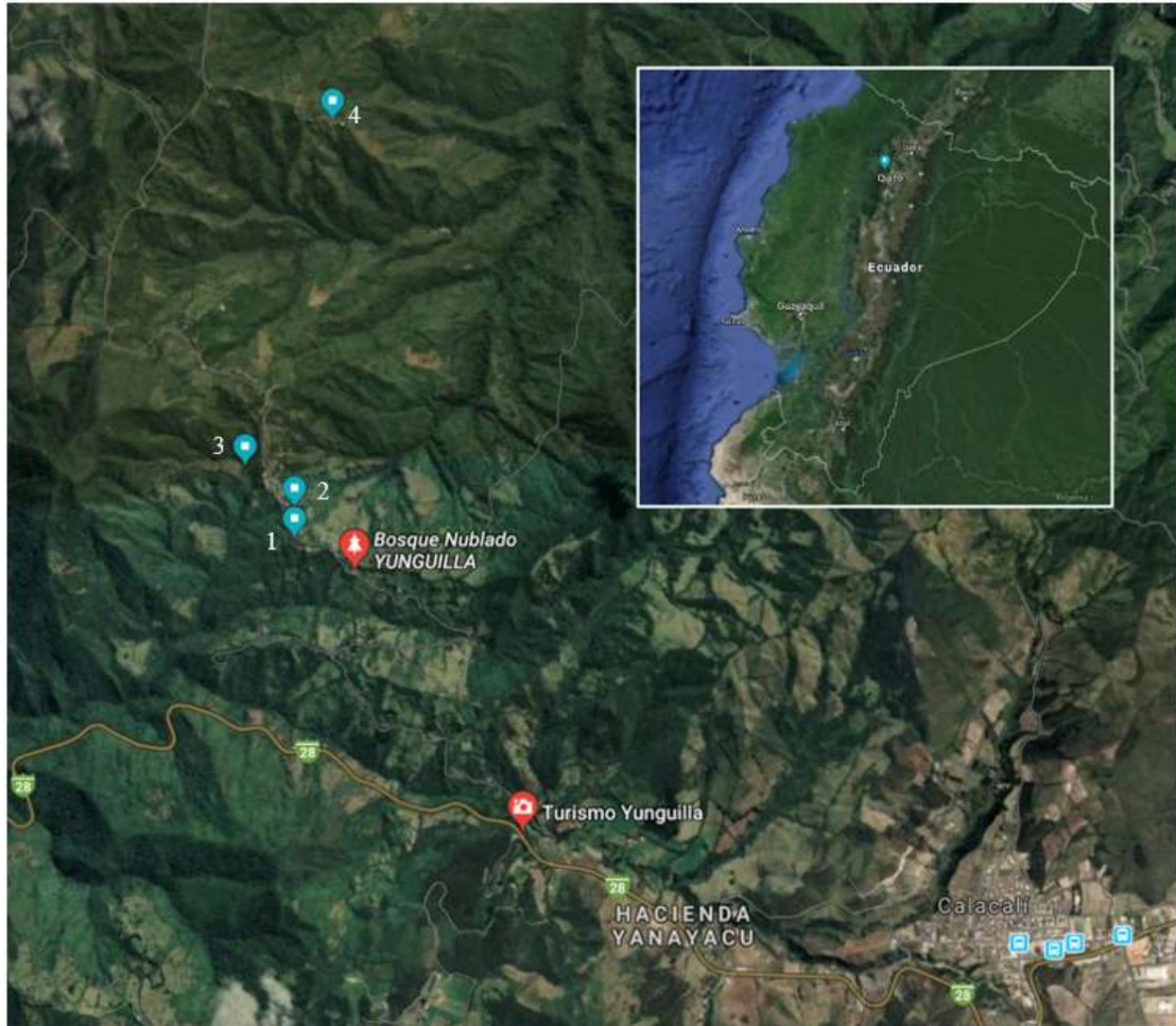


*Figure 1.* Location of study area. The four different agriculture study areas are marked with blue pins- created with Google Maps

| Quadrant | Description | Location |
|---|---|---|
| Q1 | Western organic polyculture | Community garden, **point 1** |
| Q2 | Western organic polyculture border | Community garden, **point 1** |
| Q3 | Inorganic | Personal community member garden, **point 3** |
| Q4 | Inorganic border | Personal community member garden, **point 3** |
| Q5 | Traditional organic | Personal community member farm, **point 4** |
| Q6 | Traditional organic border | Personal community member farm, **point 4** |
| Q7 | Western organic monoculture | Personal community member garden, **point 2** |
| Q8 | Western organic monoculture border | Personal community member garden, **point 2** |

*Table 1.* Description and location of each quadrant tested. Refer to this table for the quadrant designations.

*Netting*

In each quadrant of 10 m by 5 m, two netting sessions were conducted using an entomological hand net (Figure 2). One session was conducted in the morning between 8:30 AM

and 11:00 AM, and the other in the afternoon between 3:00 PM and 5:00 PM to take advantage of peak activity time (Dáttilo, Aguirre, Quesada, Dirzo, 2015). During the two-hour search period, eight netting samples were taken. Each of the eight samples were five minutes long, and ten minutes were waited between sample periods to allow the quadrant to rest and the insects to recuperate from the netting disturbance (Roulston, Smith, Brewster, 2007). The researcher would walk throughout the entire quadrant for five minutes, brushing the different vegetation with the net to disturb the insects. After five minutes the entire content inside the net would be placed into a zippered plastic bag with a small amount of 70% proof alcohol, in between 2.5 to 5 mL. A small number of insects would escape between the gap of the net and the bag. At the end of taking eight samples at least 25 mL of 70% proof alcohol was added to the bag to kill and preserve the insects (Hammer, Dickerson, Fierer, 2015). Since this collection involved brushing the net against the vegetation some leaves, dirt and other debris were collected with the insects. After the alcohol was added as much of the dirt and debris was removed from the bags within 24 to 48 hours after collection. The netting was done in a variety of weather conditions, which ranged from sunny and warm to misty and cold (Appendix C). The weather could change dramatically during the two-hour collection period. The netting was stopped if it started to precipitate more than just a mist which would affect the presence and activity of the insects. Due to time constraints for identification and the more variable weather during the afternoon the insect samples collected between 3:00 PM and 5:00 PM were not identified.
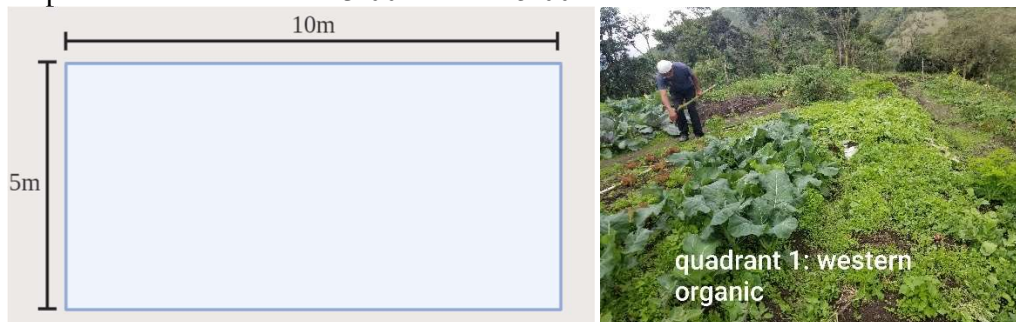


Figure 2. Measurements of quadrants tested

*Soil Sample*

Within 2 m of the center of each quadrant, a 20 $cm^3$ soil sample was taken (Figure 3). Taking the sample from the very center of the quadrant was not feasible because it was continually disturbed by the pit fall trap collection which was placed in the center of the quadrant. The insects collected in pit fall traps were not identified in this study due to a lack of time for identification. The sample was dug from the quadrant and then immediately searched for an hour to collect as many insects as possible from the sample. Visual collecting is the most widely used method for collecting sizable insects from a soil sample (Kaydan, Benedicty, Williams, Szita, 2017). Each sample was placed on black plastic to separate it from the rest of the quadrant in order to only search the 20 $cm^3$. It was not possible to collect every single insect from the soil sample as some were too small to notice or pick up with tweezers, or some moved too quickly and escaped the area of observation before capture. The captured insects were immediately placed in a zippered plastic bag. At the end of the search hour 25 mL of 70% proof alcohol was added to the bag to kill and preserve the insects (Hammer et al., 2015).

*Figure 3.* Measurements of soil sample size

*Insect Identification*

        The insects were identified in groups, first by collection method and then by quadrant. To identify the insects, the bags that the samples were stored in were washed with additional 70% proof alcohol and the contents poured into a petri dish. Insects that did not wash out with the liquid were removed from the bag with tweezers and placed in the same petri dish. A small paint brush was used to push all the insects, dirt, and other small debris from the bag to the edge of the petri dish. It was then placed under a microscope to see all the insects in detail. Moving the petri dish in a clockwise direction, insects were searched for, and once they were found were moved to a clean petri dish containing a small amount of 70% proof alcohol. Once all the insects were found, the leftover debris in the initial petri dish was discarded.

        The insects in the new clean petri dish were sorted into groups within the dish based on physical appearance in terms of order to expedite the identification process. The dish was placed under the microscope for identification. Insects were identified to minimum order level and maximum family level. Each insect identified was assigned a morphospecies to properly represent biodiversity of the total collection. There was not enough time permitted in the study to identify to a more specific classification level. Insects were saved in order to compare appearance and make morphospecies designations constant across all samples. A total of 1378 individual insects were identified. Insects were identified with project advisor Ana Maria and the use of various resources such as An Introduction to the Study of Insects (Borror, Triplehorn, Johnson, 1989) and bugguide.net.

*Plant Identification*

        The purpose of plant identification was to understand the composition of each quadrant. For the four agriculture quadrants containing crops, descriptions of the crops were written down and photos were taken of the crops and most prominent weeds in the quadrant. A field guide was asked to identify the crops and the weeds if possible. These identifications were cross referenced through various methods. The photos were compared to identification plates provided by SIT, and if the plates proved unsuccessful the photos were submitted to iNaturalist for identification. SIT professor Javier Robayo and SIT student Grace LaDuca were consulted for additional identification support. The crops were identified to species level while the prominent weeds and grasses were identified to family level, as it proved difficult to identify certain plants without flowers.

        For the four border quadrants, descriptions of the most prominent plants in the quadrant were written down as well as photographed for future identification. Field guides were asked to provide common names of certain plants if possible. Most of the common names proved insufficient in scientifically identifying the plants. The photos were compared to identification

plates provided by SIT, and if the plates proved unsuccessful the photos were submitted to iNaturalist to for identification. SIT professor Javier Robayo and SIT student Grace LaDuca were consulted for additional identification support. The dominant plants in the quadrants were identified to family level. There was not enough time in the study to focus on abundance of plants in a quadrant and count how many times a certain plant was seen. A rudimentary count of plants in border quadrants showed all to contain more plant species than the cultivated quadrants. Identification was used to understand general composition of the plants in each border quadrant.

*Data and Statistics*

Graphs showing raw abundance and the logarithmic rank abundance were created using Excel. Graphs showing the sample completeness were created using iNEXT Online (https://chao.shinyapps.io/iNEXTOnline/). Biodiversity indices and other statistics were completed using Excel. $S = \sum p_i * (\frac{1}{p_i})$, where $p$ is the percent of the community that is composed of the morphospecies/family, was used to calculate morphospecies richness, which is an index that puts emphasis on the rare species. $H = e^{-\sum[p*\ln(p)]}$ was used to calculate the transformed Shannon-Weiner diversity index (Jost, 2007). This index is used to weigh the individuals of every species evenly and estimate biodiversity in terms of evenness of the sample. $D = 1/{\sum p_i^2}$ was used to calculate the transformed Gini-Simpson index, which puts emphasis on the common species in terms of biodiversity. Transformations are used on both these equations to make them linear and therefore logically consistent (Jost, 2007). The β diversity, $\beta = \gamma/\alpha$, is calculated using the transformed Shannon-Weiner indices, which measures the effective number of communities found in a sample. For this study it is used to directly compare how similar or different the agriculture quadrants are from their borders (Jost, Chao, Chazdon, 2011). $1 - \frac{F_1}{I}$ was used to calculate sample coverage, where $I$ is the number of individuals and $F_1$ is the number of singletons. This indicates the proportion of the community represented in the sample. $1 - Sample\ Coverage$ was used to calculate coverage deficit. This indicates the proportion of the community not represented in the sample. The Chao1 indicator was calculated using $S + \frac{F_1^2}{2*F_2}$ and Chao1 indicator corrector was calculated using $S + \frac{F_1(F_1-1)}{2}$, for when a sample is missing doubletons. $F_1$ is the number of singletons, $F_2$ is the number of doubletons, and $S$ is the species richness of the sample. The Chao1 indicator is used to show the lower bound of true species richness in a community (Chao & Jost, 2012).

**Results**



Figure 4. Morphospecies in netting sample identified in each quadrant and total number of individual insects counted in each quadrant. Names of morphospecies can be found in Appendix E.

| Indices | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Cultivated | Border |
|---|---|---|---|---|---|---|---|---|---|---|
| **Abundance** | 128 | 199 | 232 | 48 | 273 | 91 | 35 | 193 | 668 | 531 |
| **Species Richness** | 37 | 50 | 38 | 27 | 56 | 28 | 17 | 63 | 103 | 113 |
| **Shannon** | 20.109 | 23.470 | 13.207 | 17.112 | 20.076 | 15.381 | 11.147 | 31.682 | 32.665 | 39.569 |
| **Simpson** | 13.213 | 12.181 | 7.467 | 9.931 | 8.633 | 8.689 | 6.694 | 15.014 | 15.512 | 13.859 |

Table 2. Biodiversity indices for netting collection method.

Out of the eight netting collections identified, a total of 1199 individuals were identified within a total of 167 different morphospecies (Appendix E). The most common orders identified were Diptera with a total of 54 different morphospecies and Hymenoptera with a total of 47 different morphospecies. The most common families identified were Cicadellidae with 22 different morphospecies, Chrysomelidae with 10 different morphospecies, and Chloropidae with 9 different morphospecies. The most common morphospecies identified was a Chloropidae with a total of 228 individuals across all eight quadrants. Some of the Diptera and Hymenoptera found were only identified to the order level due to the large sizes of the orders.

Q5, the traditional agriculture quadrant, contained the highest number of individuals found with an abundance of 273, while Q7, the monoculture quadrant contained the lowest number of individuals with an abundance of 35 (Figure 4). Q8 contained the highest species richness with a total of 63 morphospecies, while Q7 contained the lowest species richness with 17 different morphospecies. Two out of four of the border quadrants, Q2 and Q8 contained not only a higher species richness of families found through netting, but more individuals in terms of abundance (Table 2). However, Q4 and Q6 contained a lower species richness and abundance than their corresponding agriculture quadrants. This pattern does not extend to the calculated Shannon-Weiner diversity and Gini-Simpson diversity. Three out of four border quadrants have a higher Shannon-Weiner diversity than their corresponding agriculture quadrant, with Q8 having the highest Shannon-Weiner biodiversity (Table 2). This signifies that most of the border quadrants have a more even spread of biodiversity than the cultivated areas. Q6 is the only border quadrant with a lower Shannon-Weiner biodiversity than its corresponding agriculture quadrant, the traditional organic polyculture. For the Gini-Simpson Index, three out of four of the agriculture quadrants have a higher biodiversity than the border quadrants (Table 2). This signifies that the cultivated areas have a higher abundance of more common species identified than the border quadrants. The exception is Q8, which also has the highest total Gini-Simpson diversity, and is larger than the Gini-Simpson diversity for Q7.
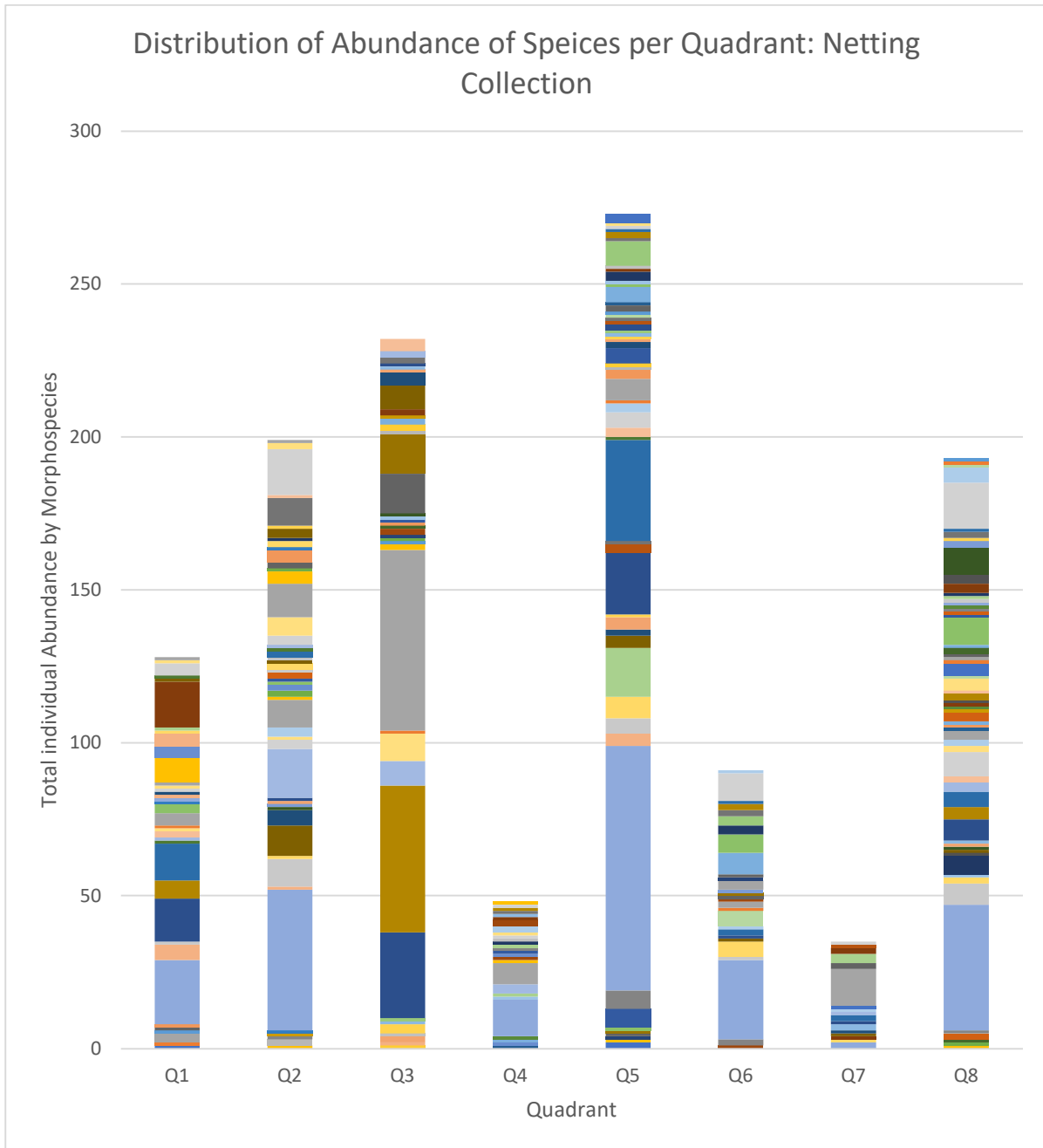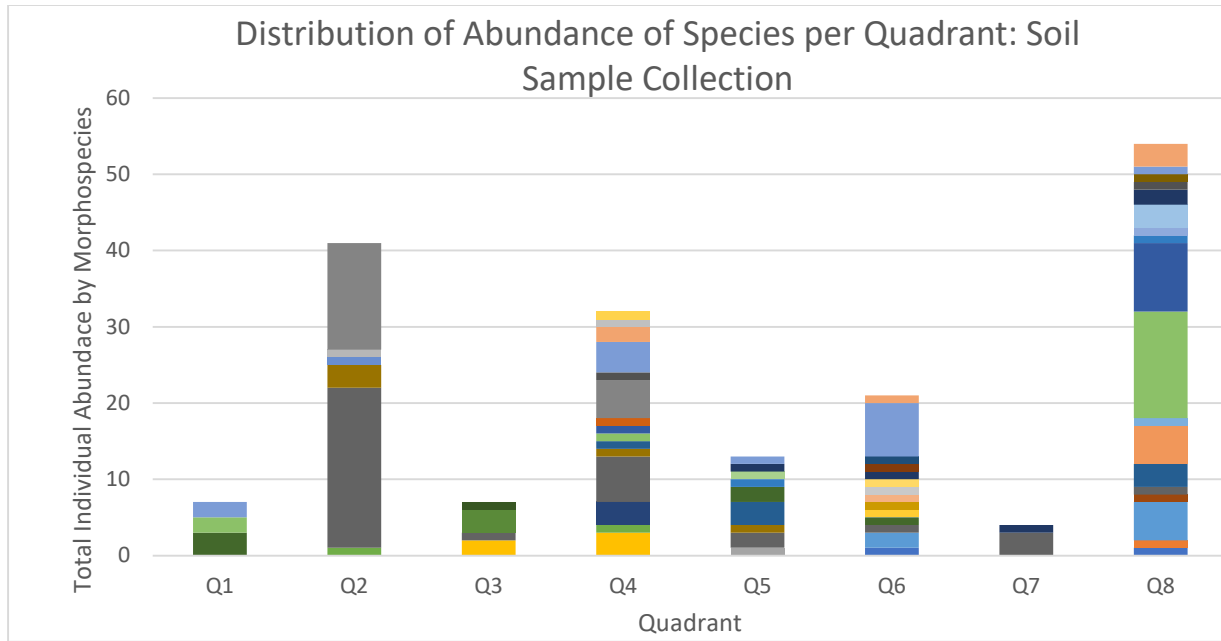
*Figure 5.* Morphospecies in soil sample identified in each quadrant and total number of individual insects counted in each quadrant. Names of morphospecies can be found in Appendix F.

| Indices | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Cultivated | Border |
|---|---|---|---|---|---|---|---|---|---|---|
| **Abundance** | 7 | 41 | 7 | 32 | 13 | 21 | 4 | 54 | 31 | 148 |
| **Species Richness** | 3 | 6 | 4 | 15 | 9 | 14 | 2 | 18 | 40 | 40 |
| **Shannon** | 2.942 | 3.231 | 3.586 | 11.655 | 8.151 | 10.277 | 1.755 | 11.379 | 10.746 | 18.481 |
| **Simpson** | 2.882 | 2.590 | 3.267 | 9.481 | 7.348 | 6.785 | 1.600 | 7.924 | 9.152 | 11.651 |

*Table 3.* Biodiversity indices for soil sample collection method

Out of the eight soil samples collected, a total of 179 individuals were identified within a total of 40 different morphospecies (Appendix F). The most common order found in the soil was Coleoptera with 14 different morphospecies, and the most common morphospecies identified were Coleoptera larva with a total of five different morphospecies. The most common morphospecies identified was a Coleoptera larva with a total of 35 individuals in all eight quadrants. Occasional classes in the Arthropoda phylum were identified as they were commonly found in the soil. The most common identified were four different morphospecies of Diplopoda and three different morphospecies of Chilopoda.

Q8, the border quadrant for the monoculture tested, contained the highest number of individuals found in the soil with an abundance of 54, while Q7, the monoculture quadrant contained the lowest number of individuals with an abundance of 4 (Figure 5). Every single border quadrant contained a higher species richness of families and abundance of individuals found in the soil (Table 3). This pattern extends to both the calculated Shannon-Weiner diversity and Gini-Simpson diversity. Q4 had the highest Shannon-Weiner diversity signifying that Q4 had the most even spread of biodiversity out of all the soil samples, while Q7 had the lowest (Table 3). Q4 also had the highest Gini-Simpson diversity signifying that Q4 has the highest diversity of the most common species sampled in the study (Table 3).
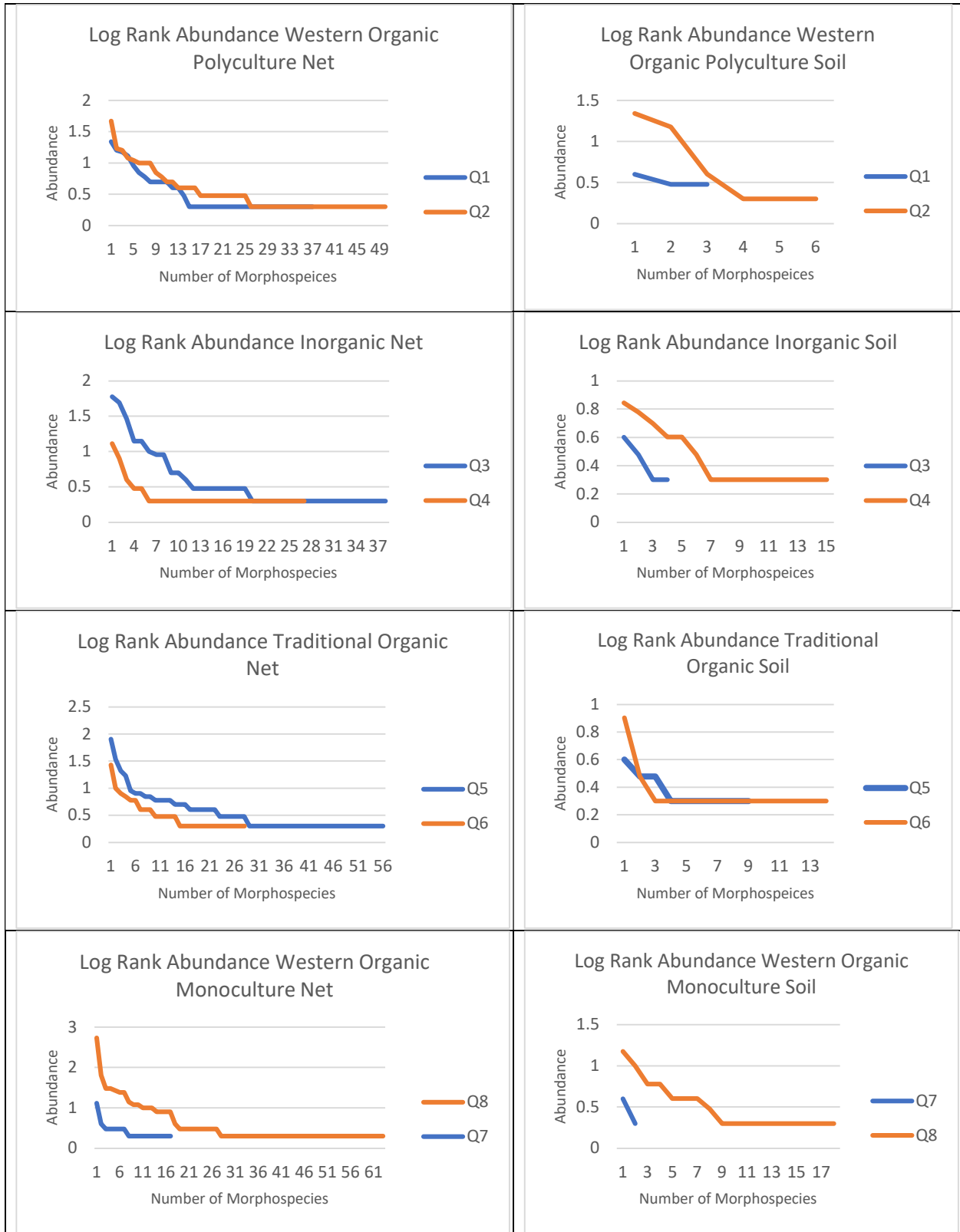
*Figure 6.* Comparison of the rank abundances in the cultivated and border quadrants. The log of the abundances was taken to visually show a clearer difference in abundance found in the quadrants cultivated verses border quadrants.

The log rank abundace graphs are visual repsentations of the abudance and simple biodiversity, and the compared abundance and biodiversities found in the corresponding cultivated and border quadrants (Figure 6). For every single soil sample collection it is clear that there were higher abundance and species richness of insects found in the border quadrants. However the spread is more varied and neuanced for the netting collection. The pure rank abundaces do not correlate to the calculated Shannon-Weiner diversity and Gini-Simpson diversity which put emphasis on other aspects in biodiversity besides abundance (Table 2, Table 3).

|  | Western Organic Polyculture (Q1 vs Q2) | Inorganic (Q3 vs Q4) | Traditional (Q5 vs Q6) | Western Organic Monoculture (Q7 vs Q8) | Cultivated vs Border |
|---|---|---|---|---|---|
| β Diversity Net | 1.451 | 1.621 | 1.300 | 1.525 | 1.294 |
| β Diversity Soil | 1.398 | 1.381 | 1.372 | 1.399 | 1.405 |

*Table 4.* β diversities for each cultivated and border quadrant for both soil and net collection. Used to compare effective number of communities within tested area.

There is statistical difference between quadrant communities in terms of β diversity which measures number of communities shared (Table 4). Since only two communities are being compared at a time the β diversity will run between 1 and 2, with a β diversity of 1 signifying no difference in the communities and β diversity of 2 signifying no similarities. The communities with the highest difference between the insect communities in the netting collection are inorganic cultivation and western organic monoculture cultivation (Table 4). There is less of a significant difference in the communities when looking at the soil collection, as none of the β diversity are higher than 1.5 (Table 4). This correlates with the identification data as there was a lower species richness for the soil samples in comparison to the netting collection.
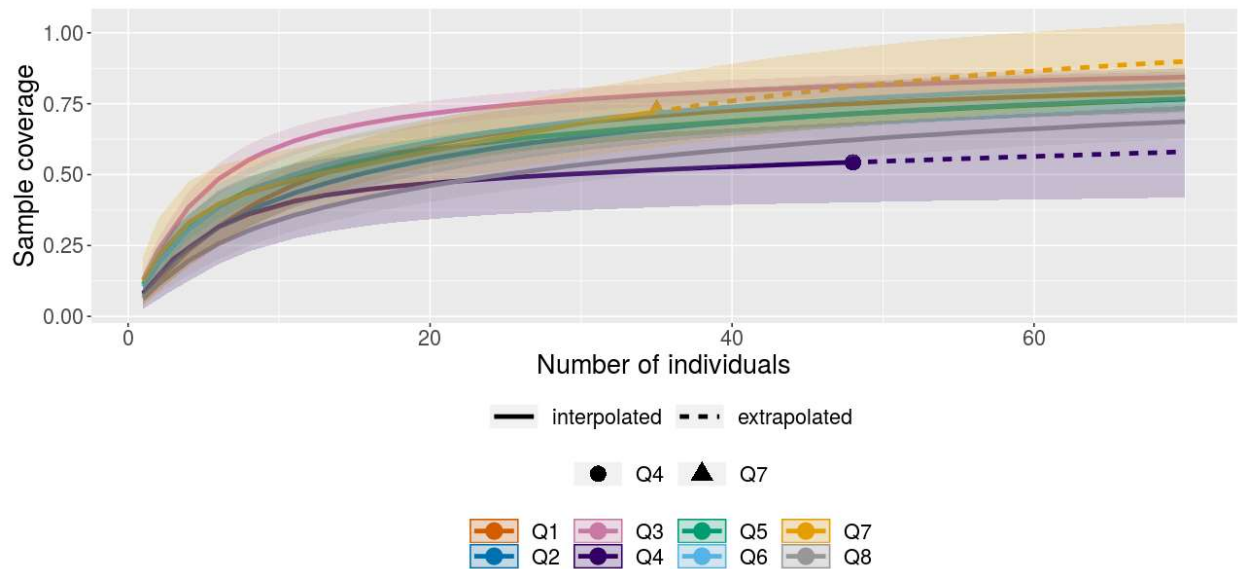


*Figure 7.* Sample completeness curve for netting collection method.

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Cultivated | Border |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sample coverage** | 0.405 | 0.500 | 0.500 | 0.185 | 0.500 | 0.500 | 0.412 | 0.429 | 0.707 | 0.683 |
| **Coverage deficit** | 0.595 | 0.500 | 0.500 | 0.815 | 0.500 | 0.500 | 0.588 | 0.571 | 0.293 | 0.317 |
| **Species Richness** | 37 | 50 | 38 | 27 | 56 | 28 | 17 | 63 | 103 | 113 |
| **Chao1** | 279 | 84.722 | 60.563 | 148 | 134.4 | 47.6 | 27 | 135 | 300.389 | 228.065 |
| **Chao1 corrector** | 268 | 350 | 209 | 258 | 434 | 119 | 62 | 693 | 1343 | 1545 |

*Table 5.* Sample coverage and lower bound of morphospecies richness for netting collection method.

The sample completeness for the netting collection quadrants are low. None of the calculated sample coverage is higher than 0.5, and many have a large coverage deficit (Table 5). Figure 7 shows the sample coverage for the number of individuals identified for all the quadrants tested. Q4 and Q7 have two of the highest coverage deficits (Table 5), and largest margins of error for sample coverage (Figure 7). Five quadrants do not plateau within the interpolated data. Combined with a high coverage deficit, this indicates that further collection would increase the amount of species found (Table 5). Additionally, the Chao1 indicators show a much higher true species richness for all the quadrants than what is represented in the actual data collected (Table 5). It is important to bear in mind the small quantity of winged insects identified in comparison to the total potential of winged insects that exist in the study area. It is reasonable to assume that the low sample coverage does not provide the most accurate representation of the community assemblage in each quadrant.
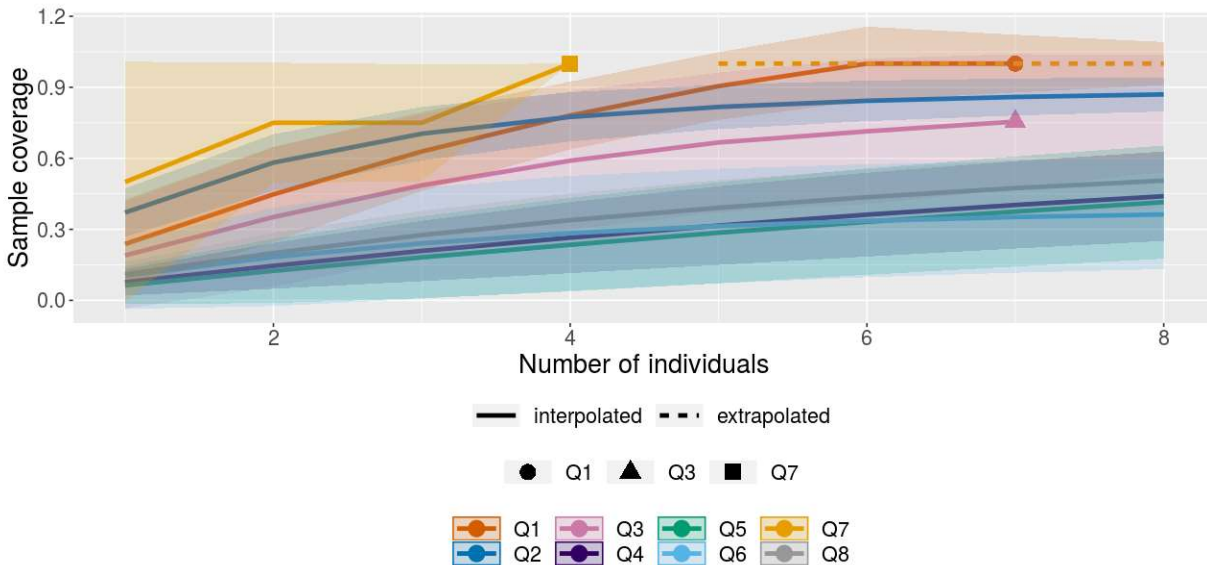


*Figure 8.* Sample completeness curve for soil sample collections.

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Cultivated | Border |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sample coverage** | 1.000 | 0.500 | 0.500 | 0.400 | 0.333 | 0.214 | 0.500 | 0.500 | 0.875 | 0.525 |
| **Coverage deficit** | 0.000 | 0.500 | 0.500 | 0.600 | 0.667 | 0.786 | 0.500 | 0.500 | 0.125 | 0.475 |
| **Species Richness** | 3 | 6 | 4 | 15 | 9 | 14 | 2 | 18 | 40 | 40 |
| **Chao1** | 3 | N/a | 6 | 55.5 | 18 | 74.5 | N/a | 58.5 | 44.167 | 130.25 |
| **Chao1 corrector** | 3 | 9 | 5 | 51 | 24 | 69 | 2 | 54 | 50 | 211 |

*Table 6.* Sample coverage and lower bound of morphospecies richness for soil sample collection method.

The sample completeness for the soil collection quadrants are varied. None of the calculated sample coverage is higher than 0.5, and many have a large coverage deficit (Table 6). Figure 8 shows the high variation in sample coverage between the quadrants tested, with Q1 attaining a high sample completeness, which is the outlier in the data collected, as there were only 7 individuals found (Table 3). All four border quadrants do not plateau within the interpolated data. Combined with a high coverage deficit, this indicates that further collection would increase the amount of species found (Table 6). The identification of the insects collected from the pit fall traps would also increase the sample coverage. Additionally, the Chao1 indicator shows a much higher true species richness for two of the border quadrants, Q6 and Q8, than what is represented in the collected data. The rest of the quadrants are relatively comparable to their Chao1 indicator (Table 6). It is important to bear in mind the small quantity of soil insects identified in comparison to the total potential of soil insects that exist in the study area. It is reasonable to assume that this low sample coverage does not provide the most accurate representation of the community assemblage in each quadrant.
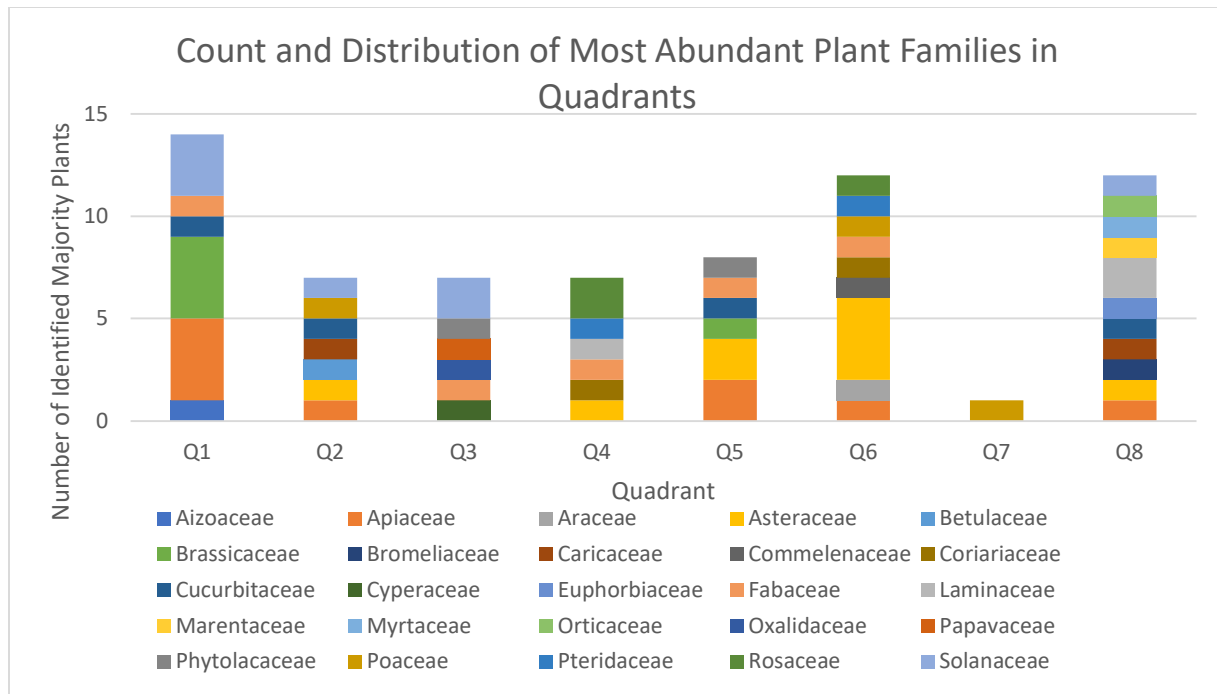


*Figure 9*. The amount of most abundant plants identified by family per quadrant. The graph is not representative of the true biodiversity of the border quadrants.

Every quadrant tested was composed of multiple plant families, except for Q7 which was the monoculture tested. Every border quadrant had a higher quantity of families identified from its corresponding cultivated quadrant apart from Q4 which had the same quantity of families identified. The common families shared between all quadrants were Apiaceae, Asteraceae, and Poaceae (Figure 9). The graph is not an accurate representation of the total makeup of every quadrant; therefore, biodiversity indices calculations would falsely represent the biodiversity of the quadrants tested. Out of the cultivated area quadrants, Q1 and Q5 were the most diverse which are the western organic polyculture and the traditional organic polyculture. Out of the border quadrants, Q8 and Q6 were the most diverse, which bordered the traditional organic polyculture and the western organic monoculture respectively (Table 1).

**Discussion**

*Insect Diversity in Cultivated Areas*

There is a high variability of insect biodiversity found in the four different types of cultivated areas. The first major difference in the management between cultivated areas is crop diversity. The two polyculture quadrants (Q1 and Q5) have much higher Shannon-Weiner diversities with 20.11 and 20.01 respectively for the netting collection (Table 2), in comparison to the two monoculture quadrants (Q3 and Q7). Plant diversity has been shown to have a positive effect on insect diversity and abundance in ecosystems (Scherber et al., 2013). However, in a review of over 62 articles studying whether plant diversity benefits agriculture, the results were overwhelming in the success of polycultures in terms of overall reduction of herbivory through a mix of intercropping and different flowering periods (Letourneau et al., 2011). Additionally, plant biodiversity can help increase overall crop yield over an extended period (Schillinger, 2011; Letourneau et al., 2011). This signifies that the polyculture quadrants do not only hold a more biodiverse insect community, they can build healthier agricultural systems which can use insect biodiversity to their advantage. The higher biodiversity in polyculture builds more stability into the agricultural system (Nicholls & Altieri, 2004), allowing for higher plant resilience and the creation of more complex food webs. Polycultures take advantage of the more complex food web because there is more natural pest control by virtue of the higher insect biodiversity (Letourneau et al., 2011). Q1 and Q5 had a higher plant biodiversity and a higher insect biodiversity than either Q3 or Q7, correlating a positive relationship between insect and plant biodiversity.

Another difference in crop management was the use of fumigation to deter insect destruction of a cultivated area. Q3 had the second lowest Shannon-Weiner diversity of the four cultivated areas (Table 2). Traditionally, pesticides reduce insect populations in comparison to organic farming methods. A study performed in three different peach orchards looked at the difference in biodiversity in conventional verses organic peach orchards (Sonoda et al., 2011). In the study it was observed that pesticide use negatively affected insect biodiversity through a population survey in comparison to organic practice (Sonoda et al., 2011). The inorganic quadrant in this study tested had a lower insect diversity for all indices than either of the cultivated areas using versions of organic polyculture (Table 2). Interestingly, Q7 had the lowest Shannon-Weiner biodiversity even though it is an organic cultivated area. Q7 is a true monoculture, with only one corn crop growing in the quadrant. Q3 is a monoculture of potatoes but has a significant quantity of other weeds and grasses growing in the quadrant, increasing the plant biodiversity. As plant biodiversity can increase insect biodiversity in an area (Futuyma & Agrawal, 2009), the presence of more plants could have increased the quadrant's overall biodiversity and resilience to counteract some of the effects of the fumigation.

The third significant difference in crop management was the different soil treatments used in each of the cultivated areas. All the quadrants till the soil but use different types and amounts of soil additives (Appendix D). Q5, the traditional organic polyculture also has the highest Shannon-Weiner diversity for the soil sample collection with 7.35 (Table 3). Q5 uses no added compost and is only watered by rain. In a study looking at the difference between the components of organic soil verses conventional soil, organic soil was proven to have higher water retention, organic matter content, and microbe biodiversity (van Bruggen et al., 2014). This leads to an increase in viable habitat for soil arthropods. It is interesting to note the higher Shannon-Weiner diversity for soil insects in the inorganic quadrant as well, which uses a synthetic fertilizer on its soil (Appendix D). While Q3 practices conventional agriculture with the

use of synthetic additives, they are applied sparingly, approximately once every five months (Appendix D). Future studies should work to observe differences in level of management intensity for conventional agriculture, as has been shown to decrease overall arthropod abundance and diversity in comparison to other farming methods (Teodoro et al., 2011).

*Insect Diversity Between Cultivated Areas and Borders*

For most of the quadrants and collections, the border quadrants had a higher biodiversity than the cultivated areas they surrounded. Every border quadrant had a higher plant biodiversity (Figure 9) and no intentional crops growing in the border. The soil had not been cleared for at least 10 years. In the soil sample collection, every border quadrant had a higher insect diversity than the corresponding cultivated quadrant (Figure 6). This result corresponds with the existing literature supporting the fact that less management intensity allows for the support and growth of arthropod communities in soil (Tylianakis, Klein, Tscharntke, 2005). However, it is important to note that distinct differences have been found in arthropod communities that exist in more open areas verses shaded communities such as forest, as community abundance increases with light intensity (Teodoro et al., 2011). Additionally, in the same study less than 1/3 of arthropod species were found in both the shaded forest ecosystem and the open pasture (Teodoro et al., 2011). None of the border quadrants were established primary or secondary forests and the β diversity for every soil sample collection is relatively low signifying similar communities shared between the cultivated and border areas. Future work would be to extend the study into more established forest systems in the area to compare abundance and composition of soil insect populations between agricultural management styles and forest.

For the netting collection, two out of four of the border quadrants had a higher insect abundance, and three out of four border quadrants had a higher Shannon-Weiner diversity, apart from Q5 (Table 2, Figure 6). This pattern can be attributed to a higher plant biodiversity in the border quadrants (Scherber et al., 2013; Cuartas-Hernández & Cómez-Murillo, 2015). This phenomenon has been observed in other agricultural studies. Increased biodiversity on the edges of agricultural fields had led to a positive edge effect with more diverse species interactions, leading to more diverse and dense insect community living on the borders (Grez et al., 2004; Schillinger, 2011) Both border quadrants with higher diversity and abundance in in this study surround organically managed fields (Table 2). In a study measuring insect biodiversity in differently managed wheat fields, there was higher insect biodiversity in the direct borders of the organically managed fields verses the conventionally managed fields (Batáry et al., 2012). It is important to note that every border represents a transition zone between directly disturbed land and undisturbed forest. Future work would be to extend the study into more established forest systems in the area to compare abundance and composition of winged insect populations between agricultural management styles and forest.

The exception to the pattern of higher abundance in the border quadrants verses the cultivated quadrants was the netting collection for the inorganic cultivation. Q3 has a much higher abundance and a higher species richness than Q4 (Table 2, Figure 6). For Q4, the quadrant was dominated by a Fabaceae and Rosaceae plant that were covered with spiny hairs. The net would catch on the hairs and prevent full access to parts of the quadrant, which limited the potential insect collection. Additionally, while Q3 is an inorganic cultivation which uses conventional practices such as fumigation and synthetic fertilizer, the most recent application of the fumigation was 5 months before the study was conducted (Appendix D). Fumigation can function not to only kill insect, but simply make them flee the area that the chemical was applied (Rodrigues, Varriale, Godoy, Mistro, 2012). It is possible that the insects in Q3, which consisted

largely of a Cicadellidae morphospecies and a Chrysomelidae morphospecies had enough time to return to the cultivated area in between fumigation periods. While this result was not directly observed in the species richness of the two quadrants, the lower biodiversity found in conventional agriculture correlates to the higher Shannon-Weiner diversity calculated for Q4, the border quadrant. While the pure abundance of Q4 was lower than Q3 potentially due to a problem with collection, the Shannon-Weiner diversity was higher (Table 2). The border of the inorganic cultivated area is more diverse in terms of evenness of identified morphospecies.

      The exception to the pattern of higher insect abundance and diversity in the border quadrants verse the cultivated quadrants was the netting collection for the traditional organic polyculture. Q5 has a much higher abundance and species richness than Q6. However, there was a severe weather difference between the collection times in each quadrant that was not as dramatic for other collection periods. The two-hour collection period for Q5 was 10°C warmer than the collection period for Q6 (Appendix C). Optimum insect collection temperatures are much warmer than what was experienced in the cloud forest during the collection period, with a minimum of 28°C for optimum insect activity (Williams & Osman, 1960). Additionally, the weather during the two collection periods was different. During the collection period in Q5 there was significant sun, while the collection period in Q6 experienced lots of clouds and mist. Insect activity decreases with precipitation (Poulson, July 1996), and the difference in weather could have affected the number of insects collected in Q6 due to lack of activity.

*Agriculture as Functioning Biological Corridors*

      With increased agricultural fragmentation it is essential to understand if forms of agriculture can function as biological corridors. There was less biodiversity and abundance found in most of the cultivated areas verses their corresponding borders (Figure 6). Insect populations respond to fragmentation in various ways. Literature explains that insect populations are effected by large scale fragmentation in simplified ecosystems that lack biodiversity with large patches of cleared land (Rösch et al., 2013; Jha et al., 2010). It is possible to mitigate the effects of fragmentation by connecting small fragments of complex patches that already contain higher levels of plant biodiversity (Rösch et al., 2013). Traditionally, natural diverse grass strips that are left unmanaged serve as effective biological corridors for insects (Krewenka, Holzchuh, Tscharntke, Dormann, 2011). Literature also supports the possibility that insect population densities can experience short-term growth with increased small-scale fragmentation because the isolation of populations of the same species minimizes competition (Grez et al., 2004). However, the long terms effects of this positive correlation have not been studied, and it is necessary to find ways to mitigate the genetic isolation and loss of ecosystem services already affecting insects due to fragmentation (Leimu et al., 2010; Aizen & Feinsinger, 1994).

      Q5, the traditional organic polyculture quadrant and its border share 1.300 winged insect communities and 1.372 soil insect communities (Table 4), which are the two most similar communities between all the cultivated and border quadrants tested. Q5 also has the highest insect and plant biodiversity out of all the cultivated quadrants tested (Figure 4, 5, 9). The combination of these factors demonstrates that the traditional organic polyculture would be the most effective as a biological corridor for insects, both for conservation and for agricultural purposes. While few pollinators were collected in this study due to a lack of flowering plants during the season the study was conducted, pollinators depend on fragment connections for pollen transfers (Townsend & Levey, 2005; Van Greet, Van Rossum, Triest, 2010). With biological corridors bees can transfer genetic data to a higher variety of plants over longer distances, increasing genetic variation (Townsend & Levey, 2005). A larger gene pool is

necessary for natural and cultivated plant fitness. Furthermore, the most commonly identified order of insect in this study were Diptera, which are essential for natural pest control in agriculture and to the nutrient cycle (Mohan et al., 1993; Weisser & Siemann, 2008). Q5 contained over 16 morphospecies of Diptera, with an estimated coverage deficit of 0.500 (Table 6). It is feasible to estimate there is a much higher biodiversity of Diptera supported within traditional organic polyculture (Scherber et al., 2014). Q5 supports a more complex community of insects due to its variety of crops and low intensity management (Tscharntke et al., 2008), mimicking the most effective biological corridors for insects to use in fragmented ecosystems (Rösch et al., 2013; Townsend & Levey, 2005; Van Greet, Van Rossum, Triest, 2010).

## Conclusion

Out of four different agricultural management styles studied, the traditional organic polyculture contained the highest biodiversity and abundance of both soil and winged insects found in a cultivated area. It also had the most similar soil and winged insect communities to its border surrounding the field. Polycultures, intercropping, and alternative agricultural management styles can house a higher abundance and biodiversity of insects, and have been proven to reduce overall insect herbivory as well as increase crop yield. This type of agriculture that mimics natural aspects of ecosystems such as increased plant biodiversity, natural pest control by the presence of other insects, and more nutrient rich soil has the potential function as biological corridors between cultivated and natural fragments in deforested and recovering ecosystems.

This study is only a beginning to understanding the value of organic polycultures as biological corridors for insects. Future work would be to expand the sample size to increase sample coverage. This could be either by collecting from the same quadrant multiple times to demonstrate consistency and collect more rare insects or expand the study to test more quadrants and more types of borders. It is also valuable to test quadrants in primary and secondary forest to understand how well agriculture can function as a corridor for insects for pure natural habitats. This study would also benefit from summer collections as weather highly impacted the study. More research needs to be done not only to understand how agricultural management styles can function as biological corridors, but how to optimize these corridors to support insect populations and build a more efficient and sustainable agricultural system.

## Acknowledgments

**Bibliography**

About Us: Yunguilla Cloud Forest. (2016). Retrieved from Conservando el Bosque Nublado: Yunguilla website: http://www.yunguilla.org.ec/en/about-us/

Aizen, M. A., & Feinsinger, P. (1994). Forest Fragmentation, Pollination, and Plant Reproduction in a Chaco Dry Forest, Argentina. *Ecology*, *75*(2), 330–351.

Batáry, P., Holzschuh, A., Orci, K. M., Samu, F., & Tscharntke, T. (2011). Responses of plant, insect and spider biodiversity to local and landscape scale management intensity in cereal crops and grasslands. *Agriculture, Ecosystems and Environment*, *146*, 130–136.

Borror, D. J., Triplehorn, C. A., & Johnson, N. F. (1989). *An Introduction to the Study of Insects* (6th ed.). Thomas Learning, Inc.

Carrera, M. I., Bustamante, M., & Sáenz, M. (2016). *Las áreas protegidas del Distrito Metropolitano de Quito: Conocer nuestro patrimonio natural* (No. FA-003-2015). SAMDMQ/Fondo Ambiental: CONDESAN.

Castellanos, A. (2011). Andean bear home ranges in the Intag region, Ecuador. *Ursus*, *22*(1), 65–73.

Cayuela, L., Golicher, D. J., & Rey-Benayas, J. M. (2006). The Extent, Distribution, and Fragmentation of Vanishing Montane Cloud Forest in the Highlands of Chiapas, Mexico. *Biotropica*, *38*(4), 544–554.

Chao, A., & Jost, L. (2012). Coverage-based rarefaction and extrapolation: Standardizing samples by completeness rather than size. *Ecology*, *93*(12), 2533–2547.

Cuartas-Hernández, S., & Gómez-Murillo, L. (2015). Effect of Biotic and Abiotic Factors on Diversity Patternsof Anthophyllous Insect Communities in a Tropical Mountain Forest. *Neotropical Entomology*, *44*(214–223).

Dáttilo, W., Aguirre, A., Quesada, M., & Dirzo, R. (2015). Tropical Forest Fragmentation Affects Floral Visitors but Not the Structure of IndividualBased Palm-Pollinator Networks. *PLoS ONE*, *10*(3), 15.

DeBach, P. (1974). Biological Control by Natural Enemies, 322. Cambridge University Press, London.

Didham, R. K., Ghazoul, J., Stork, N. E., & Davis, A. J. (1996). Insects in fragmented forests: A functional approach. *Trends in Ecology and Evolution*, *11*(6), 255–260.

Doumenge, C., Gilmour, D., Pérez, M. R., & Blockhus, J. (1995). Tropical Montane Cloud Forests: Conservation Status and Management Issues. In L. S. Hamilton, J. O. Juvik, & F. N. Scatena (Eds.), *Tropical Montane Cloud Forests* (pp. 24–37). New York, NY: Springer US.

Fagua, J. C., & Ramsey, R. D. (2019). Geospatial modeling of land cover change in the Choco´-Darien global ecoregion of South America; One of most biodiverse and rainy areas in the world. *PLoS ONE*, *14*(2), 25.

Foottit, R. G., & Adler, P. H. (Eds.). (2009). *Insect Biodiversity: Science and Society*. United Kingdom: Blackwell Publishing Ltd.

Futuyma, D. J., & Agrawal, A. A. (2009). Macroevolution and the biological diversity of plants and herbivores. *PNAS*, *106*(43), 18054–18061. https://doi.org/doi10.1073pnas.0904106106

Gibb, T. J. (2019). *Insect Collection and Identification: Techniques for the Field and Laboratory* (2nd ed.). Elsevier Science & Technology.

Grimaldi, D. and M. S. Engel. (2005). Evolution of the Insects. Cambridge University Press, New York. 755 pp.

Grez, A., Zaviezo, T., Tischendorf, L., & Fahrig, L. (2004). A transient, positive effect of habitat fragmentation on insect population densities. *Population Ecology*, *141*, 444–451.

Hammer, T. J., Dickerson, J. C., & Fierer, N. (2015). Evidence-based recommendations on storing and handling specimens for analyses of insect microbiota. *PeerJ: Life and Environment*, *3*. Retrieved from https://peerj.com/articles/1190/#supp-3

Hancock, M. H., & Legg, C. J. (2012). Pitfall trapping bias and arthropod body mass. *Insect Conservation and Diversity*, *5*, 312–318. https://doi.org/10.1111/j.1752-4598.2011.00162.x

Hermes, C., Segelbacher, G., & Shaefer, H. M. (2018). A framework for prioritizing areas for conservation in tropical montane cloud forests. *Écoscience*, *25*(1), 97–108. https://doi.org/10.1080/11956860.2017.1419787

Jha, S., Dick, C. W., & Dirzo, R. (2010). Native bees mediate long-distance pollen dispersal in a shade coffee landscape mosaic. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(31), 13760–13764.

Jost, L. (2007). Partitioning diversity into independent alpha and beta components. *Ecology*, *88*, 2427–2439.

Jost, L., Chao, A., & Chazdon, R. L. (2011). Compositional similarity and β (beta) diversity. In *Biological Diversity: Frontiers in Measurement and Assessment* (pp. 66–84). Retrieved from http://chao.stat.nthu.edu.tw/wordpress/paper/87.pdf

Kayden, M. B., Benedicty, Z. K., Williams, D. J., & Szita, É. (2017). Soil Insect (Hemiptera, Coccomorpha) Survey of Soil Samples from Southern Asia with Description of Two New Species of Rhizoecidae. *Acta Zoologica Academiae Scientiarum Hungaricae*, *6*(3), 309–325. https://doi.org/10.17109/

Krewenka, K. M., Holzschuh, A., Tscharntke, T., & Dormann, C. F. (2011). Landscape elements as potential barriers and corridors for bees, wasps and parasitoids. *Biological Conservation*, *144*, 1816–1825.

Kruess, A., & Tscharntke, T. (2000). Species richness and parasitism in a fragmented landscape: Experiments and field studies with insects on Vicia sepium. *Oecologia*, *122*, 129–137.

Leimu, R., Vergeer, P., Angeloni, F., & Ouborg, N. J. (2010). Habitat fragmentation, climate change, and inbreeding in plants. *Annals of the New York Academy of Sciences*, 84–98. https://doi.org/10.1111/j.1749-6632.2010.05450.x

Letourneau, D. K., Armbrecht, I., Rivera, B. S., Lerma, J. M., Carmona, E. J., Daza, M. C., … Trujillo, A. R. (2011). Does plant diversity benefit agroecosystems? A synthetic review. *Ecological Applications*, *21*(1), 9–21.

Lozada, T., de Koning, G. H. J., Marché, R., Klein, A.-M., & Tscharntke, T. (2005). Tree recovery and seed dispersal by birds: Comparing forest, agroforestry and abandoned agroforestry in coastal Ecuador. *Perspectives in Plant Ecology, Evolution and Systematics*, *8*, 131–140.

Martínez-Morales, M. A. (2004). Landscape patterns influencing bird assemblages in a

fragmented neotropical cloud forest. *Biological Conservation*, *121*, 11–126.

Mohan, S., Gopalan, M., & Sreenarayanan, V. V. (1993). Fish-Meal Waste as an Attractant for Economically Important Flies of Agricultural Crops. *Bioresource Technology*, *43*(2), 175–176.

Nault, L. R. (1994). Transmission biology, vector specificity and evolution of planthopper-transmitted plant viruses. In R. F. Denno and T. J. Perfect (eds). *Planthoppers: Their Ecology and Management*, 429–448. Chapman and Hall, New York.

Naylor, R. L. and P. R. Ehrlich. (1997). Natural pest control services and agriculture. G. C. Daily (ed). *Nature's Services. Societal Dependence on Natural Ecosystems*, 151–174. Island Press, Washington, DC.

Nicholls, C. I., & Altieri, M. A. (2004). Designing Species-Rich, Pest-Suppressive Agroecosystems through Habitat Management. In *Agroecosystems Analysis* (pp. 49–62). Madison, WI: American Society of Agronomy.

Poulsen, B. O. (1996). Relationships between frequency of mixed-species flocks, weather and insect activity in a montane cloud forest in Ecuador. *IBIS*, *138*, 466–470.

Rodrigues, L. A. D., Varriale, M. C., Godoy, W. A. C., & Mistro, D. C. (2013). Spatiotemporal dynamics of an insect population in response to chemical substances. *Ecolocial Complexity*, *16*, 51–58.

Rösch, V., Tscharntke, T., Scherber, C., & Batáry, P. (2013). Landscape composition, connectivity and fragment size drive effects of grassland fragmentation on insect communities. *Journal of Applied Ecology*, *50*, 387–394.

Roulston, T. H., Smith, S. A., & Brewster, A. L. (2007). A Comparison of Pan Trap and Intensive Net Sampling Techniques for Documenting a Bee (Hymenoptera: Apiformes) Fauna. *Journal of the Kansas Entomological Society*, *80*(2), 179–181.

Scherber, C., Vockenhuber, E. A., Stark, A., Meyer, H., & Tscharntke, T. (2014). Effects of tree and herb biodiversity on Diptera, a hyperdiverse insect order. *Oecologia*, *174*, 1387–1400.

Schillinger, W. F. (2010). Practical lessons for successful long-term cropping systems experiments. *Renewable Agriculture and Food Systems*, *26*(1), 1–3.

Sonoda, S., Izumi, Y., Kohara, Y., Koshiyama, Y., & Yoshida, H. (2011). Effects of pesiticide practices on insect biodiversity in peach orchards. *The Japanese Society of Applied Entomology and Zoology*, *46*, 335–342. https://doi.org/10.1007/s13355-011-0041-2

Southwick, E. E. and L. Southwick, Jr. (1992). Estimating the economic value of honey bees (Hymenoptera: Apidae) as agricultural pollinators in the Untied States. *Journal of Economic Entomology, 85,* 621–633.

Stork, N. E. (1993). How many species are there? *Biodiversity & Conservation*, *2*(3), 215–232. https://doi.org/10.1007/BF00056669

Teodoro, A. V., Muñoz, A., Tscharntke, T., Klein, A.-M., & Tylianakis, J. M. (2011). Early succession arthropod community changes on experimental passion fruit plant patches along a land-use gradient in Ecuador. *Agriculture, Ecosystems and Environment*, *140*(1–2), 14–19.

Townsend, P. A., & Levey, D. J. (2005). An Experimental Test of Whether Habitat Corridors Affect Pollen Transfer. *Ecology*, *86*(2), 466–475.

Tscharntke, T., & Brandl, R. (2004). Plant-Insect Interactions in Fragmented Landscapes. *Annu. Rev. Entomol.*, *49*, 405–430.

Tscharntke, T., Sekercioglu, C. H., Dietsch, T. V., Sodhi, N. S., Hoehn, P., & Tylianakis, J. M. (2008). Landscape Constraints on Functional Diversity of Birds and Insects in Tropical Agroecosystems. *Ecology*, *89*(4), 944–951.

Tylianakis, J.M., Klein, A.M., Tscharntke, T. (2005). Spatiotemporal variation in the diversity of hymenoptera across a tropical habitat gradient. *Ecology*, *12*, 3296–3302.

van Bruggen, A. H. C., Sharma, K., Kaku, E., Karfopoulos, S., Zelenev, V. V., & Blok, W. J. (2015). Soil health indicators and Fusarium wilt suppression in organically and conventionally managed greenhouse soils. *Applied Soil Ecology*, *86*, 192–201.

Van Geert, A., Van Rossum, F., & Triest, L. (2010). Do Linear Landscape Elements in Farmland Act as Biological Corridors for Pollen Dispersal? *Journal of Ecology*, *98*(1), 178–187.

Weeks Jr., R. D., & McIntyre, N. E. (1997). A comparison of live versus kill pitfall trapping techniques using various killing agents. *Kluwer Academic Publishers*, *82*, 267–273.

Weisser, W. W., & Siemann, E. (2008). The Various Effects of Insects on Ecosystem Functioning. In Wolfgang W. Weisser & E. Siemann (Eds.), *Insects and Ecosystem Function* (pp. 3–24). https://doi.org/10.1007/978-3-540-74004-9_1

Williams, C. B., & Osman, M. F. H. (1960). A New Approach to the Problem of the Optimum Temperature for Insect Activity. *Journal of Animal Ecology*, *29*(1), 187–189.

**Appendix**

| Quadrant | Description |
| --- | --- |
| Q1: western organic | Part of the community garden, quite large with a variety of crops growing in the garden on various double tilled beds. Surrounded by different types of habitats including secondary forest, pasture, a maintained nursery, and a clearing used for a parking lot. Every part of the garden had a path about a foot wide surrounding the edge, separating the garden from its various borders. The gooseberry plant was flowering. |
| Q2: western organic border | Part of the 10 m border space in between the maintained community garden and the reforested secondary forest. Separated from Q1 by the path. The land had never been explicitly cultivated but some squash like crops and chiwalcan just ended up there probably by virtue of being so near the garden. The land was cleared at some point within the last 10 years because there are no shrubs or semi established trees, just long-standing trees or pioneer species. The zambo was flowering as well as the hierba de mora and a type of Solanaceae. |
| Q3: inorganic | Part of a community member's personal garden where they focus on growing potatoes. They use fumigation as a tactic but unclear at the moment when the last time they fumigated was or what type they use considering there was a decent number of weeds growing in the quadrant. The border is completely secondary forest, but parts were overgrown with invasive bamboo and other parts consisted of more native plants (that happened to be majority spiny). A couple weeds were flowering. |
| Q4: inorganic border | Directly bordering cleared land for the potato plot. Consisted of secondary forest that had some decently established trees but mostly consisted of pioneer spiny plants. Decent ground litter, probably10 cm |

| | | |
|---|---|---|
| | thick before reaching actual soil. The large trees were beginning to flower but nothing had bloomed, and the mint like plant was flowering but was only a very small part of the entire quadrant. | |
| Q5: traditional organic | Part of a community family's personal farm about a 25-minute drive from the center of the community. A large space with a variety of borders including pasture, other types of cultivation that are not traditional agriculture, and fallow land that used to be cultivated but is either resting or no longer in use. The bean crop was flowering as well as one additional weed. | |
| Q6: traditional organic border | Directly bordering the area of traditional agriculture. Land was cultivated at some point but is now fallow and being overgrown by various pioneer species such as grasses, vines, and "mandor". Soil was much harder and more compressed than any other soils encountered before. Various wildflowers were blooming. | |
| Q7: western organic monoculture | Part of a community member's personal garden. Mostly large corn monoculture, occasional small pockets of other plants but all separated. Variety of borders consisting of a house/road/human area, pasture, slight piece of secondary forest that is practically growing on a 90 degree angle. Nothing flowering. | |
| Q8: western organic monoculture border | Consists of tiny bit of land on the side of the corn field mostly populated by grass, zambo and other majority pioneer plants. The area would have been cleared at some point but hasn't been cultivated for anything recently. Various plants were blooming including one tree with trumpet flowers, some mint like thing and some Fabaceae. *no quality secondary forest border around (was shown this location very last minute and did not have time to be picky) | |

*Appendix A: detailed descriptions of quadrants tested*

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 |
|---|---|---|---|---|---|---|---|---|
| **Date** | 11/11 | 11/13 | 11/15 | 11/18 | 11/20 | 11/20 | 11/28 | 11/28 |
| **Soil pH** | 6.8 | 7.5 | 7.5 | 7.5 | 7.7 | 8 | 7.5 | 8 |
| **Soil humidity** | 8.5 | 4 | 10 | 3 | 3 | 3 | 2 | 4 |
| **Temp soil collection** | 19 | 13.9 | 15.3 | 16.5 | 26.1 | 14.4 | 19.2 | 16.4 |
| **Humidity soil collection** | 83% | 95% | 89% | 91% | 77% | 86% | 83% | 81% |
| **Weather** | cloudy, little mist | cloudy, little mist | cloudy | sunny, slight breeze | sunny, slight breeze | sunny, slight breeze | partly sunny | partly sunny |

*Appendix B*. Abiotic conditions during soil sample collection

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 |
|---|---|---|---|---|---|---|---|---|
| **Date morning** | 11/10 | 11/12 | 11/14 | 11/16 | 11/19 | 11/21 | 11/26 | 11/27 |

| Date afternoon | 11/10 | 11/12 | 11/14 | 11/16 | 11/19 | 11/20 | 11/26 | 11/27 |
|---|---|---|---|---|---|---|---|---|
| **Temp morning** | 25.9 | 15.9 | 13.6 | 26.5 | 16.5 | 14.2 | 17.1 | 15.5 |
| **Temp afternoon** | 29.5 | 17.9 | 18.6 | 16.8 | 15.4 | 16.6 | 19.9 | 21.4 |
| **Humidity morning** | 59% | 91% | 90% | 92% | 88% | 84% | 90% | 83% |
| **Humidity afternoon** | 50% | 91% | 83% | 91% | 79% | 74% | 83% | 78% |
| **Weather morning** | lots of sun | misty, cloudy, sun comes out a bit last half hour | partly cloudy, slight breeze, total sun last hour | partly cloudy, sun peeking through | partly cloudy, decent sun | partly cloudy, misty | nice and sunny, slight breeze | partly cloudy, but sun came out |
| **Weather afternoon** | sunny first hour, misty last hour | misty cloudy, sun peaking a bit | cloudy, misty, got cold | cloudy with dropping temp | windy, misty | slight mist | partly cloudy, nicest afternoon yet | mostly cloudy, mist rolling through, no precipitation |

*Appendix C.* Abiotic conditions during morning and afternoon netting collections

| Questions | ¿Qué tipo de agricultura practica? | ¿Usa algunos aditivos? | ¿Cuantas veces usa estes aditivos? | ¿Añade agua a sus cultivos? | ¿Hace algo para prevenir la entrada de insectos en los cultivos? |
|---|---|---|---|---|---|
| **Western organic polyculture** | Organica | fertalizante y compost | 3 meses | lunes, miércoles, viernes en verano | Sí |
| **Notes** | no químicos, toda naturaleza nada sintética, solo fertilizador | | | no necesita ahora porque es invierno y hay lluvia | usa ceniza- quema basura a lado del huerto, además de humo pone ceniza directamente en el suelo |
| **Traditional Organic** | organica tradicional | compost | 6 meses | no, solo que lleuve | no |
| **Notes** | | | | | |

| Conventional | agricultura inorganica, convencional | fumigación, sintetico fertalizante | 2 veces en 5 meses | no usa irigación | fumigación |
|---|---|---|---|---|---|
| **Notes** | | Marcas: Ridomil cello verde, 10/30/10 | la última vez fue 5 meses pasados | | |
| **Western organic monoculture** | organico | no | NA | no, solo que llevue | no |
| **Notes** | no tipo de fumigación, solo 5 años pasados cuando crecieron papas | | | | |

*Appendix D.* Growing practices for the four types of agriculture tested

| Morphospecies | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 |
|---|---|---|---|---|---|---|---|---|
| acrididae sp.1 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| agromyzidae sp.1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| agromyzidae sp.2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| anthribidae sp.1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| aphelinidae sp.1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| aphelinidae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| aphididae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| apinae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| apis sp. 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Asilidae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| bibionidae sp.1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| bibionidae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| braconidae sp.4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| braconidae sp.1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| braconidae sp.2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| braconidae sp.3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| braconidae sp.5 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| braconidae sp.5 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| braconidae sp.6 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 |
| braconidae sp.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| cecidomyiidae sp.1 | 0 | 1 | 0 | 0 | 6 | 2 | 0 | 1 |
| cecidomyiidae sp.2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| ceraphonidae sp.1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| ceratopogonidae sp.1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| chlropidae sp.1 | 21 | 46 | 0 | 12 | 80 | 26 | 2 | 41 |
| chlropidae sp.2 | 5 | 1 | 1 | 0 | 4 | 0 | 0 | 0 |
| chlropidae sp.3 | 1 | 9 | 0 | 0 | 5 | 1 | 0 | 7 |
| chlropidae sp.4 | 0 | 1 | 0 | 0 | 7 | 5 | 1 | 2 |
| chlropidae sp.5 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| chlropidae sp.6 | 0 | 0 | 0 | 1 | 16 | 0 | 0 | 0 |
| Chlropidae sp.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| Chlropidae sp.8 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Chlropidae sp.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| cicadellidae sp.10 | 0 | 10 | 0 | 0 | 4 | 1 | 1 | 1 |
| cicadellidae sp.11 | 0 | 5 | 0 | 0 | 2 | 0 | 1 | 0 |
| cicadellidae sp.12 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| cicadellidae sp.13 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| cicadellidae sp.14 | 0 | 1 | 2 | 0 | 4 | 0 | 0 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| cicadellidae sp.15 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| cicadellidae sp.16 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 |
| cicadellidae sp.17 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 1 |
| cicadellidae sp.18 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| cicadellidae sp.2 | 14 | 1 | 28 | 0 | 20 | 1 | 1 | 7 |
| cicadellidae sp.20 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| cicadellidae sp.21 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| cicadellidae sp.3 | 6 | 0 | 48 | 0 | 0 | 0 | 0 | 4 |
| cicadellidae sp.4 | 12 | 0 | 0 | 0 | 33 | 2 | 2 | 5 |
| cicadellidae sp.5 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| cicadellidae sp.6 | 1 | 16 | 8 | 3 | 0 | 0 | 1 | 3 |
| cicadellidae sp.7 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 2 |
| cicadellidae sp.22 | 0 | 3 | 0 | 0 | 5 | 0 | 0 | 8 |
| cicadellidae sp.8 | 1 | 1 | 9 | 0 | 0 | 0 | 0 | 2 |
| cicadellidae sp.9 | 0 | 3 | 0 | 0 | 3 | 1 | 1 | 2 |
| crysomelidae sp.1 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 |
| crysomelidae sp.10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| crysomelidae sp.2 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| crysomelidae sp.3 | 4 | 9 | 59 | 7 | 7 | 2 | 12 | 3 |
| crysomelidae sp.4 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 0 |
| crysomelidae sp.5 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| crysomelidae sp.6 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| crysomelidae sp.7 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| crysomelidae sp.8 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 0 |
| crysomelidae sp.9 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| curculionidae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| curculionidae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| cydnidae sp.1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| cynipidae sp.1 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 |
| cynipidae sp.2 | 0 | 0 | 1 | 0 | 3 | 0 | 0 | 1 |
| cynipidae sp.3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| cynipidae sp.4 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| cynipidae sp.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| delphasidae sp. 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| delphasidae sp.3 | 0 | 1 | 1 | 1 | 5 | 0 | 0 | 0 |
| derodontidae sp.1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 |
| diapriidae sp.1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| diapriidae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| diptera sp.1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| diptera sp.10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| diptera sp.2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| diptera sp.3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| diptera sp.4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| diptera sp.11 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| diptera sp.5 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| diptera sp.6 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| diptera sp.7 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| diptera sp.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| diptera sp.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| dixidae sp.1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| dolichopodidae sp.1 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| elateridae sp.1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| elmidae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| eulossini sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| eupelmidae sp.1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| eurytomidae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| eurytomidae sp.2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| eurytomidae sp.3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| formicidae sp.1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| formicidae sp.2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| formicidae sp.3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| formicidae sp.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| hymenoptera sp.1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| hymenoptera sp.2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| hymenoptera sp.3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| hymenoptera sp.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ichneumonidae sp.1 | 1 | 3 | 0 | 1 | 0 | 0 | 0 | 0 |
| ichneumonidae sp.2 | 1 | 6 | 0 | 1 | 0 | 0 | 0 | 4 |
| ichneumonidae sp.3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| ichneumonidae sp.4 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| ichneumonidae sp.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| ichneumonidae sp.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| lathridiidae sp.1 | 1 | 11 | 0 | 0 | 0 | 3 | 0 | 1 |
| lygaidae sp.1 | 8 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| megachilidae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| megaspilidae sp.1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| membracidae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| milichiidae sp.1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| miridae sp.2 | 0 | 2 | 13 | 0 | 2 | 1 | 2 | 1 |
| miridae sp.3 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 |
| miridae sp.4 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| miridae sp.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| muscidae sp.1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| muscidae sp.2 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| muscidae sp.3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| muscidae sp.4 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| muscoidea sp.1 | 0 | 0 | 2 | 0 | 5 | 7 | 0 | 1 |
| muscoidea sp.2 | 0 | 0 | 0 | 0 | 1 | 6 | 0 | 9 |
| muscoidea sp.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| muscoidea sp.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| muscoidea sp.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| mycetophilidae sp.1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| mymaridae sp.1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| mymaridae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| mymaridae sp.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| nabidae sp.1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| nabidae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| neelidae sp.1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pentatomidae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| phoridae sp.1 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| phoridae sp.2 | 0 | 1 | 0 | 0 | 3 | 3 | 0 | 1 |
| piophilidae sp.1 | 15 | 0 | 2 | 1 | 1 | 0 | 2 | 3 |
| piophilidae sp.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| reduviidae sp.1 | 1 | 3 | 8 | 0 | 0 | 0 | 0 | 0 |
| reduviidae sp.2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| reduviidae sp.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| reduviidae sp.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| scelionidae sp.1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| sciaridae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| scolytidae sp.1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| scolytidae sp.2 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Sepsidae sp.1 | 0 | 0 | 0 | 0 | 8 | 3 | 0 | 0 |
| sphecidae sp.2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| sphecidae sp.3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| staphylinidae sp.1 | 0 | 9 | 2 | 1 | 1 | 2 | 0 | 2 |
| staphylinidae sp.2 | 0 | 0 | 0 | 1 | 2 | 2 | 0 | 0 |
| staphylinidae sp.3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| syrphidae sp.1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| syrphidae sp.2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| tachinidae sp.1 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 0 |
| tephritidae sp.1 | 4 | 15 | 0 | 1 | 1 | 9 | 1 | 15 |
| tephritidae sp.2 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 |
| tephritidae sp.3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 5 |
| tephritidae sp.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| thripidae sp.1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| thripidae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| tipulidae sp.1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| torymidae sp.1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| torymidae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

acrididae sp.1 · agromyzidae sp.1 · agromyzidae sp.2 · anthribidae sp.1 · aphelinidae sp.1 · aphelinidae sp.2 · aphididae sp.1 · apinae sp.1 · apis sp. 1

Asilidae sp.1 · bibionidae sp.1 · bibionidae sp.2 · braconidae sp.4 · braconidae sp.1 · braconidae sp.2 · braconidae sp.3 · braconidae sp.5 · braconidae sp.5

braconidae sp.6 · braconidae sp.7 · cecidomyiidae sp.1 · cecidomyiidae sp.2 · ceraphonidae sp.1 · ceratopogonidae sp.1 · chlropidae sp.1 · chlropidae sp.2 · chlropidae sp.3

chlropidae sp.4 · chlropidae sp.5 · chlropidae sp.6 · Chlropidae sp.7 · Chlropidae sp.8 · Chlropidae sp.9 · cicadellidae sp.10 · cicadellidae sp.11 · cicadellidae sp.12

cicadellidae sp.13 · cicadellidae sp.14 · cicadellidae sp.15 · cicadellidae sp.16 · cicadellidae sp.17 · cicadellidae sp.18 · cicadellidae sp.2 · cicadellidae sp.20 · cicadellidae sp.21

cicadellidae sp.3 · cicadellidae sp.4 · cicadellidae sp.5 · cicadellidae sp.6 · cicadellidae sp.7 · cicadellidae sp.22 · cicadellidae sp.8 · cicadellidae sp.9 · crysomelidae sp.1

crysomelidae sp.10 · crysomelidae sp.2 · crysomelidae sp.3 · crysomelidae sp.4 · crysomelidae sp.5 · crysomelidae sp.6 · crysomelidae sp.7 · crysomelidae sp.8 · crysomelidae sp.9

curculionidae sp.1 · curculionidae sp.2 · cydnidae sp.1 · cynipidae sp.1 · cynipidae sp.2 · cynipidae sp.3 · cynipidae sp.4 · cynipidae sp.5 · delphasidae sp. 2

delphasidae sp.3 · derodontidae sp.1 · diapriidae sp.1 · diapriidae sp.2 · diptera sp.1 · diptera sp.10 · diptera sp.2 · diptera sp.3 · diptera sp.4

diptera sp.11 · diptera sp.5 · diptera sp.6 · diptera sp.7 · diptera sp.8 · diptera sp.9 · dixidae sp.1 · dolichopodidae sp.1 · elateridae sp.1

elmidae sp.1 · eulossini sp.1 · eupelmidae sp.1 · eurytomidae sp.1 · eurytomidae sp.2 · eurytomidae sp.3 · formicidae sp.1 · formicidae sp.2 · formicidae sp.3

formicidae sp.4 · hymenoptera sp.1 · hymenoptera sp.2 · hymenoptera sp.3 · hymenoptera sp.4 · ichneumonidae sp.1 · ichneumonidae sp.2 · ichneumonidae sp.3 · ichneumonidae sp.4

ichneumonidae sp.5 · ichneumonidae sp.6 · lathridiidae sp.1 · lygaidae sp.1 · megachilidae sp.1 · megaspilidae sp.1 · membracidae sp.1 · milichiidae sp.1 · miridae sp.2

miridae sp.3 · miridae sp.4 · miridae sp.5 · muscidae sp.1 · muscidae sp.2 · muscidae sp.3 · muscidae sp.4 · muscoidea sp.1 · muscoidea sp.2

muscoidea sp.3 · muscoidea sp.4 · muscoidea sp.5 · mycetophilidae sp.1 · mymaridae sp.1 · mymaridae sp.2 · mymaridae sp.3 · nabidae sp.1 · nabidae sp.2

neelidae sp.1 · Pentatomidae sp.1 · phoridae sp.1 · phoridae sp.2 · piophilidae sp.1 · piophilidae sp.3 · reduviidae sp.1 · reduviidae sp.2 · reduviidae sp.3

reduviidae sp.4 · scelionidae sp.1 · sciaridae sp.1 · scolytidae sp.1 · scolytidae sp.2 · Sepsidae sp.1 · sphecidae sp.2 · sphecidae sp.3 · staphylinidae sp.1

staphylinidae sp.2 · staphylinidae sp.3 · syrphidae sp.1 · syrphidae sp.2 · tachinidae sp.1 · tephritidae sp.1 · tephritidae sp.2 · tephritidae sp.3 · tephritidae sp.4

thripidae sp.1 · thripidae sp.2 · tipulidae sp.1 · torymidae sp.1 · torymidae sp.2

*Appendix E.* Morphospecies shown in the raw data comparison graph for the netting collection (Figure 4)

| Morphospecies | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 |
|---|---|---|---|---|---|---|---|---|
| aphididae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| blattidae sp.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| carabidae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| chilopoda sp.1 | 0 | 0 | 2 | 3 | 0 | 0 | 0 | 0 |
| chilopoda sp.2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 5 |
| chilopoda sp.3 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| chrysomelidae sp.1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| cicadellidae sp.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| coleoptera sp.1 | 0 | 21 | 1 | 6 | 2 | 1 | 3 | 1 |
| coleoptera sp.2 | 0 | 3 | 0 | 1 | 1 | 0 | 0 | 0 |
| coleoptera sp.3 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 3 |
| coleoptera sp.4 | 3 | 0 | 0 | 0 | 2 | 1 | 0 | 0 |
| coleoptera sp.5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| collembola sp.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| culicidae sp.1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| cydnidae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| delphasidae sp.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| diplopoda sp.1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 14 |
| diplopoda sp.2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 9 |
| diplopoda sp.3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| diplopoda sp.4 | 0 | 14 | 0 | 5 | 0 | 0 | 0 | 0 |
| Endomychidae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| formicidae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| isopoda sp.1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| lampiridae sp.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| lepidoptera sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| lygaidae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| miridae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| miridae sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| nepdiae sp.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| oligocheta sp.1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 |
| oligocheta sp.2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| oligocheta sp.3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| ptilodactylidae sp.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| scarabaeidae sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| sphecidae sp.1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| staphylinidae sp.1 | 2 | 0 | 0 | 4 | 1 | 7 | 0 | 1 |
| staphylinidae sp.2 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 3 |
| staphylinidae sp.3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| tenebrionidae sp.1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

| aphididae sp.1 | blattidae sp.1 | carabidae sp.1 | chilopoda sp.1 | chilopoda sp.2 | chilopoda sp.3 |
| chrysomelidae sp.1 | cicadellidae sp.1 | coleoptera sp.1 | coleoptera sp.2 | coleoptera sp.3 | coleoptera sp.4 |
| coleoptera sp.5 | collembola sp.1 | culicidae sp.1 | cydnidae sp.1 | delphasidae sp.1 | diplopoda sp.1 |
| diplopoda sp.2 | diplopoda sp.3 | diplopoda sp.4 | Endomychidae sp.1 | formicidae sp.1 | isopoda sp.1 |
| lampiridae sp.1 | lepidoptera sp.1 | lygaidae sp.1 | miridae sp.1 | miridae sp.2 | nepdiae sp.1 |
| oligocheta sp.1 | oligocheta sp.2 | oligocheta sp.3 | ptilodactylidae sp.1 | scarabaeidae sp.1 | sphecidae sp.1 |
| staphylinidae sp.1 | staphylinidae sp.2 | staphylinidae sp.3 | tenebrionidae sp.1 | | |

*Appendix F.* Morphospecies shown in the raw data comparison graph for the soil sample collection (Figure 5)

*Pit Fall Traps- not used in the results but collection was still done*

Nine pit fall traps were built in the center of each quadrant tested. The pit fall traps were concentrated in an area around 1m$^2$. It was not always possible to equally position each pit fall trap on its exact point in the square in order to avoid damaging crops or breaking strong roots from plants growing in the quadrant. White plastic containers about 0.5 L in volume were used as the traps. A hole was dug a centimeter deeper than the actual size of the container. A container with a lid on was then placed in the hole, and dirt was added around the container to fill in the hole. The lid was used to prevent unnecessary soil entering the trap. The rim of the container was positioned slightly below the surface of the ground. Once the container was buried the lid was removed. A small amount of soil always fell in because of the disturbance the lid caused to the loose soil surrounding the top of the container. This process was repeated nine times for each pit trap. Most of the quadrants were on an incline, so the containers were buried starting with the traps farther up the hill and moving downward to prevent unnecessary soil falling into the traps. Once all the traps were in place, 2-3 drops of Dr. Bronner's lavender scented, biodegradable soap was added to each trap. Then the traps were filled a quarter way with water (Weeks Jr. & McIntyre, 1997). This order was used so the movement of adding the water could properly incorporate the soap into the trap. Rooves made from the plastic, clear tops of the containers and three sticks poked through the tops of the containers were placed about 7 cm above the ground over the traps to prevent rain from entering and overflowing the traps. The traps were left for 24 hours.

After 24 hours had passed the rooves were removed from above the traps, and the traps removed from the ground. A coffee filter was placed over the top of an empty container and a rubber band was used to hold the filter in place. The contents of one of the traps was poured over the coffee filter to separate the insects from the water. Some dirt was caught in the filter along with the small microinsects, while some dirt stayed at the bottom of the now empty trap. The majority of the insects caught by the filter were small insects less than 3 mm in length and could float on the surface of the water. Some of the microinsects were still alive when the traps were emptied and were able to escape the trap once the water was poured through the filter (Hancock & Legg, 2012). Tweezers were used to search through the wet dirt in the container because some of the larger insects sank to the bottom and mixed with the dirt. These insects were placed in zippered plastic bag. For the insects caught by the filter, once the water had drained from the filter the microinsects were removed by either scraping the filter to collect the insects and place them in the plastic bag, or the filter was directly placed in the plastic bag because it proved too difficult to move the microinsects without crushing them completely. The water was then dumped from the container, and the filter process was repeated nine times to filter all the traps.

At the end of this process at least 25 mL of 70% proof alcohol was added to the bag to kill and preserve the insects (Hammer et al., 2015).

The weather during this 24-hour trap period was varied, from sunny and warm to cold and rainy. Most of the trapping periods experienced both types of weather patterns in addition to being active overnight.



*Figure 10.* Measurements of pit fall trap set up

*Pit Fall Trap Limitations*

It was difficult to find an effective way to separate the microinsects from the water in the traps. It was impossible to take them directly from the water because they were too small and did not break the water surface tension even with the addition of soap. A coffee filter was used to separate the mircroinsects from the water, but even when they were out of the water it was impossible to remove the microinsects from the filter without scraping and crushing them. Therefore, the filters were directly stored in the bags along with the larger insects that could be taken directly from the traps. There was also no way to completely prevent soil from entering the traps so the samples were stored for an extended period of time with soil. Finally, there was no possible manner to collect all the insects from the traps because some were still alive at the time of filtration and were able to fly away and escape. Also, some insects were hidden by the soil, and even though time was spent searching the soil at the bottom of the trap it is natural to assume that some insects were not found.