MONITORING INSECT POPULATION DYNAMICS IN WILLAMETTE VALLEY HAZELNUT ORCHARDS THROUGH NOVEL INTEGRATED PEST MANAGEMENT STRATEGIES

by

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A THESIS

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Hazelnuts, one of the largest crops within the Willamette Valley, OR, have expanded rapidly, partially due to the timely and cost effective use of new technologies, such as spraying for filbertworm management. Although there are many insects in an orchard, the Filbertworm (*Cydia latiferreana)* is cited as the most destructive to hazelnut crops due to larvae burrowing into kernels and decreasing market profits for farmers (OSU Extension, 1965). Populations of filbertworm are modernly managed with broad spectrum insecticide applications, which can be harmful to all organisms inside and outside of an orchard, including humans. With the simultaneous use of cover crops, pheromone disruption may be a viable alternative pest management strategy to target the Filbertworm while also reducing pesticide use and maintaining beneficial arboreal insect populations orchard settings. In this research, I aimed to understand (1.1) How effective is pheromone dispensing when combined with cover crops and (1.2) without the use of broad spectrum insecticide in reducing insect pests, and (2) how does insect diversity - including the abundance of beneficial species – change? When testing these questions, some trends that emerged were a shift in pest families between management types, and greater observed beneficial and neutral insect abundances using alternative management, although trends were not statistically significant. This research is important as agriculture expands and intensifies

due to rising populations. Understanding methods that impose as little harm as possible is increasingly pressing.

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Table of Contents

List of Figures

List of Tables

Introduction

A large and growing industry in the Willamette Valley is *Corylus avellana* (European hazelnut). This region is responsible for producing 99% of the United States annual hazelnut crop, with acreage encompassing more than 80,000 acres (College of Agricultural Sciences, 2022). Since the introduction of hazelnuts to the West Coast of the United States, the industry continuously evolves to adapt to changing conditions, often overcoming problems with common pests such as the filbertworm, *Cydia latiferreana* Given the adverse effects of pesticide application, new methods of pest management are nonetheless under-researched, as research can be time-consuming and costly. These constant and evolving factors, like filbertworm, push farmers and researchers to investigate alternative methods of orchard management to meet the demand of the expanding industry.

Crop production has diversified in many ways since the beginning of the green revolution ("The Evolution of Chemical Pesticides," 2019). This has translated to the hazelnut industry, as pesticide use has been vital to the expansion of the industry within the Willamette Valley. Broad spectrum insecticide use is typically used to mitigate pest issues as it is a relatively cheap and easy way to eradicate pests, but its use has unforeseen consequences. When applying a pesticide to a general area, known as broadcast application, all insects and other living organisms within the vicinity are affected, depending on pesticide formulation. Although certain species can be targeted, known as narrow-spectrum insecticides, those others in proximity may still be affected. In Oregon hazelnut systems, common orchard inhabitants, such as arboreal mammals, birds, and insects can be negatively affected by the use of broad spectrum application. Additionally, humans can be affected by these pesticides. Workers applying insecticides have heightened rates of cancer and other life-altering diseases (Carson, 2002). Similarly, nearby neighbors are exposed to harms and at an increased risk of asthma, lung disease, and varying forms of cancer, birth defects, and genetic alteration (PSU Extension, 2022). With this being said, the effects of these alternative techniques are also unknown and traditional methods are often considered more reliable and cost effective.

Insects play a large role in an ecosystem, whether beneficial, pest, or neutral player. In any agroecosystem, insects are vital to the continuation of crop production. While insects are often known for their ability to pollinate various plants, they also serve the greater ecosystem by serving as food for other taxa, dispersing seeds, cycling nutrients, maintaining soil structure and fertility, and regulating populations of other organisms (Scudder, 2017).

Within the Willamette Valley, countless studies (Danne et al., 2010; OSU Extension, 1965) have been conducted regarding insect prevalence in hazelnut orchards. Some of the common insects within these orchards include but are not limited to:

Scientific Name	**Common Name**	**Status**
Cydia latiferreana	Filbertworm	pest
Curculio occidentis	Filbert Weevil	pest
Archips rosana, Choristoneura rosaceana	Leafrollers	pest
Myzocallis coryli, Corylobium avellanae	Aphids	pest
Phytoptys avellanae / Cedidophyopsis vermiformi, Tetranychus urticae, Eotetranychus willamettei, Tetranychus pacificus	Mites	pest

Syrphus spp.	Syrphid flies	beneficial
Chrysopa spp., *Hemerobius* spp.	Lacewings	beneficial
Adalia spp.	Ladybird beetles	beneficial
Forficula auricularia, Forficula auricularia, Pterostichus scitulus	Other generalists: Earwig, Sheetweb spider, common Ground beetle	beneficial

Table 1: Common insects in Willamette Valley hazelnut orchards including both common and scientific names (OSU Extension, 2009).

Insects have both positive and negative effects in an orchard as noted above, yet the most destructive to hazelnut production in the Pacific Northwest is the filbertworm. The filbertworm (FBW) may pose the greatest threat to hazelnut production due to their destructive nature (OSU Extension, 1965). Larvae burrow in kernels and deplete the affected nuts of all nutritional value, leaving farmers with hollow nuts. Upon collection, nuts must be sorted and hollowed nuts are discarded. This decreases profit while increasing workload for the industry. Common predators of filbertworm, such as bats and parasitic wasps (PNW Handbook), can be injured or eradicated when broad spectrum insecticide application is used.

In Oregon hazelnut systems, an alternative to insecticide application is pheromone dispensing via Isomate FBW Ring (Pacific Biocontrol). This method disrupts mating cycles as the ring emits synthetic pheromones to mimic that of the female FBW, confusing males due to the overabundance of pheromone and lack of mate. Coupled with Pherocon lures (Trécé, Inc.) and Pherocon II sticky traps (Trécé, Inc.) for monitoring FBW flight patterns, this is a viable solution to disrupting filbertworm populations while maintaining other insect populations and overall diversity (Miller et al., 2019).

As the industry expands, understanding sustainable pest management is pivotal to reducing the potential risks of conventional techniques. Acknowledging the importance of insect population and pest-predator dynamics inside orchards will be of ever increasing importance as commercial hazelnut agriculture continues to expand and intensify. Insect diversity monitoring is important because of the vital role these populations play in the greater ecosystem. By maintaining these populations in orchards, a better understanding of pest-predator dynamics inside of orchards can be achieved.

Cover cropping is an agroecological approach which introduces an additional crop to a cash crop in an effort to provide various ecosystem services. Utilizing cover crops may have the ability to increase crop yield, increase soil quality by increasing organic matter and nutrient composition, suppress weeds, and control pests (Adetunji et al., 2020). Cover crop success may increase when native plants are utilized, as native plants are better suited for the region due to coevolutionary traits (Danne et al., 2010).

Within a hazelnut orchard, rows between trees often remain barren, yet the incorporation of cover crops can make this underutilized space much more ecologically productive. Native plants can be used to fill these empty spaces between tree rows. When utilized, they may play a role in pest-predator dynamics, in addition to host dynamics. These spaces can serve as habitats for various species that would otherwise be absent without the presence of native plants. Furthermore, this increase in habitat can act to serve species that target pest insects in orchards through habitat facilitation (Gurr et al., 2017). These plants can host parasitoid wasps, a predator of the filbertworm, a native pest (Gianessi, 2009).

By applying new methods for filbertworm management with an insect monitoring component, I studied the dynamics of beneficial insect preservation and filbertworm mitigation through two simultaneous treatments: the use of native cover crops to enhance pest-predator dynamics and the use of filbertworm mating disruption for filbertworm management. Here, I monitored how both beneficial and pest insect populations respond to these simultaneous treatments.

As a means of understanding how sustainable pest management techniques could be affecting insect dynamics within Willamette Valley hazelnut orchards, I asked (1.1) How effective is pheromone dispensing when combined with cover crops and (1.2) without the use of broad spectrum insecticide in reducing insect pests, and (2) how does insect diversity - including the abundance of beneficial species – change?

Methods

To test my research questions, I focused on a site located in Gervais, Oregon, in a mature hazelnut orchard composed of *Barcelona* variety hazelnuts. The site is 50 acres, with 10 acres having the treatment application (pheromone rings and cover crops), and the other 40 being managed conventionally (broad spectrum insecticide application).

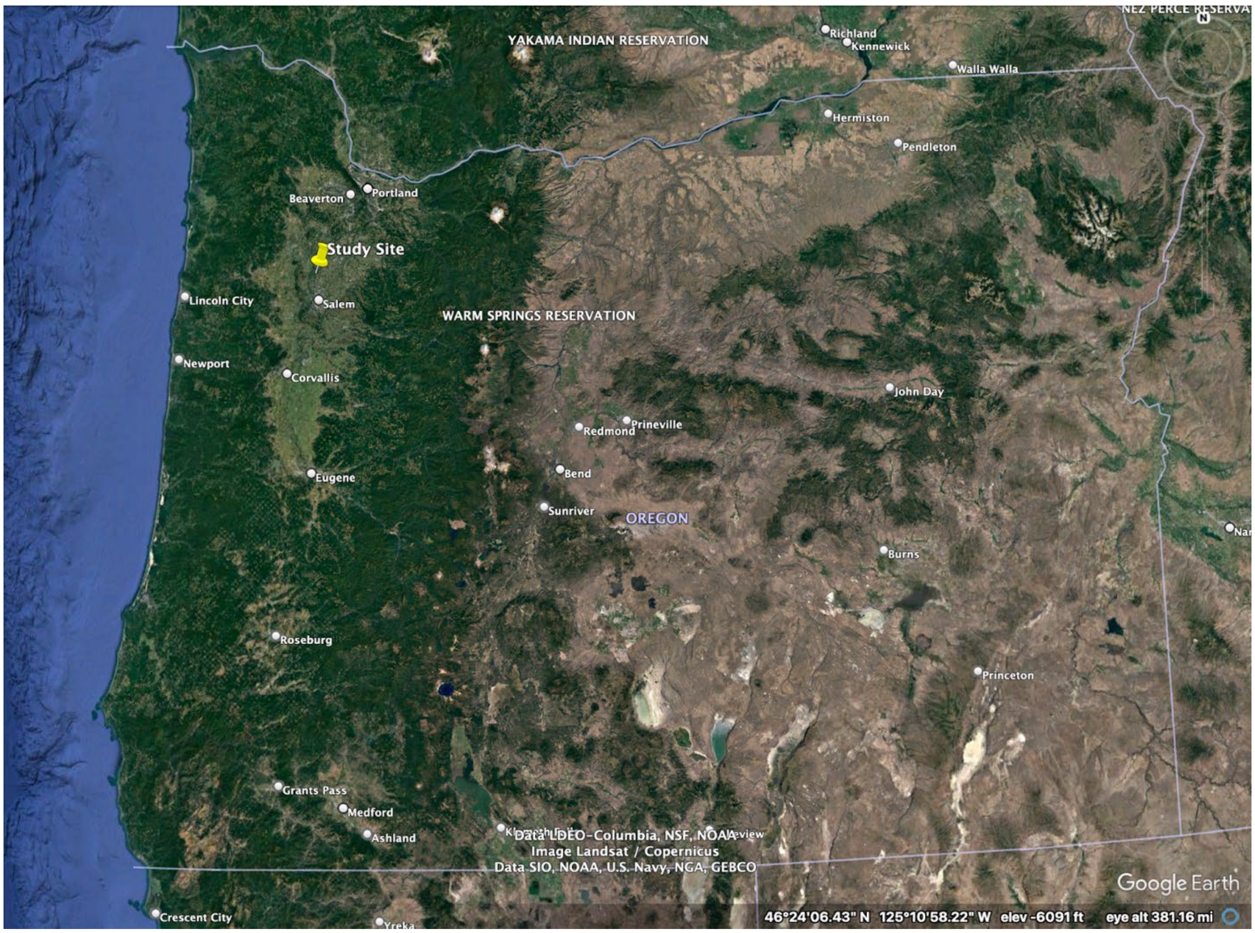

Figure 1: Geographical reference of the study site. Located in the Northwest corner of the state of Oregon between Salem and Portland, the site is marked with a yellow pin and labeled accordingly.

Experimental Design

Figure 2: Experimental design of the hazelnut orchard located in Gervais, OR. Purple coloring indicates the use of alternative pest management treatments and red coloring indicates the use of conventional pest management treatments. Yellow dots represent the placement of monitoring traps.

I set up an experiment contrasting two simultaneous treatments for filbertworm mating disruption and beneficial insect monitoring. Cover crops and pheromone disruption ("alternative") are tested as a treatment compared to a control of no cover crop and broad spectrum insecticide use ("conventional"). Both treatments were monitored for filbertworm and beneficial insects using Pherocon IIC sticky traps equipped with pheromone caps. Three traps were placed in the top third of the canopy inside the tree row throughout both the control and treatment sections of the orchard. Simultaneously, pheromone rings were hung throughout the orchard within the canopy using a hook on a telescoping pole into the top third of the canopy. Rings were placed on every other tree, alternating every other row, with a density of 10 rings per acre for optimal coverage (Miller et al., 2018). Traps were monitored every two weeks, and filbertworms were counted and recorded in the field. Pheromone caps were replaced every six weeks. At the end of the filbertworm mating season in August, traps were collected and processed for beneficial insect counts.

Data Collection

In the lab, I used an OLYMPUS SZX12 Stereo Zoom Microscope with a DF PLAPO 1X P lens to inspect the specimens in the traps for identification. All traps were labeled by cell, one through 16 horizontally and A through E vertically. Initially, the OSU *Hazelnut Pest and Beneficial Insects an Identification Guide* and *TRIPLEHORN Borror and DeLong's Introduction to the Study of Insects* were used to familiarize myself with the insects that may be present on the sticky traps. Photos were taken through the microscope via iPhone of every cell with insects present. Photos were labeled with the trap type and number in addition to cell number. After all insect species had been photographed, photos were marked up, identifying each insect present and returning to the microscope if needed. Resources such as the application Bug ID: Insect Identifier AI by Roman Iskandarrov, Facebook group Pacific Northwest Entomology, and *Insect Collection and Identification 2nd Edition, Techniques for the Field and Laboratory,* by Timothy J. Gibb and Christian Oseto were used to help identify and key out unfamiliar specimens. Once all insects had been identified down to family, trap number and type, family, and count were recorded. A column was then added that described families' effects on commercial hazelnut production as “positive, negative or neutral”. This data was then analyzed through the statistical analysis software, ‘RStudio’.

Data Analysis

I used ‘RStudio’ (2023.12.1+402 (2023.12.1+402)) to analyze family diversity within traps Species abundance per trap, species abundance by status, and species abundance by status sorted by effect, and categorizing insect family by captured population size, highlighting the most abundant insects were visualized as figures.

As a means of statistically analyzing insect family diversity, the Shannon, Simpson, and Evenness Indices were calculated. The Shannon-Wiener index can be used to measure species diversity in a community. Using the formula $H = -\Sigma p_i * \ln(p_i)$, the index can be calculated and evaluated to understand the diversity of said community. The natural log of the species sum within the entirety of the community is multiplied by the sum of the remaining community. The greater the value of H, the greater the species diversity in a community. Moreover, the smaller the value of H, the less diverse the community. Similarly, the Simpson index can be calculated using the formula $(D) = \frac{1}{\sum_{i=1}^{s} p_i^2}$ **p** is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ is still the sum of the calculations, and s is the number of species. The higher the value for this index, the higher the diversity of species. Evenness can be calculated using the Shannon Equitability Index, using the formula $EH = H / ln(S)$. In this, the Shannon-Wiener index is divided by the natural log of the total number of unique species. These proportions indicate the diversity and evenness of insect populations within the orchard, which correlates with hypotheses pertaining to the health of an orchard. An evenness proportion ranging from 0-1, 1 indicating complete evenness. Increased diversity within an orchard indicates greater overall health. (Bobbitt, 2022)

Results

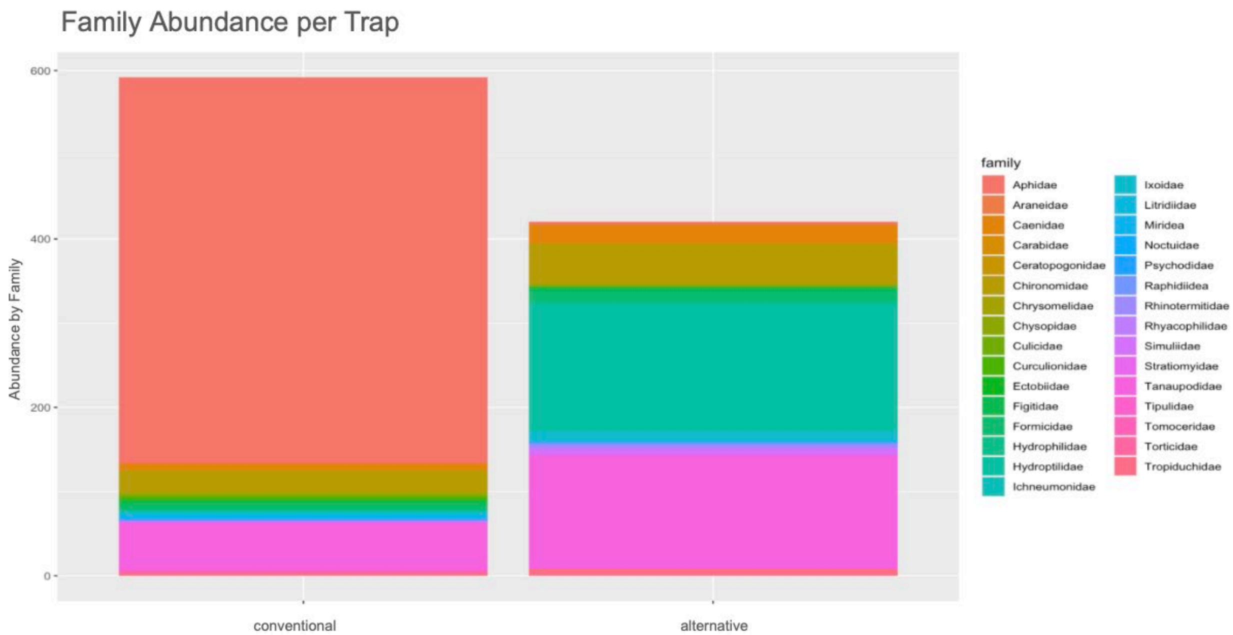

Figure 3: Abundance by family is measured on the y-axis and sorted by management type on the x-axis. The bars for both control and treatment are filled and stacked with family frequencies. The most abundant insect family is Aphidae where the conventional mean is 302 and the alternative mean is 5. The p-value for Apihdae is 0.36468, making it insignificant at the (α=0.05) confidence level.

Family Name	P-Value
Aphidae	0.36468
Araneidae	0.373901
Caenidae	0.063465
Carabidae	0.373901
Ceratopogonidae	1

Chironomidae	0.31643
Chrysomelidae	0.155016
Chysopidae	0.124337
Culicidae	0.373901
Curculionidae	0.373901
Ectobiidae	0.373901
Figitidae	0.883461
Formicidae	0.389725
Hydrophilidae	0.373901
Hydroptilidae	0.089112
Ichneumonidae	0.373901
Ixoidae	0.053338
Litridiidae	0.373901
Miridea	0.083474
Noctuidae	0.373901
Psychodidae	0.373901
Raphidiidea	0.158302
Rhinotermitidae	0.373901
Rhyacophilidae	0.373901
Simuliidae	0.179488
Stratiomyidae	0.373901
Tanaupodidae	0.224642
Tipulidae	0.373901
Tomoceridae	0.373901
Torticidae	0.373901
Tropiduchidae*	0.043244*

Table 2: P-values were calculated using a two-tailed unpaired t-test grouped by family count comparing conventional and alternative treatments.

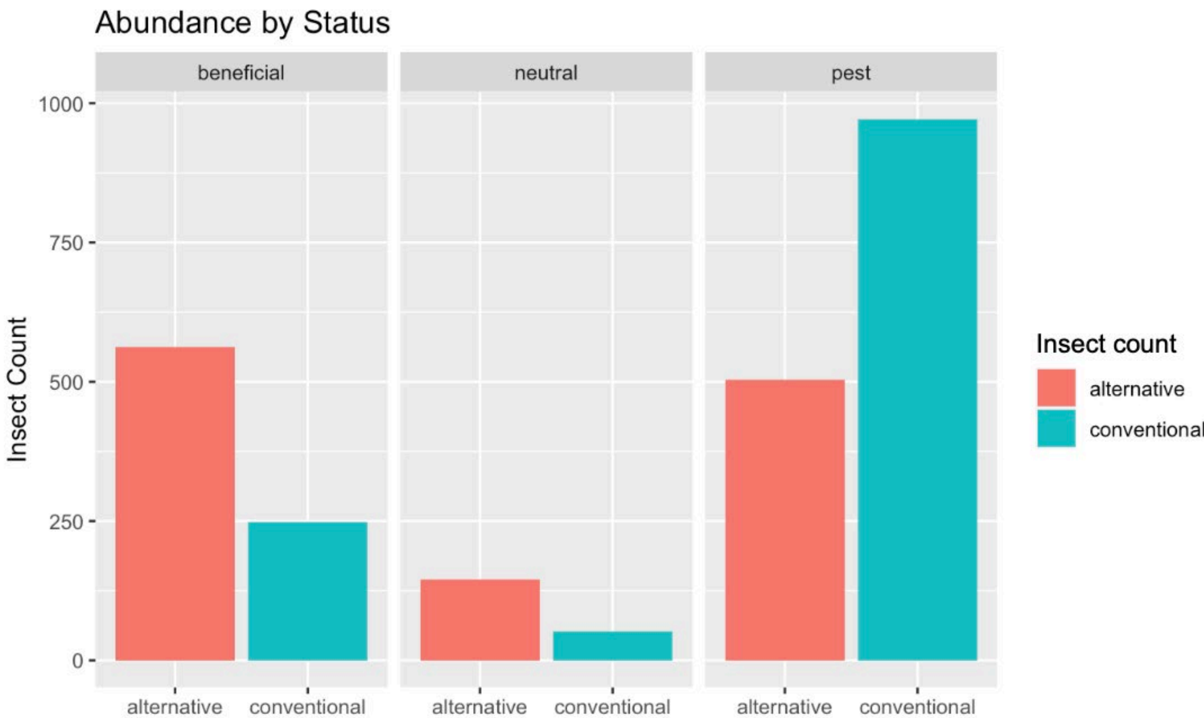

Figure 4: Abundance by status is measured with the y-axis measuring insect count and the x-axis groups by treatment type. This is faceted by insect composition status, being described as either beneficial, neutral, or pest. The conventional management type displays greater abundance of pest insects (n= 972) and decreased beneficial (n=249) and neutral (n=52) insects in comparison to alternative management pest (n=503) beneficial (n=562) and neutral (n=146). There was no statistical difference between beneficial (p=.20728) or pest (p=.633954) means between the two management types at an (α=0.05) confidence interval.

Treatment Type	**Shannon Index**	**Simpson Index**	**Evenness**
Conventional	1.673	0.835	0.0347
Alternative	2.718	0.109	0.702

Table 3: Index measurements calculating the Shannon, Simpson, and Evenness indices for both conventional and alternative treatments. All indices indicated greater diversity in the alternative treatment.

My results showed that management type did not have a significant difference in managing filbertworm populations or insect diversity. Using a two-tailed unpaired t-test with a confidence interval of $\alpha=0.05$, Tropiduchidae ($p=0.043244$) was the only statistically significant family. A two-tailed unpaired t-test also revealed that there was no significant difference at an $\alpha=0.05$ confidence interval between the composition of pest ($p=.633954$) and beneficial ($p=.20728$) insects across management types. The conventional Shannon index is 1.673. The conventional Simpson index is 0.835. The conventional Evenness is 0.0347. The alternative Shannon index is 2.718. The alternative Simpson index is 0.109. The alternative Evenness is 0.702.

Discussion

Throughout this research, I am aimed to better understand insect population dynamics in hazelnut orchards, and how insect management affects the populations. I asked two questions: (1.1) How effective is pheromone dispensing when combined with cover crops and (1.2) without the use of broad spectrum insecticide in reducing insect pests, and (2) how does insect diversity - including the abundance of beneficial species – change? As a means of understanding the original research questions, my results revealed insect population trends amongst management types, yet were ultimately statistically insignificant.

Filbertworm, the most costly pest to orchards, were targeted through pheromone disruption and broad spectrum insecticide application in this research. *Cydia latiferreana,* family Tortricidae, was observed once in the conventional portion of the orchard. This is not sufficient data to accurately understand how effective alternative methods are compared to conventional methods with relation to managing filbertworm populations. Although no clear conclusions could be drawn regarding management type and filbertworm populations, some implications could be drawn on why these populations were not statistically significant. The lack of filbertworm representation in the sample is likely not indicative of the entirety of the filbertworm population within the orchard. Further research is needed to better understand the dynamics of pest management and insect diversity as it relates to filbertworm management. The methods used in this research are made with the intent of collecting data for filbertworms specifically, yet this research provides compelling data that may help draw insights of orchard arboreal insect populations as they relate to my second research question.

My results showed that the alternative treatment did not have significant effects on family abundance within the treatment types, as they relate to the second research question. A two-tailed unpaired test (α=0.05) revealed varying p-values for each family when comparing alternative treatment to conventional treatment family counts. These values compare the means of conventional and alternative insect counts of a given family to see if one mean is significantly different than the other. Although Tropiduchidae was the only statistically significant value, it is interesting to look at the other species with the same relative abundance. Caenidae, Chironomidae, Formicidae, Ixoidae, Miridea, and Simuliidae all had relatively small p-values, though all insignificant (Figure 7).

I observed a (non-significant) trend toward greater insect diversity in the section of the orchard that utilized the alternative pest management method. A greater Shannon index value reflects both greater evenness and richness, indicating greater diversity within the alternative community. An ecologically diverse community has a value anywhere from 1.5 to 3.5, rarely exceeding 4 (*Biodiversity Index*, n.d.), the conventional Shannon index (H= 1.673) compared to the alternative index (H = 2.718), indicates greater diversity in the alternative section of the orchard. This increase in diversity within the alternative section of the orchard may be attributed to the lack of broad spectrum insecticide application and increased trophic cascades due to cover crop and resource presence (Bowers et al., 2020). As the conventional management targets all species, it is understandable that family diversity would decrease in these sections of orchard. Conversely, specifically treating a certain species, in this instance filbertworm, would in theory maintain insect diversity (Hickman, 2019). Although diversity was greatest in the alternative treatment traps, the composition of pest, beneficial, and neutral insects differed from the conventional group (Figure 5)

The Simpson index differs from the Shannon as smaller values are representative of more diverse communities. Taking into account abundance and presence, this value can be anywhere from zero to one. The alternative section had a greater value, therefore inferring greater insect diversity compared to the conventional. Alternatively to the Shannon index, smaller Simpson indexes are indicative of greater diversity. The alternative treatment statistical analysis infers greater diversity than the conventional treatment when comparing the conventional Simpson index of 0.835 to the alternative index of 0.109. The alternative section of the orchard had more species with greater abundance. This again could be attributed to the lack of broad spectrum insecticide application and cover crop usage (Hickman, 2019).

This new method of pest management– the use of pheromone disruption and native cover crop usage in tandem – likely has long term effects on the orchard agroecosystem when compared to conventional methods. Understanding how insect diversity affects greater trophic levels and overall orchard health may have profound impacts on crop production which could be translated to other orchard crops. These results were unexpected because it is assumed the insect populations would be greater in the absence of pesticides. Insect populations are likely greatly affected by long term cycles that take years to reinstate due to their deliberate extirpation amongst commercial crops (Elizalde, 2020).

Conventional and alternative pests differed in prevalence (Figure 5 & Figure 6). Aphids, the most abundant pest in the conventional section, pose similar harm as filbertworm on the orchard (Olsen, 2002). Hydroptilidae is the most abundant alternative pest. The difference in conventional and alternative pests could be associated with an increase in natural processes in the alternative section attributed to the lack of broad spectrum insecticide application. Pest-predator dynamics may have led to a decrease of Aphidae populations in the alternative sections of the orchard, coupled with increased habitat for other families, in adherence with source–sink dynamic theories (Gundersen, 2001). Families Tanaupodidae and Chironomidae act as predators to Aphidae, the most abundantly observed pest in the conventional orchard. There were twice as many Tanaupodidae and Chironomidae insects in the alternative traps. Understanding the effects of one pest compared to others' severity, such as Aphidae and Hydroptilidae, may be explained by means of how destructive they are to the hazelnut crop. In this instance, Aphidae poses a greater threat to the crop due to its destructive nature (AliNiazee,1996). One trap in the alternative treatment group had a high count of Aphidae individuals. This trap may have been placed in a tree that became infected, causing results that are not representative of the overall treatment type.

This raises the question of how alternative pest management systems differ from pest-predator dynamics in terms of reducing pests in an orchard (Finke, 2010). For these conditions to be plausible, there would have to be an absence of conventional pest management strategies, so understanding how alternative methods differ from pest-predator dynamics could be difficult to test separately as it seems to be impossible to have one without the other (Jana, 2013). Possibly leaving an orchard barren without pest management strategies and one with selecting for FBW like the setup here may decimate an orchard.

Further research should be conducted using a greater sample size to better understand how insect diversity is affected by these pest management strategies. In this orchard, by increasing the number of sticky traps from three per section to six in each section, I would anticipate that more clear conclusions could be drawn, in addition to the effects of each management strategy. To minimize this confounding variable in the future, I would suggest increasing the number of traps in the orchard to collect more data, repeating these methods in various orchards throughout the Valley, or conducting these methods throughout the course of several years, allowing for increased determination of outliers and gain a more statistically powerful sample of the orchard treatments. Given a greater sample size, certain p-values may be statistically significant given they accurately represent these two orchard management strategies. If there were to be a larger sample size it may be more representative of insect populations within the orchard, drawing clearer conclusions about how conventional and alternative pest management systems affect insect demographics in a population. Furthermore, future research should be conducted as there is no insight as to how grounded insects are affected by these treatments, especially when pest management strategies are coupled. These coupled treatments may greatly increase non-arboreal insect diversity, preserving insect diversity across the ecoregion and increasing beneficial insect populations in agroecosystems better than before (Lee-Mader, 2015).

Understanding insect population as it relates to management type is difficult and complex. More research is needed to assess how effective pheromone disruption is at managing filbertworm populations. Statistically insignificant trends were observed with relation to management population diversity and should be researched further as they could help to maintain natural systems to improve overall orchard health. All and all a key takeaway from this experiment is that high pest abundance was observed within the conventional treatment traps and beneficial insects were most abundant in alternative treatment traps, yet insects captured were limited to those within the canopy of the orchard.

Overall, the need for broad spectrum insecticide application is decreasing in hazelnut orchards for filbertworm management. The observed diversity within alternative insect communities fosters important ecosystem services such as encouraging pest-predator dynamics. Understanding these dynamics is important as they may provide natural remedies to pest problems while increasing overall orchard diversity. Although more research is needed to understand the effects of alternative pest management systems, there were no detectable drawbacks to these methods as they relate to pest infestations. This management technique may alleviate the need for abundant insecticide use for Willamette Valley hazelnut growers targeting filbertworm.

Appendix

Scientific Name	**Common Name**
Camassia leichtlinii	great camas
Collinsia grandiflora	giant blue eyed Mary
Collomia grandiflora	grand collomia
Geum macrophyllum	largeleaf avens
Lomatium dissectum	fernleaf biscuitroot
Phacelia nemoralis	shade phacelia
Prunella vulgaris	self-heal
Sidalcea campestris	meadow checker-mallow

Table 4: Native seed mix referenced in the introduction including scientific and common names

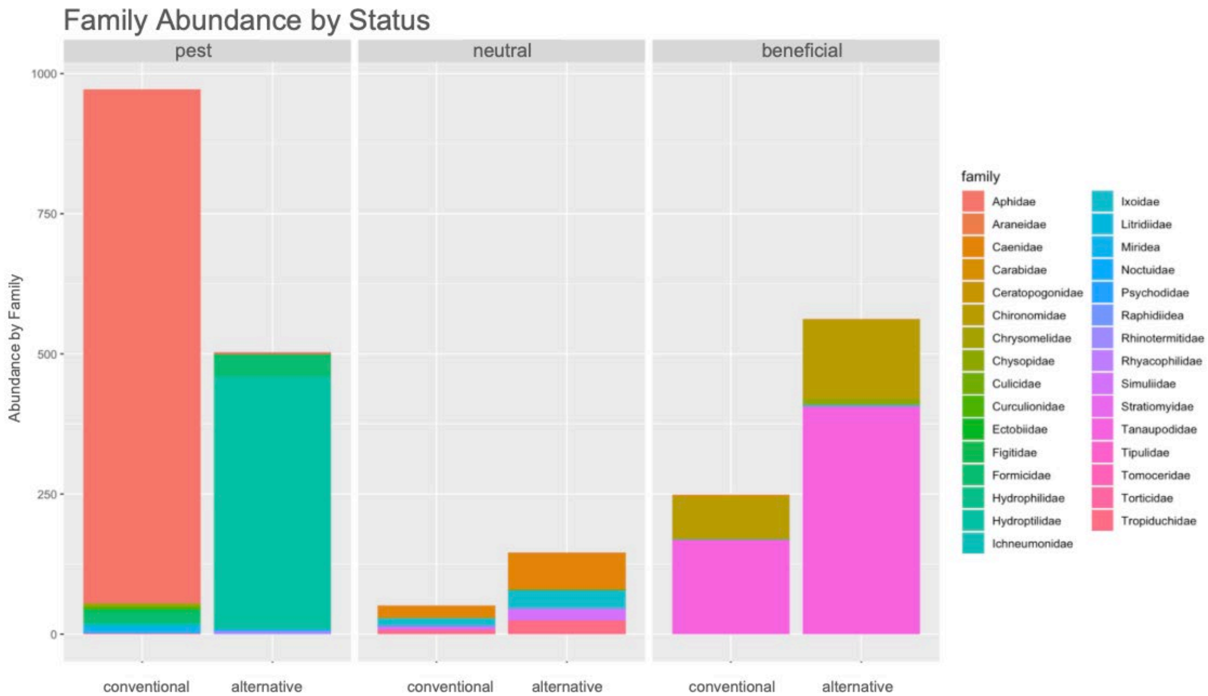

Figure 5: Family abundance was further refined by the effect on commercial hazelnut crops. The y-axis measures insect counts by family and the x-axis groups by treatment type. There are three different subgraphs: pest, neutral, and beneficial comparing conventional and alternative treatment diversities. Conventional and alternative pests differ as Aphidae (conventional mean pest =305) differs from Hydroptilidae (alternative mean pest=109). Tanaupodidae was the greatest observed beneficial insect for both conventional (mean=56) and alternative (mean=135) sections, yet abundance was greater in alternative. Neutral insects were more abundant in conventional methods (family n=8, individual n=51) yet alternative (family n=9, individual n=146) sections demonstrated similar family diversity and greater abundance in alternative sections.

Figure 6: Insect count (by family) by status is measured with insect count on the y–axis and grouped by pest and beneficial insect status. These families had the greatest individual abundances, consisting of Aphidae (conventional mean = 305, alternative mean = 1), Hydroptilidae (conventional mean = 2, alternative mean = 166), and Tanaupodidae (conventional mean = 56, alternative mean = 135). These families did not show statistically significant differences between treatment types, as p-values were 0.36468, 0.089112, and 0.224642, respectively.

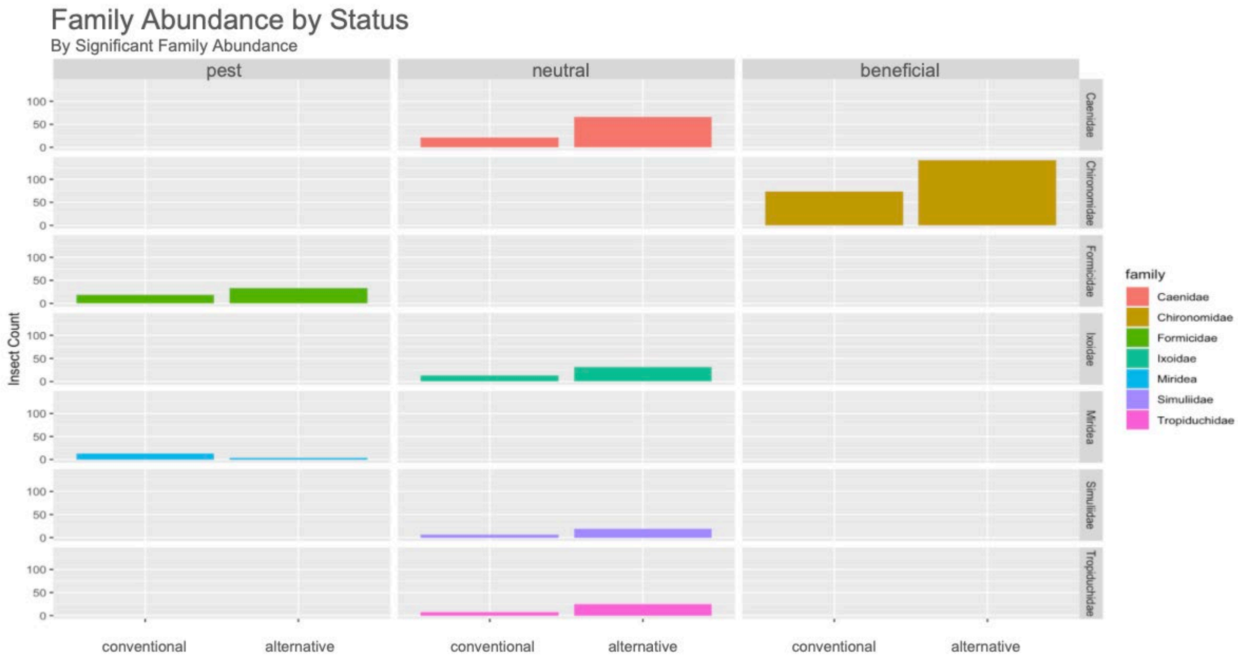

Figure 7: Insect count by status sorted based on treatment type and effect on orchards. The families selected are fairly abundant within the orchard, including Caenidae ($p = 0.063465$),Chironomidae ($p = 0.31643$), Formicidae ($p = 0.389725$) Ixodidae ($p = 0.053338$), Miridea ($p = 0.083474$), Simuliidae ($p = 0.179488$), Tropiduchidae ($p = 0.043244$). Of every family listed in this figure, none displayed statistical significance comparing treatment type family counts.

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