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Alfalfa Trap Cropping Increases Abundance Of Key Arachnids In An Organic Strawberry Agroecosystem

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ALFALFA TRAP CROPPING INCREASES ABUNDANCE OF KEY ARACHNIDS IN AN ORGANIC STRAWBERRY AGROECOSYSTEM

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ABSTRACT

ALFALFA TRAP CROPPING INCREASES ABUNDANCE OF KEY ARACHNIDS IN AN ORGANIC STRAWBERRY AGROECOSYSTEM

By Sutapa Biswas

Eighty three percent of the strawberries consumed in North America are grown in California, where the widespread use of insecticides has become hazardous to public health. The intensive use of pesticides for growing strawberries causes serious health risks to farm workers, in addition to contaminating the soil and groundwater. The cost to the environment and public health in the United States is estimated at $12 billion annually. Finding effective nontoxic management strategies for insect pests has become essential for long term sustainability. One strategy strawberry producers can use to promote sustainability is to increase the effectiveness of biological control techniques. Field experiments in other crops suggest that arachnid diversity and abundance may provide such a role in controlling insect pests and that agroecosystem diversification can enhance arachnid populations. This study therefore evaluated the composition, abundance, and pest control potential of arachnid communities in an organic strawberry field in California. The study found that by integrating alfalfa trap crops into organic strawberries, arachnid populations were substantially increased. Results reflected substantial increases in both male and female arachnid populations in and near alfalfa strip crops, with spider and harvestman arachnid families increasing most dramatically. Preliminary data suggest that an increase in alfalfa trap crops may lead to a reduction of the primary strawberry insect pest, *Lygus hesperus*, which is consumed by arachnids. These results provide useful new information for California farmers.

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INTRODUCTION

The agricultural landscape in California has changed dramatically since World War II. Major changes include the increased use of pesticides and inorganic fertilizers, which has encouraged the cultivation of monoculture crops. This agroecosystem simplification has resulted in species extinction, nutrient leaching of fields and problems with pesticides (environmental contamination and growth of resistance to pesticides) (Tscharntke et al. 2007).

Over the last few decades, the emphasis in research has shifted to improvement of production methods (including integrated pest management (IPM)) and the adoption of alternatives to chemical pesticides for the purpose of controlling insect pests. One fundamental aspect of this approach is the concept of pest suppression by supporting natural enemies that are part of the agroecosystem, also known as biological control.

Biological control as an element of IPM has gained increased importance as an alternative to the use of pesticides in the agricultural sector. Biological control involves managing one or more organisms in order to reduce the population density of an agricultural pest. Mainstream biological control research has traditionally focused on specialist natural enemies, such as parasitoid wasps and specialist insect predators, which consume pest insects.

In recent decades, however, momentum in the scientific community has shifted toward the exploration and promotion of generalist predators, such as spiders (Riechert 1999). Spiders (Araneae) represent a substantial part of the total biodiversity in agroecosystems (Marc et al. 1999), and they are considered to be the most abundant and diverse terrestrial predators (Coddington and Levi 1991). According to Platnick (2006), 110 spider families, consisting of 3,618 genera and 39,112 species have been identified. More than 600 species have thus far been identified in US crop fields (Young and Edward 1990).

The ways that natural enemies function in crop fields depend on habitat preference, phenology, and behaviors. Knowledge of the types and numbers of spider fauna in crop fields is required to promote or protect natural enemies. In addition, the complexity of vegetation structure of the surroundings is considered to be an extremely important component. This is because the level of complexity influences spiders through a variety of biotic and abiotic phenomena, which may affect the density and diversity of spider populations in both natural ecosystems (Greenstone 1984) and agroecosystems (Rypstra et al. 1999).

Biological Control

Biological control has been defined as the study and uses of parasites, predators and pathogens for the regulation of host (pest) densities (DeBach 1964). Bale et al. (2008) states that biological control is a key component of a "systems approach" to IPM, involving counteracting insecticide-resistant pests through reduced use of chemicals and pesticides. Currently, IPM programs combine various non-chemical control methods with the use of insecticides. The use of natural enemies in combination with insecticides has been gaining increasing popularity. Biological control has two main dimensions. First, most organisms in nature are consumed by others, which leads to a reduction in prey populations. Second, control reduces rather than eradicates the target population, allowing for both pests and their natural enemies to be present in an agroecosystem at low densities (Bale et al. 2008).

The three biological control techniques are classical, augmentation, and conservation. Classical biological control involves the introduction and establishment of natural enemies to reduce exotic pest densities below levels that are deleterious to crops. The key to success for classical biological control is efficient dispersion and reproductive capabilities of predators (Van Lenteren et al. 2012). Perennial crops (e.g., fruit plantations and forests) have been successfully protected through the use of classical biological control because the long-term nature of the ecosystem enables the interaction between pests and natural enemies to become stable over a period of time. Augmentation requires the commercial production of released agents, with the periodic introduction of natural enemies into the system (Van Lenteren et al. 2012). Augmentation has two parts, inundation and seasonal inoculation. In seasonal inoculation, the natural enemies are raised in the laboratory periodically and then released into short-term crops where each growing season can have many pest generations. Conservation biological control enhances or maintains the natural enemy populations in crop fields. Conservation biological control techniques have been shown to enhance generalist predators and reduce pest densities by 73% and damage by 71% (Symondson et al. 2002). Conservation biological control has great potential from an agronomic point of view because it utilizes pre-existing cultural practices, e.g. conservation tillage or no tillage, reduced mechanical disturbances (planting, cultivation, weed control, and crop harvest), mulching, strip-cropping, reduced pesticide use, increased structural or vegetational diversity, and crop diversification (Riechert and Bishop 1990; Samu 2003; Thorbek and Bilde 2004). Thorbek and Bilde (2004) stated that mechanical disturbances such as grass cutting, loosening of soil, and weed control reduce densities and increase the mortality of natural enemies within the system. In the US, mulch treatments are used to increase spider densities in vegetable gardens (Riechert and Bishop 1990).

An agricultural system that adopts conservation biological control techniques has substantial impact on spider populations. Sunderland and Samu (1993) reported an increase in spider densities in response to habitat diversification. Several studies have demonstrated that more diverse crops and non-crop habitat surrounding the crop fields facilitate predator dispersion and also encourage predator residence (Sunderland and Samu 1993; Schmidt and Tschartnke 2005; Tschartnke et al. 2007). Others have shown that spider density increased 50% in an alfalfa/grass meadow cropping system within its strip harvested portion (Samu 2003), and that predator densities increased in grass-sown banks in wheat fields (Thomas et al. 2001).

California Farming Practice

California's agricultural history has two opposing narratives. According to the first narrative, California farmers are progressive, highly educated, early adopters of modern machinery, and unusually well organized. Through irrigation, they have made a "desert" bloom (Barton 2003). Through cooperation, they prospered as their high-quality products appealed to markets around the globe. The other narrative states that California agriculture has abused the Golden State's natural environment (Olmstead and Rhode 2003). It is true that California's agriculture is unique in many ways, such as in the numbers of crops produced, the diversity of cropping systems, and the Mediterranean type climate. As the leading agricultural state, California ranks first in production of 49 different crops and livestock products (Altieri 1992). California accounts for 11.2% of the total US production of agricultural goods (United States Department of Agriculture 2010). California supplies a major portion of the fresh fruits and vegetables to the global marketplace.

California's agricultural center is the Central Coast, where farmers use crop specialization, external outputs, and highly developed irrigational systems. More than 200 different types of crops are grown in the Central Coast of, generating annual revenue of as much as $5 billion. Known as the "salad bowl of America," the Salinas Valley produces up to 82,000 tons of lettuce annually, in addition to spinach, chard, kale, and other leafy green vegetables (Stuart 2009). Strawberries, for which there is a strong international demand, are one of the major fruit crops produced in California. Because strawberries attract insect pests in large numbers, the traditional response of growers has been to use chemical pesticides to control pests and diseases.

In the past, California crop production depended on internal resources, organic matter, and biological controls. Today, however, many of these practices have been replaced by chemicals and mechanized techniques. Strawberry fields are fumigated before planting to protect new plants from soil-borne diseases. After fumigation, fertilizers are applied to the soil.

California strawberry growers are severely restricted by agricultural regulations governing the use of pesticides in fields. The intensive use of pesticides has been found to cause serious risks to the health of farm workers, in addition to contaminating the soil and groundwater. Such costs are estimated nationwide at $12 billion annually (Pimentel, 2005). According to Jackson (2002), less than 1% of applied agro-chemicals reach their intended pest targets, while the other 99% have very negative impacts on human health and the environment.

As an alternative, IPM practices are now being implemented as a way to balance concerns about health with those relating to pest outbreaks. To reduce the overall use of pesticides by California strawberry growers, IPM programs emphasize a combination of modification of cultural practices, biological control through the use of insect predators, and selection of pest resistant crop varieties (Phillips and Jolley 2004). Biological control methods, which represent an important aspect of IPM, can greatly reduce the need for pesticides in vegetable and crop farming (Letourneau et al. 2009).

Because of the multitude and complexity of pest issues, strawberries are among the most challenging horticultural crops to grow. Although pest problems vary by site, the most common strawberry pests in the Central Coast of California are spider mites, and the western tarnished plant bug or "lygus bug"[1] (Allen and Gaede 1963). Alfalfa (*Medicago sativa* L.) is a preferred host of the western tarnished plant bug (Scott 1977). Adult lygus bugs overwinter under alfalfa leaves, which can harbor large populations of these pests. Using alfalfa as a trap crop is an important feature of lygus bug management. For this reason, California strawberry growers occasionally plant alfalfa with strawberries in organic fields. Lygus bugs migrate from surrounding hillsides to the trap crops, which can then be treated with insecticides or vacuumed (Swezey et al. 2007)

The Role of Spiders as a Biocontrol Agent

Research has shown the importance of generalist predators as more effective biological control agents, in comparison with specialists, for reducing prey densities in frequently disturbed habitats such as crop fields (Riechert 1999; Symondson et al. 2002). Generalist predators feed on alternative prey sources, such as detrivores, in the absence of herbivore prey (Chen and Wise 1999) and can be present in the crop fields even at low pest densities. Spiders (which belong to the Arthropoda phylum, the Chelicerata subphylum, the Acrachnida class, and the Aranae order) are indigenous, generalist predators and a major component of biological control within many agroecosystems (Riechert and Bishop 1990; Young and Edwards 1990). Hunting spiders, in contrast specialized web-weaving spiders, are better at controlling pests because they capture a wide variety of prey types and sizes.

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[1] *Lygus hesperus*

In Texas cotton fields, the lynx spider (Oxyopes salticus) has been shown to feed on 34 species of insects from 21 families and nine orders (Nyffeler et al. 1987). Pedigo (2001) noted that, an appropriate biological control agent not only reduces pest densities but also stabilizes them at low levels, maintaining stability of populations. An understanding of the role of spiders in controlling insect pest populations in the field calls for knowledge of their responses when fluctuations in prey population densities occur (Riechert and Lockley 1984).

Spiders generally react in one of two ways. They may increase consumption by exhibiting what is known as functional response, or they may increase their own density by displaying what is known as a numerical response (Holling 1959). A functional response, of which there are three types, refers to the change in numbers of prey attacked per unit time by single predators as prey density is changed (Riechert 1984). Holling (1959) defined three response curves. With Type I response, prey intake is proportional to prey density until satiation is reached (e.g. filter feeders). In Type II response, predators increase their prey consumption at a decreasing rate. The Type III response is one in which feeding rates lag in the beginning and are followed by an increase in prey consumption at an accelerated rate. Rypstra (1999) and Marc et al. (1999) stated that the Type II response is more common for spiders, as they eat fewer insects when insects are abundant. Nyffeler and Benz (1987) found that this functional response is present in cereal agroecosystems. Kiritani and Kakiya (1975) observed the functional response for Lycosidae (wolf spider family) in paddy fields.

In contrast, numerical response refers to a change in population density of predators as a function of changing prey density (Marc et al. 1999). This type of response has two components: aggregation and reproduction. Greenstone (1980) stated that there is no numerical response to prey density. However, Riechert and Lockley (1984) explained that there is considerable evidence in the literature that spiders exhibit both reproductive and numerical responses. Riechert and Lockley (1984) showed that in the field, spiders move from patches of low prey density to patches with higher prey density.

Spiders have been successfully used as biological control agents in apple orchards and rice paddies. In Asia, spiders are often used as biocontrol agents in rice fields. Chinese farmers use straw and bamboo to collect spiders and then move them to paddy fields that are experiencing pest outbreaks (Riechert and Bishop 1990; Marc et al. 1999). This method of spider augmentation reduces pesticide use for paddy fields and decreases environmental and health effects (Marc et al. 1999). Spider assemblages have also been shown to reduce pest damage in rice paddies, soybean (Carter and Rypstra 1995), and other vegetable crops (Richert and Bishop 1990). Ground dwelling spiders are one of the most important predators of leafhopper and plant hopper rice pests (Nyffeler and Benz 1987). Riechert and Lawrence (1997) noted that, when spiders were removed from a field, herbivorous pests increased in number, while pest populations were much lower where spider populations were maintained.

Spiders as Predators in US Agricultural Ecosystems

Young and Edwards (1990) reported that, more than 600 spider species are associated with US crop fields, with web builders constituting 44% and hunter species making up the other 56%. Common web builder spider families are Tetragnathidae, Araneidae, Linyphiidae, Theridiidae, and Dictynidae, while the most common hunter spider families are Oxyopidae, Salticidae, Clubionidae, and Lycosidae (Nyffeler 2003). Most of these spiders are Polyphagous insectivores. Unlike other parts of the country, *Pardosa ramulos* is a commonly found species in California crop fields (Oraze et al. 1988). The diverse diets of spiders include the insect orders Heteroptera, Homoptera, Coleoptera, Diptera, Hymenoptera, and Lepidoptera. More commonly, web builder spiders have been successfully used as biocontrol agents in two types of agroecosystems: orchards and rice paddies. Riechert et al. (1984) made a substantial contribution toward evaluating the predatory potential of spiders. Many field experiments, performed over the last 35 years, have contributed that spiders can suppress pest populations and reduce crop damage (Greenstone 1999). In the US, spider fauna are commonly monitored in cotton, soybeans, and alfalfa fields (Nyffeler et al. 2003). Some researchers have found that generalist predators are more efficient than specialists at reducing pest densities in the crop field (Symondson et al. 2002). Most spiders are generalist predators, so they do not depend on one specific type of prey. Hunting spiders are better biological control agents, because most hunting spiders can capture crop pests in different stages of their life cycle (Young 1989; Lockley and Young 1987).

A variety of spiders offer more effective biological control because the species have different hunting strategies, habitat preferences, and active periods, thus making them, as a group, highly efficient. Young and Edward (1990) conducted 29 faunal surveys of spiders in nine crop fields (cotton, soybean, alfalfa, guar, rice, grain sorghum, peanuts, corn, and sugarcane), located in New York, Florida, and California. *Tetragnatha laboriosa*, *Oxyopes salticus* and *Phidippus audax*, representing some of the most abundant spiders in North America, were found in all nine crops (Katson 1978). These three species are also effective biological control agents in fields and adjacent habitats.

Opiliones (Harvestmen) as Predators in Crop Fields

Harvestmen (Opiliones), arachnids known popularly as daddy longlegs, are often confused with spiders (Araneae). Harvestmen are distinguishable from spiders by their broadly oval bodies. One study by Pinto-Da-Rocha et al. (2007) revealed that Opiliones are present worldwide. Very little information is available about the Opiliones fauna associated with organic strawberry production. The orders differ from one another in that spiders have silk and venom glands, which they use to immobilize and kill their prey. Harvestmen lack these predatory tools and therefore do not have spinnerets. Opiliones are generally nocturnal. Harvestmen only live for one year, dying in the cold weather of winter.

Opiliones comprise a major, and frequently numerically dominant, component of the community of polyphagous predators in terrestrial ecosystems (Nyffeler & Benz, 1987; Halaj & Cady, 2000). Some species of Opiliones have been identified as important predators in agriculture, although most of them inhabit forested landscapes (Pinto-Da-Rocha et al. 2007). *Phalangium opilio* L. is a polyphagous predator frequently found in agricultural habitats. It was apparently introduced from Europe to North America (Cokendolpher and Lee 1993). Although the potential importance of *Phalangium opilio*'s feeding on pests has been recognized, very little is known about its activity patterns or its within-plant distribution in various crops. *Phalangium opilio* has been found in a variety of agro-ecosystems in New Zealand, including pasture land (Martin 1983) and carrot crops (Berry et al. 1996). Hilbeck and Kennedy (1996) found *Phalangium opilio* feeding on Colorado potato beetle in commercial potato fields in eastern North Carolina. *Phalangium opilio* was also among the arthropods included in a survey of predators of Colorado potato beetles in Delaware potato fields conducted by Heimpel and Hough-Goldstein (1992). Dixon and McKinlay (1989) found that *Phalangium opilio* composed 54% of the harvestmen caught in pitfall traps in potato fields in Scotland; half of them consumed aphids, based on examination of their guts. Newton and Yeargan (2001) reported that *Phalangium opilio* feeds on corn earworm eggs in soybean fields. Butcher et al. (1988) found evidence of two-spotted spider mites in the diet of harvestmen, without concluding that this was a significant controlling influence on mite populations in New Zealand strawberry crops. Halaj and Cady (2000) stated that there was insufficient evidence to conclude that harvestmen are important predators of insect pests in soybeans.

Conservation of Spider Communities

Managing cultivation techniques in agriculture is important to spider conservation. After a harvest, spiders migrate to the nearest undisturbed landscape in order to find food and shelter (Marc et al. 1999). The presence of non-crop habitat surrounding an agricultural field increases the density of spider populations (Schmidt et al. 2005). Complex landscape structures, such as the combination of crop and non-crop lands, are important for long-term conservation through biological control and sustainable crop production (Tscharntke et al. 2007). Spider populations are more diverse in organic croplands, which are more likely to be surrounded by perennial non-crop habitats (Schmidt et al. 2005). Similarly, weed populations in organic fields provide a higher level of structural complexity, increasing the availability of herbivore prey. During their life cycle, spider species move between different these habitats, thereby increasing species richness in complex landscapes (Srivastava 1999). Minimum tillage and mulches, weed abundance and strip planting of diverse crops provide habitat diversity, supporting larger and more diverse spider communities. As multispecies spider assemblages are more effective than single species with regard to reducing pest insects (Riechert and Lawrence 1997), it is necessary to manage the surrounding environments by including "reservoirs" and "ecological units," such as pastures, hedgerows, and wet areas (Marc et al. 1999) in order to increase spider communities in crop fields.

Recently, in addition to local factors, the spatial surroundings of habitat patches have also been gaining much attention, as they exert a strong influence on local diversity and abundance of organisms (Holland et al. 2004). As a part of the biological control technique of conservation, habitat management controls specific ecosystem services such as pest regulation by enhancing the natural enemies' impact through manipulating plant-based resources in crop fields (Fiedler et al. 2008). Samu (2003) stated that more interspersed methods of field diversification can be more effective toward enhancing spider populations. For this reason, natural enemies can consider application of this technique a good strategy for biological control. According to Marshall (1988), field margins are a key feature of agricultural landscapes, present in some form at the edges of all agricultural fields. Marshall and Moonen (2002) defined margin strip as "any strip established in the field or at the edge of the field, between the crop and the boundary".

The concept of trap cropping has also been included in the ecological framework of habitat manipulation in agroecosystems, Hokkanen (1991) defined trap crop as "plant stands grown to attract insects or other organisms like nematodes to protect target crops from pest attack, preventing the pests from reaching the crop or concentrating them in a certain part of the field where they can be economically destroyed". There is little knowledge of the biodiversity of the arachnid fauna in strawberry fields and the adjacent alfalfa trap crop that are found in local organic farms. Agricultural arachnology research in contrast to entomological research has made relatively little progress in the area of IPM and biological control (Uetz et al. 1976).

Though strawberry fields support arachnid populations, few studies have documented the types and numbers of arachnids they support and how enhancing vegetation diversity of these fields through companion plantings of alfalfa trap crops potentially affects these arachnid populations. This study therefore, aimed to explore the use of two particular types of arachnids (spiders and harvestmen) for purposes of biological control and to explore the use of alfalfa trap crop, for the purpose of increasing the populations of these arachnids. This biological solution may represent a promising alternative to the use of chemical pesticides, which would reduce the risks to human health and the environment.

This research was designed to evaluate Opiliones (harvestmen) and 15 spider families in strawberries that contain alfalfa trap crops in Salinas, California. Alfalfa trap crop are planted between rows of strawberries in order to attract lygus bugs, on which the arachnids feed. The findings of this research can be used to educate strawberry growers and stakeholders of strawberry farms in developing environmentally friendly techniques for controlling insect pests. The findings may offer potential support for the practice of IPM in the production of strawberries in California and elsewhere.

RESEARCH QUESTIONS

Previous studies have shown evidence of spiders and harvestmen in crop fields. No other study to date, however, has analyzed and compared the community composition, abundance, and diversity of arachnids associated with organically or conventionally managed strawberry fields. Although local organic farmers have been planting alfalfa trap crops in their fields to enhance the biological complexity of the fields, no research has evaluated how alfalfa trap crops practice affect the arachnid communities in associated crop fields. This study aimed to document arachnid activity in strawberry fields in costal California and evaluated the experimental use of alfalfa trap crop to enhance arachnid populations. The main aim of this study was to determine the abundance of the arachnid community in organically grown strawberry fields, in the context of their use for biological control of insect pests (i.e. lygus bug) in organic strawberry production. The study posed the following questions and hypotheses.

RQ1: How do alfalfa trap crops affect spider and harvestman populations?

RQ2: What taxa of spider and harvestman are present in alfalfa trap crops and in strawberry rows, and what is the relative abundance of each taxa?

H1: Arachnids overall will be more abundant

- H_{1a}: in alfalfa rows than strawberry rows
- H_{1b}: near vs. far from the alfalfa

H2: Males, females, and immature individuals will each be more abundant

- H_{2a}: in alfalfa rows than strawberry rows
- H_{2b}: near vs. far from the alfalfa

H3: Web-builder, hunter guilds, and harvestmen will each be more abundant

- H_{3a}: in alfalfa rows than strawberry rows
- H_{3b}: near vs. far from the alfalfa

H4: Certain spider families will be more abundant

- H_{4a}: in alfalfa rows than strawberry rows
- H_{4b}: near vs. far from the alfalfa

METHODS

Study System

The study was conducted on an organically managed strawberry farm (latitude 37° north and longitude 121° west) in Prunedale, CA, near the city of Salinas in Monterey County (Fig. 1). The California coast offers a unique growing environment; as the Pacific Ocean creates moderate air temperatures year-round, with warm sunny days and cool foggy nights.

According to the United States Census Bureau, the population of the Central Coast region increased 10% between 2000 and 2010 (Census Bureau 2011). The greatest amount of population growth occurred along the coast, with growth in inland areas due to agriculture. Good soil conditions, a mild climate, access to water, and a skilled population of farm laborers make this valley an extremely important agricultural region at both the state and national levels. This valley produces many different types of fruits and vegetables, but is best known for its berries, including strawberries, cranberries, and blueberries.

The primary agricultural crops produced in the Central Coast are strawberries and leafy greens. California is the major state for strawberry production in the U.S., accounting for over 80% of the fresh market product grown in this country. California strawberry industry represents the tenth highest grossing industry in the entire country (Barton 2003). Though California strawberries are grown throughout the state, the Watsonville and Salinas areas account for about 50% of the state's harvested strawberry value.

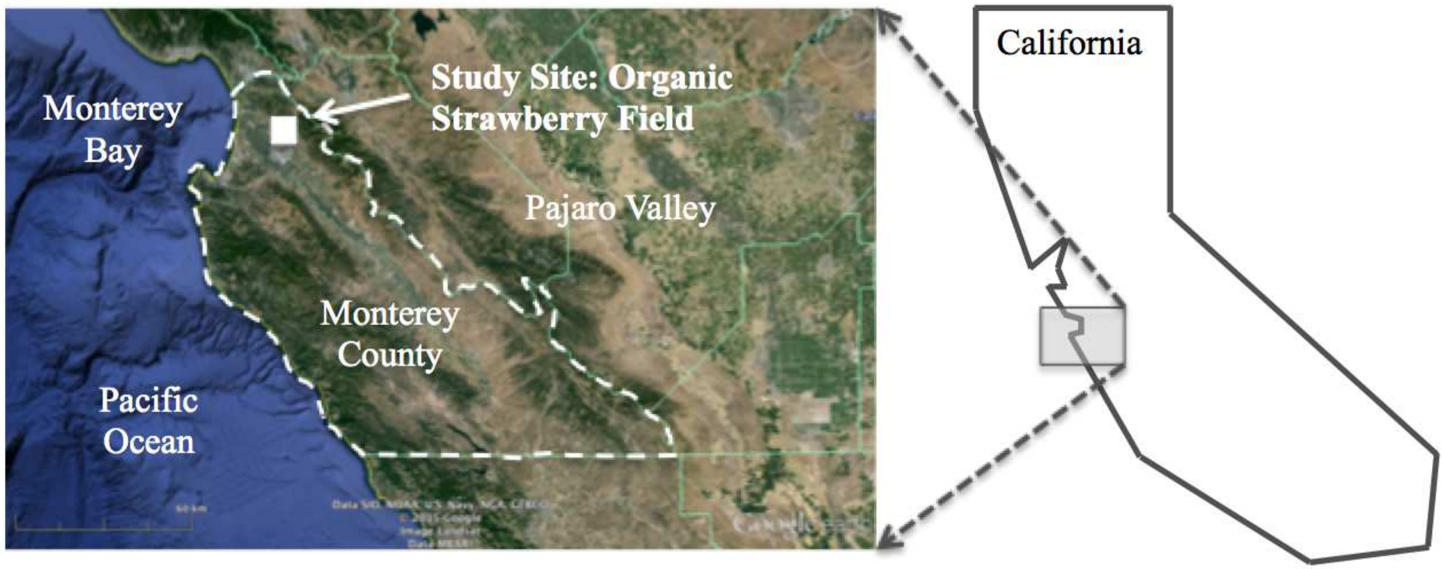

Figure 1 Map of study site location in Monterey County, California. Image source: Google Earth™ 2015.

Study Design

In an organically managed strawberry farm, strawberries were planted with alfalfa trap crops every 50 rows. Three blocks (~200 sq. ft. each) were established for arachnid population sampling from June through October 2013. In each block, arachnids were collected within an alfalfa trap crop, in three rows (2-4) near the alfalfa and in three rows (19-21) far from the alfalfa (Figure 2). Pitfall traps were used to collect arachnids from specific in-field habitats. A total of 42 pitfall traps was used in each plot. Six pitfall traps were placed about 10 meters apart in each previously mentioned strawberry and alfalfa row, for a total of six traps within the alfalfa, 18 traps in three strawberry rows near the alfalfa, and 18 traps in three strawberry rows far from the alfalfa. The traps were replaced weekly. The entire flow of the study design is shown in Figure 3.

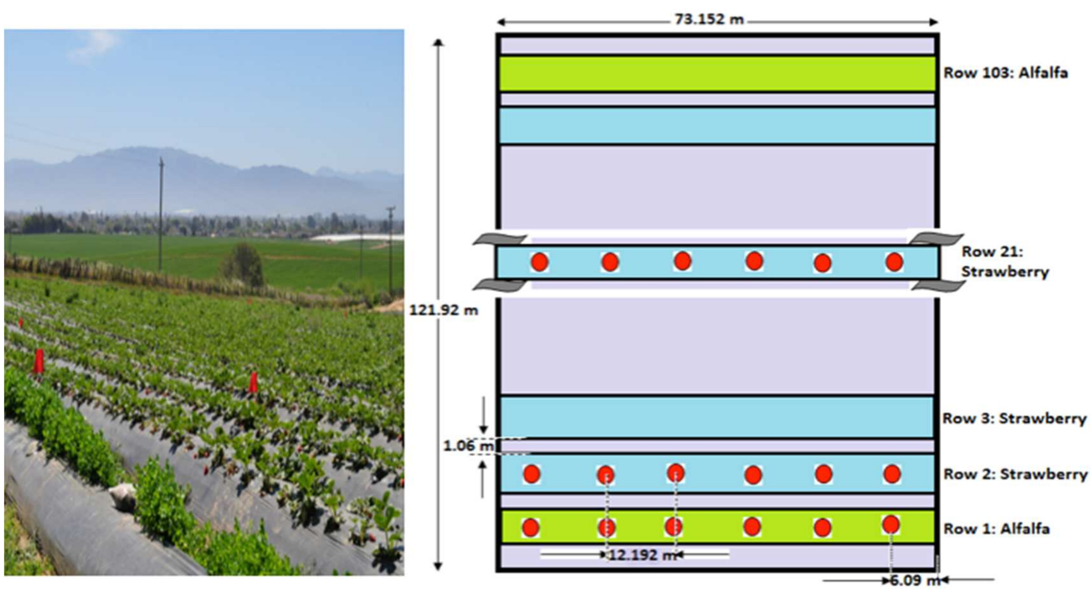

Figure 2 Pitfall trap locations in strawberry bed near (2-4) alfalfa strip and far (19-21) from strip in organically managed field. (Photo credit: author)

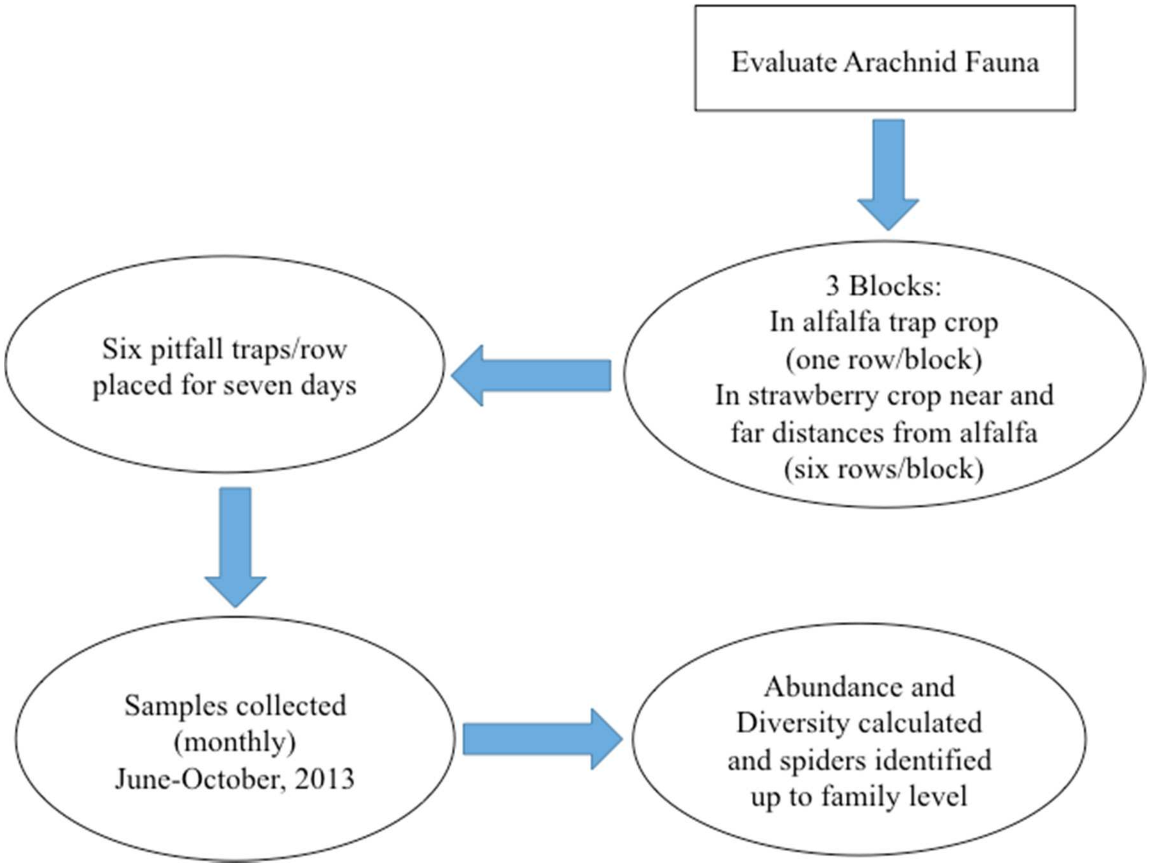

Figure 3 Study design.

Data Collection

Pitfall Traps

Pitfall trapping is one of the most common methods to sample surface-active terrestrial arthropod communities (Uetz et al. 1976). Pitfall traps involve the placement of an open container in the ground to estimate the abundance and species composition of active arachnids in the area (Figure 4). These traps passively collect organisms moving across the ground, so they provide relative measures of activity and not absolute density (Work et al. 2002). Pitfall traps are considered an excellent tool for detecting and monitoring the season-long activity of insects and other ground dwelling arthropods (e.g. spiders and harvestmen) in a particular area. Pitfall traps, which are easy to maintain, non-destructive to habitat and capture both diurnal and nocturnal species continuously. For these reasons, pitfall traps are recommended for comparative community studies.

The traps were made using 595 ml plastic cups with 10 cm diameter wide mouths placed in the ground between plants. The plastic traps were set into the soil, with the rim level to the plastic mulch. Each trap was filled with a preservative consisting of soapy water and salt, commonly used for arthropod collection.

Figure 4 Pitfall trap placement in strawberry and alfalfa rows. (Photo credit: author)

Arachnid Identification

After collection, all arachnids were placed in individual glass vials filled with 75% ethanol and labeled appropriately. Arachnid specimens collected from the traps were examined using a dissecting microscope. The specimens from each sample were counted, and arachnid abundance and taxonomic richness were recorded. Spiders were identified to the family level at 40-60x magnifications using an identification manual for

North American spider genera (Ubick et al. 2005) and a field guide to spiders of California and the Pacific Coast states (Adams et al. 2014).

Data Analysis

Arachnids collected were classified based on abundance, guilds, family and sexual differences (male, female, and immature).

A Generalized Linear Model (GLM) from SYSTAT 13 was used to fit the distribution of spider family abundance and diversity as a function of time and distance from the reference alfalfa trap crop. For each abundance computation, counts were used as response variables, while the independent variables were time (month), treatment (alfalfa vs. strawberry), and location (in, near and far from alfalfa rows). For all abundance-related analysis, the raw counts of arachnids captured (June to October) using pitfall trap sampling from three plots were used. The analysis reported mean arachnids per trap over time, location, and treatment.

RESULTS

A total of 1,991 arachnid specimens were captured using pitfall traps, including 1,690 spiders (representing 15 families) and 301 Opiliones (harvestmen) (Table 1). Family identifications of the spiders were made from the adults captured, because reliable keys were not typically available for identifying immature arachnids.

The most abundant families captured during this study were Theridiidae (630), Clubionidae (257), Lycosidae (198), Lynyphidae (162), Dysderidae (96), Tetragnathidae (93), Thomisidae (80), Oxyopidae (47), Leptoniidae (40), Salticidae (34), Gnaphosidae

(19), Corinnidae (16), Caponidae (8), Anapidae (8), and Zoridae (2) (Figure 5). Most of these families were present in both alfalfa and strawberry.

Table 1 Arachnid Families (counts) found in Organic Strawberry Fields, with percent by sex and age.

	Family	Total	Male count	Male %	Female count	Female %	Immature count	Immature %
Hunting Spiders		797						
	Clubionidae	257	131	50.97	122	47.47	4	1.56
	Lycosidae	198	71	35.86	59	29.80	68	34.34
	Dysderidae	96	27	28.13	39	40.63	30	31.25
	Thomisidae	80	54	67.50	26	32.50		
	Oxyopidae	47	28	59.57	1	2.13	18	38.30
	Leptonetidae	40	2	5.00	38	95.00		
	Salticide	34	2	5.88	32	94.12		
	Gnaphosidae	19	12	63.16	7	36.84		
	Corinnidae	16	4	25.00	12	75.00		
	Caponiidae	8	3	37.50	5	62.50		
	Zoridae	2			2	100.00		
Web-Building Spiders		893						
	Theridiidae	630	416	66	149	23.7	65	10.3
	Linyphiidae	162	98	60.5	64	39.5		
	Tetragnathidae	93	50	53.7	25	26.9	18	19.4
	Anapidae	8	2	25	2	25	4	50
Opilliones		301						
	Harvestmen		183	60.8	110	36.5	8	2.6

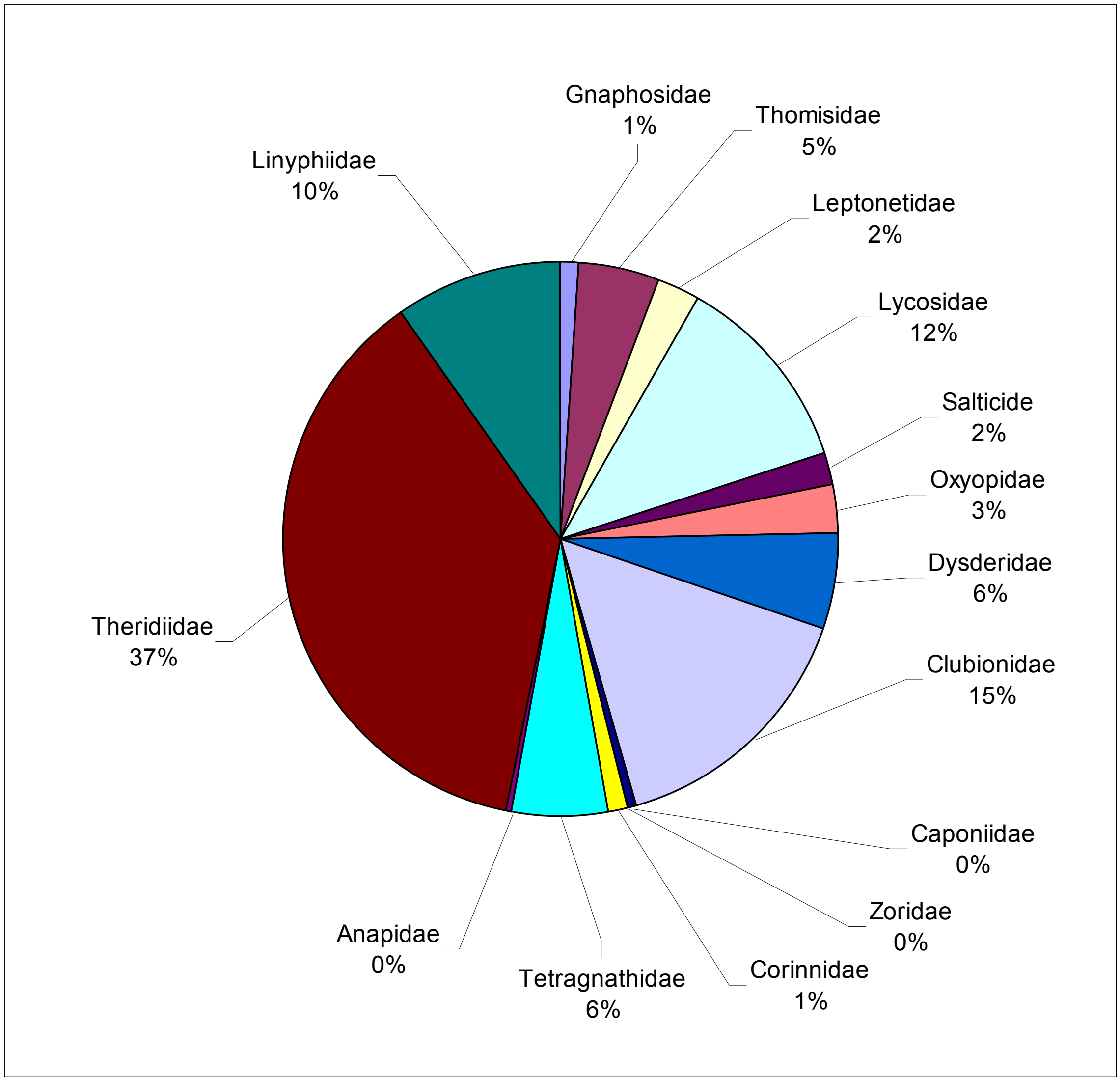

Figure 5 Spider family composition by abundance.

Abundance

Arachnids were found in pitfall traps throughout the five-month sampling period. The average number of arachnids caught per trap was highest during mid- and late-summer (Figure 6), then dropped considerably during the fall (Figure 6). Overall arachnid abundance increased in alfalfa trap crops and decreased moving out into strawberry (Figure 6). These results demonstrated consistent and strong location effects, regardless of month.

Arachnid seasonality in the organic strawberry field showed the highest densities during the months of June to August (Figure 6). The overall abundance however was consistently higher in the alfalfa trap crop for the entire period of study. Abundance patterns were non-overlapping for the three locations (alfalfa trap crop, near rows of strawberries, and far rows of strawberries), with alfalfa showing the largest mean numbers of arachnids followed by near and far categories.

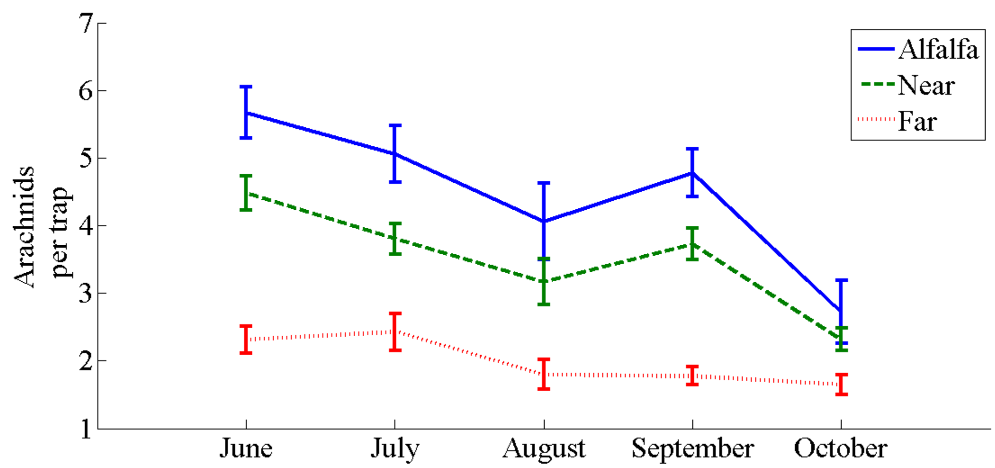

Figure 6 Arachnid abundance (mean ± SE) in pitfall traps from June-October 2013 with sample size n = 126. The abundance was consistently highest in the alfalfa rows, with numbers decreasing with distance to the outer edge of the field.

Sexual Differences with Regard to Behavior and Abundance

Male, female, and immature spider abundance was also analyzed (Figure 7-12). Male spiders were consistently more numerous than females. Adult female abundance peaked during the months of September, whereas the abundance of adult males was relatively stable throughout the season (Figure 7). Immature spiders were captured in large numbers in September and October. The number of male and female arachnids was always relatively higher in the alfalfa rows than the strawberries (Figure 7 and Figure 8), and the number of immature spiders in alfalfa and strawberry rows did not differ ($p = 0.051$)(Figure 9). The numbers of adult spiders decreased with distance from the alfalfa rows ($p < 0.001$) (Figure 10 and Figure 11). Moreover the numbers of immature spiders did not vary at different locations ($p = 0.096$)(Figure 12).

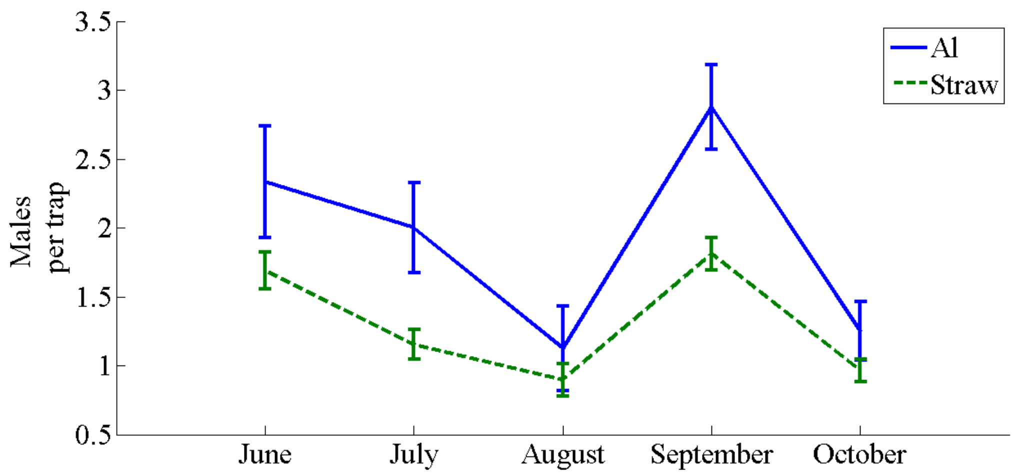

Figure 7 Abundance (mean ± SE) of male ($p < 0.001$) spiders by treatment (Al: alfalfa or Straw: strawberry) with sample size n = 126.

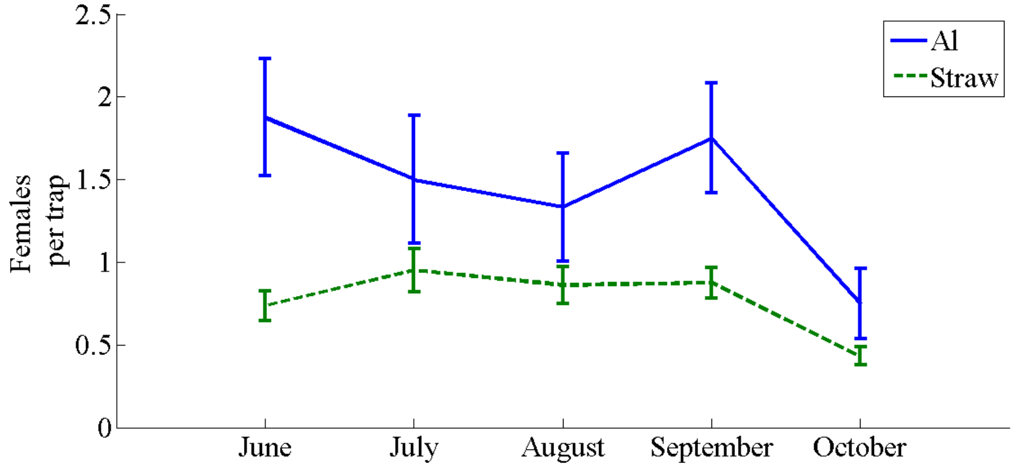

Figure 8 Abundance (mean ± SE) of female ($p < 0.001$) spiders by treatment (Al: alfalfa or Straw: strawberry) with sample size n = 126.

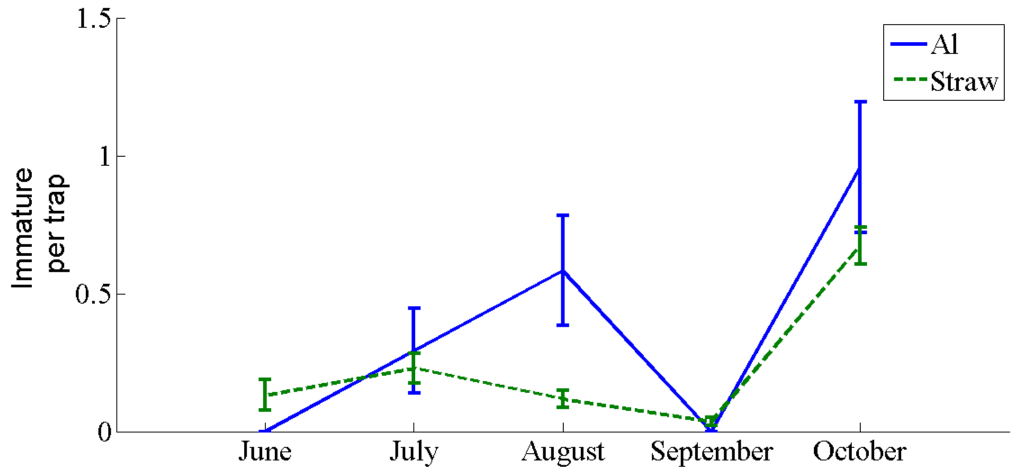

Figure 9 Abundance (mean ± SE) of immature ($p > 0.001$) spiders by treatment (Al: alfalfa or Straw: strawberry) with sample size n = 126.

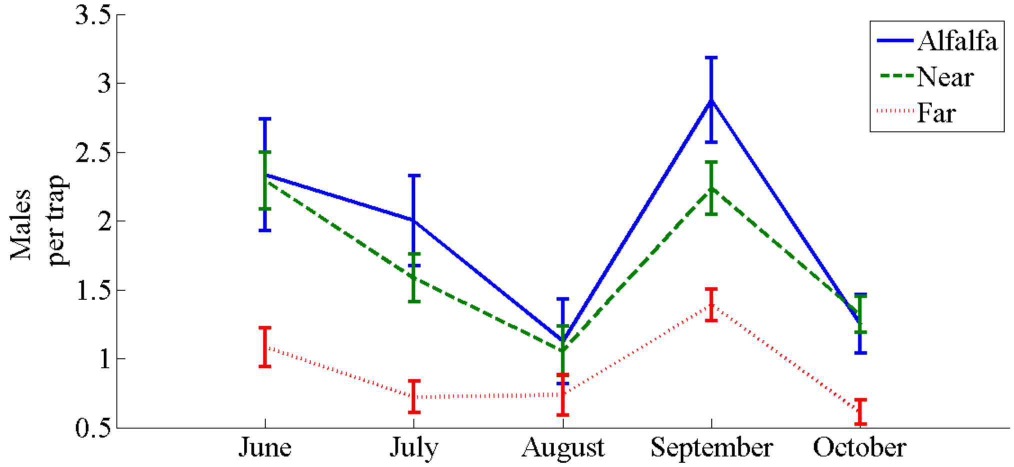

Figure 10 Abundance (mean ± SE) of male ($p < 0.001$) spiders by location (alfalfa, near strawberry, and far strawberry) with sample size n = 126.

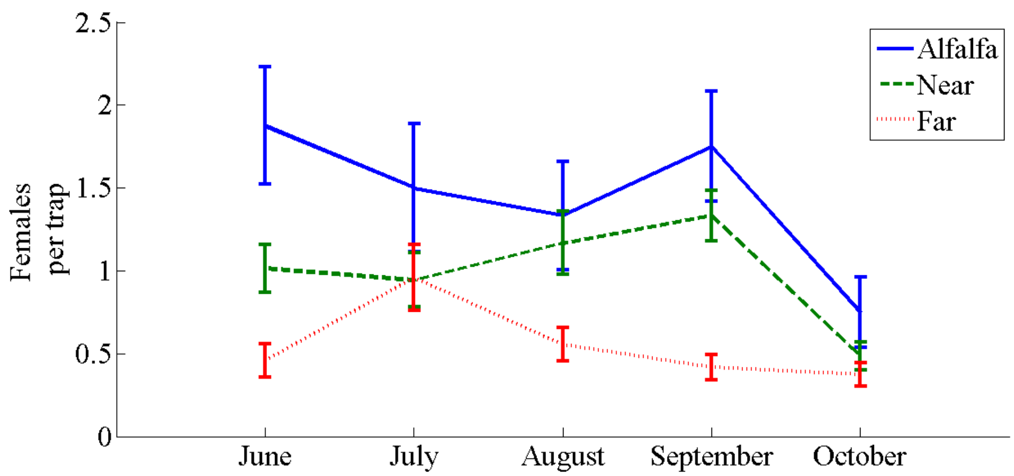

Figure 11 Abundance (mean ± SE) of female ($p < 0.001$) spiders by location (alfalfa, near strawberry, and far strawberry) with sample size n = 126.

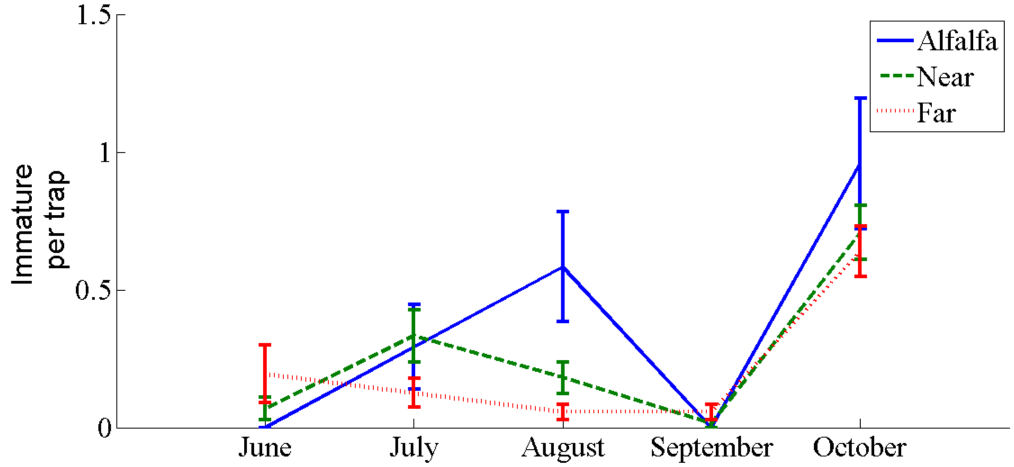

Figure 12 Abundance (mean ± SE) of immature (p > 0.001) spiders by location (alfalfa, near strawberry, and far strawberry) with sample size n = 126.

Guild Structure

The arachnids in this study were also classified by predatory behavior. The dominant spider guilds were hunters (n=797) and web-builders (n=893). The hunter guild included 11 families: Thomisidae, Lycosidae, Dysderidae, Clubionidae, Oxyopidae, Gnaphosidae, Leptoniidae, Salticidae, Caponidae, Zoridae and Corinnidae. Web-builders were comprised of four families: Tetragnathidae, Anapidae, Theridiidae, and Linyphiidae.

The abundance of hunting spiders declined significantly over time. Hunters were consistently more numerous in alfalfa than strawberry (p<0.001)(Figure 13), and the hunting group decreased with distance (p<0.001)(Figure 14) from alfalfa. Web-building spiders yielded a very different pattern. Even though their abundance also changed over time, total numbers were comparable in alfalfa and strawberries (p=0.081)(Figure 15) and web-building spider presence was dependent upon location (p<0.001)(Figure 16).

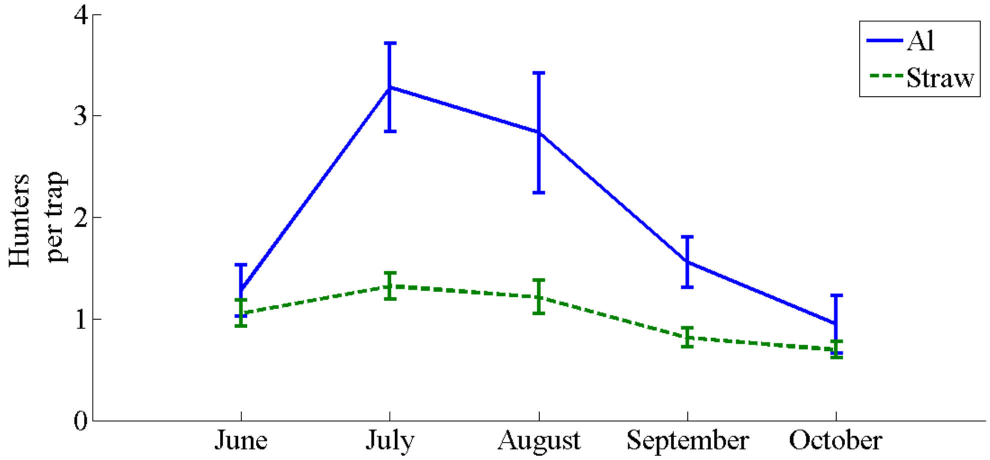

Figure 13 Abundance (mean ± SE) of hunter ($p < 0.001$) spiders (mean sample per trap) by treatment (Al: alfalfa or Starw: strawberry) with sample size n = 126.

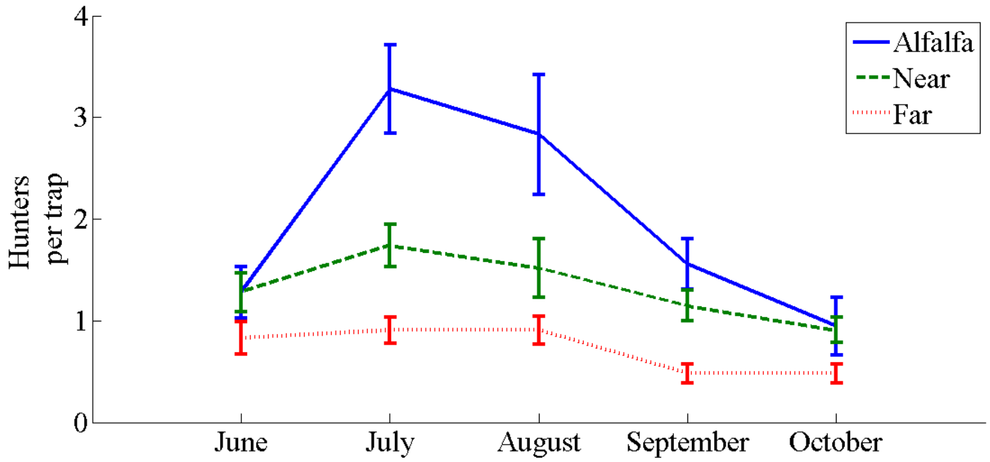

Figure 14 Abundance (mean ± SE) of hunter ($p < 0.001$) spiders by location (alfalfa, near strawberry, and far strawberry) with sample size n = 126.

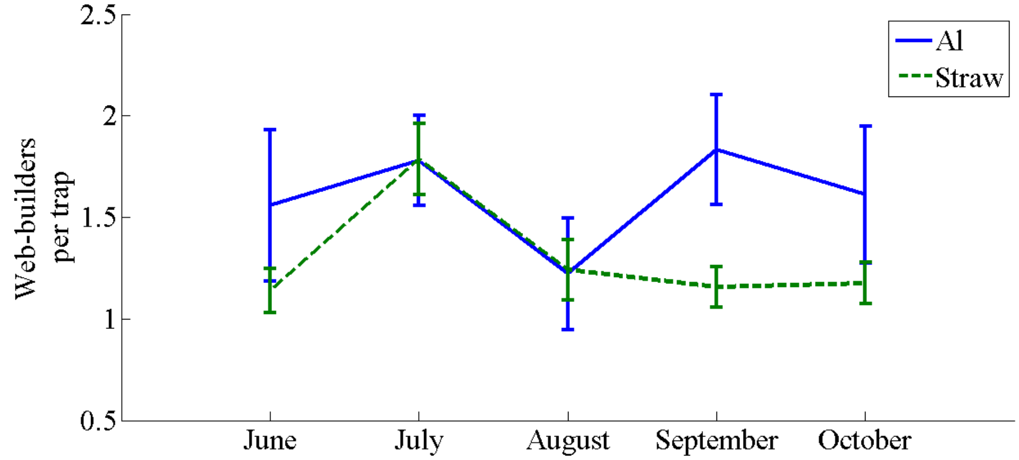

Figure 15 Abundance (mean ± SE) of web-builder ($p > 0.05$) spiders (mean sample per trap) by treatment (Al: alfalfa or Straw: strawberry) with sample size n = 126.

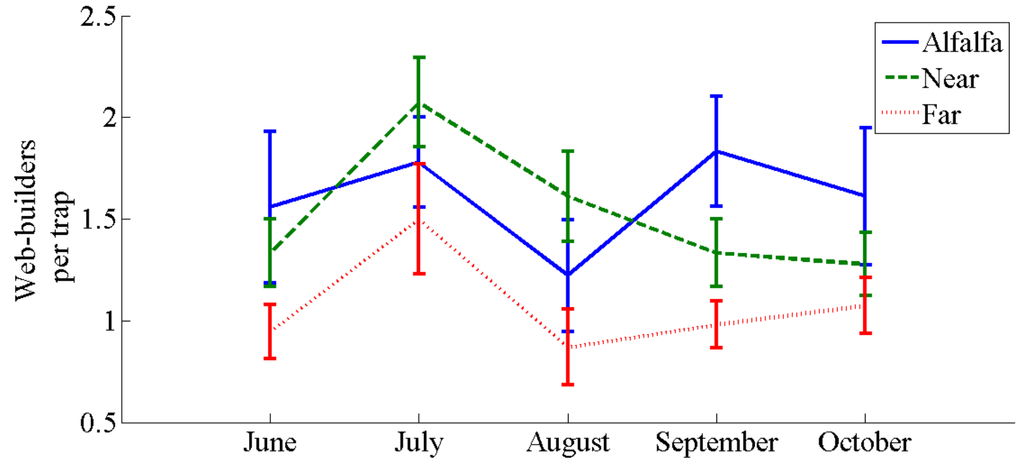

Figure 16 Abundance (mean ± SE) of web-builder ($p < 0.001$) spiders by location (alfalfa, near strawberry, and far strawberry) with sample size n = 126.

Both hunting and web-building spiders had different temporal variation, expressed in terms of total spiders per trap for each guild. In general, the number of spiders per trap for hunting spiders was comparable with web-building spiders in the month of June, and both guilds peaked in July. In August through October, the counts of hunting spiders appeared to have decreased, while web-building spider abundance remains consistent, yielding a higher presence (i.e. more spiders per trap).

Hunting spiders were more abundant in alfalfa trap crops than in adjacent strawberries ($p<0.001$)(Figure 13). There were more web-building spiders in the alfalfa rows as compared to the strawberry fields in September ($p = 0.081$)(Figure 15), but not during the rest of the season.

Common Spider Families

To better understand the specific nature of spider response to vegetation (i.e. alfalfa vs. strawberry), the study evaluated responses of dominant spider families (e.g. Clubionidae, Lycosidae, Theridiidae and Linyphiidae), meaning those with more than 100 individuals trapped during the study.

Hunter Group

The most common families were Clubionidae (n=257) and Lycosidae (n=198). The abundance of Clubionidae spiders significantly rose from June to July, and then declined through October. Clubionidae were more abundant in alfalfa and less abundant in strawberry ($p<0.001$)(Figure 17). Clubionidae showed a significant decrease as distance from alfalfa increased ($p<0.001$)(Figure 18).

The abundances of Lycosidae spiders increased with time, but a less pronounced increase observed in strawberries as compared to alfalfa during the month of August. Overall, the abundance of Lycosidae was not significantly higher in alfalfa

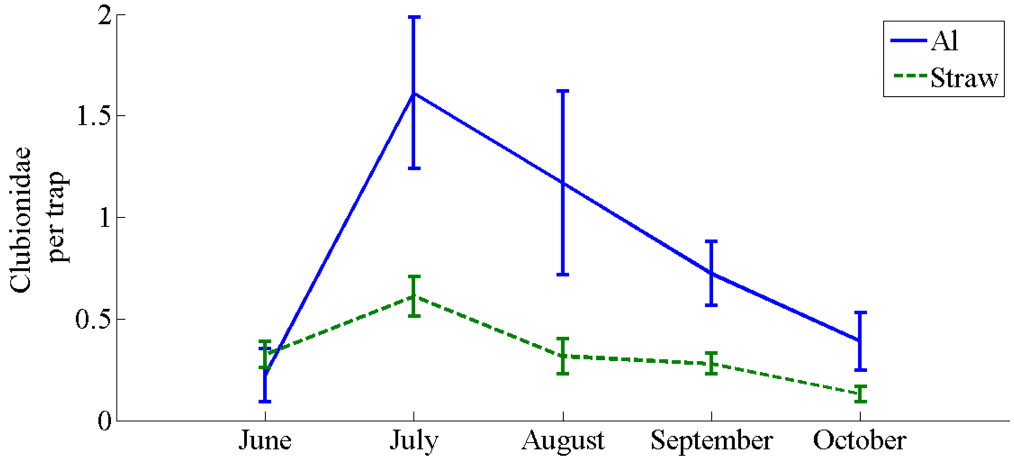

Figure 17 Abundance (mean ± SE) pattern across dominant spider family Clubionidae ($p < 0.001$) over treatment (Al: alfalfa and Straw: strawberry) and time with sample size n = 126.

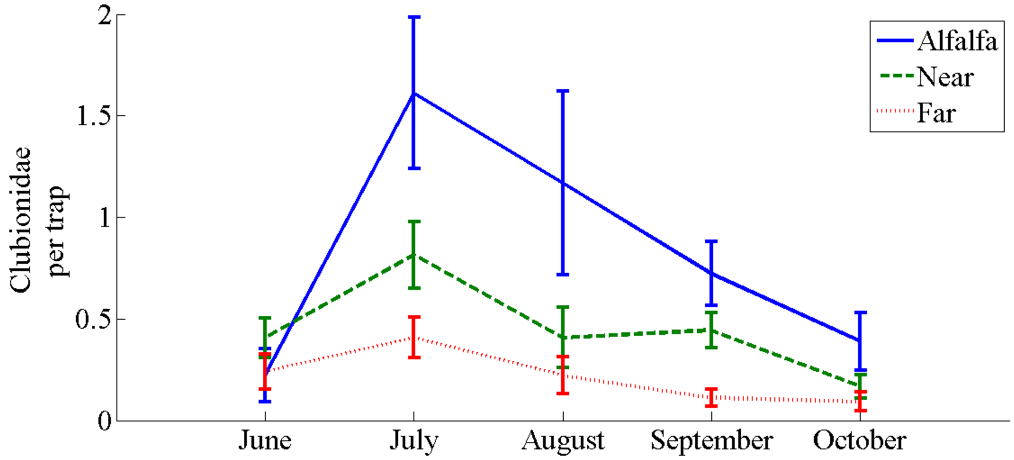

Figure 18 Abundance (mean ± SE) pattern across dominant spider family Clubionidae ($p < 0.001$) over location (alfalfa, near strawberry, and far strawberry) and time with sample size n = 126.

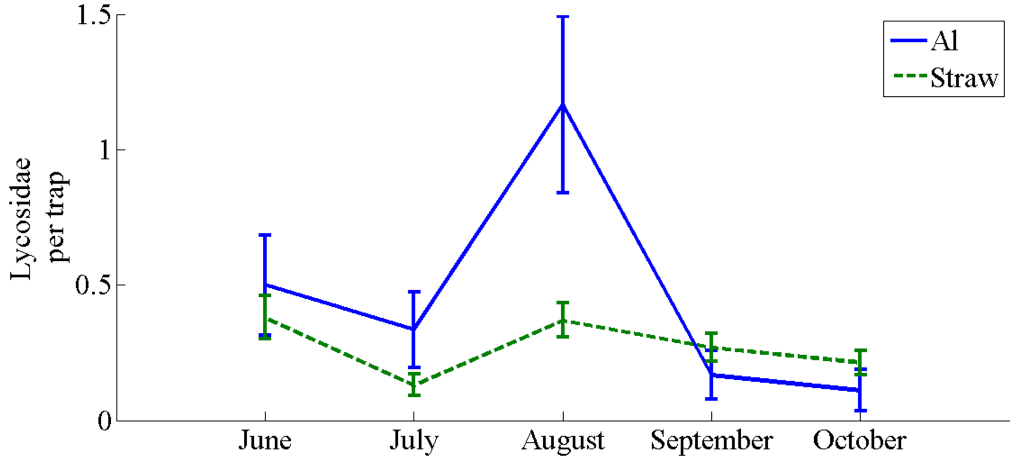

Figure 19 Abundance (mean ± SE) patterns across dominant spider family Lycosidae ($p > 0.001$) over treatment (Al: alfalfa and Straw: strawberry) and time with sample size n = 126.

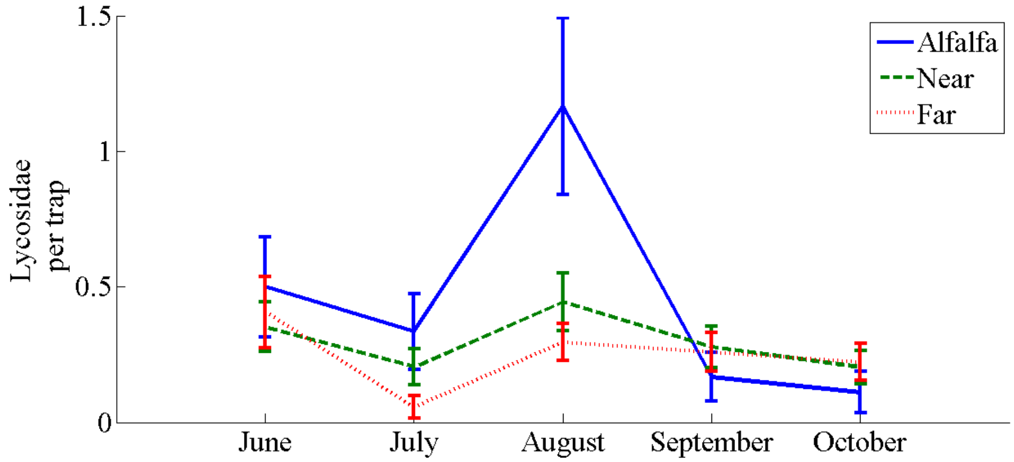

Figure 20 Abundance (mean ± SE) patterns across dominant spider family Lycosidae ($p > 0.001$) over location (alfalfa, near strawberry, and far strawberry) and time with sample size n = 126.

(p=0.677)(Figure 19). Though Lycosidae abundance decreased with distance from the alfalfa rows (p=0.884)(Figure 20), they exhibited a major overlap in abundance between rows of strawberries that were near and far from the alfalfa.

Web-Builder Group

Theridiidae (n=630) and Linyphiidae (n=162) were the most dominant families from the web-building group. Theridiidae abundance over time was very similar to Clubionidae, showing a significant increase from June to July, and then declining through October. The alfalfa trap crop affected the abundance of Theridiidae but the decrease in abundance from alfalfa to strawberry was less compared to Clubionidae (p<0.001)(Figure 21). The abundance of Theridiidae in alfalfa and rows near alfalfa was very comparable but the abundance dropped off more in strawberry rows farther from the alfalfa, compared to Clubionidae and Lycosidae (p <0.001)(Figure 22). Numbers of Linyphiidae were consistent in strawberry and alfalfa (p = 0.954)(Figure 23). In a more refined scale, their presence also did not vary by location (p = 0.368)(Figure 24). However, their abundance was still significant over time and increased the latest of all spider families considered in the season.

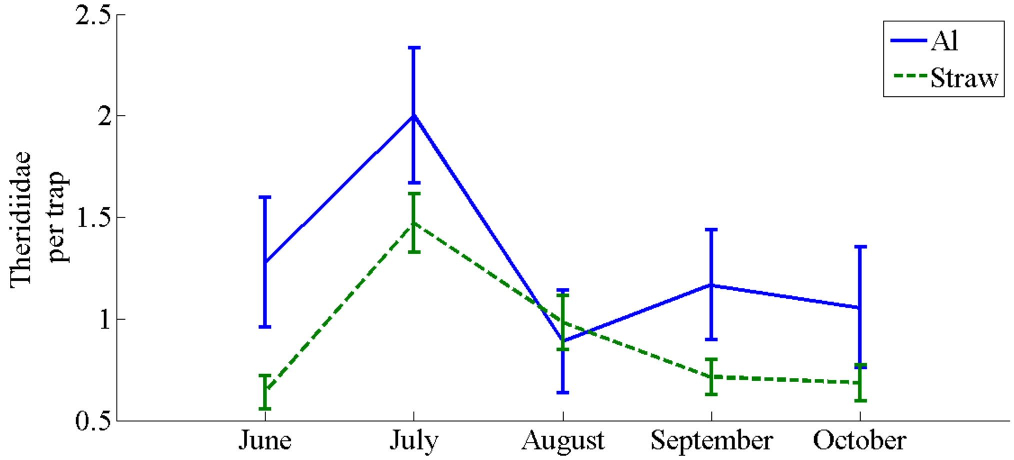

Figure 21 Abundance (mean ± SE) patterns across dominant spider family Theridiidae ($p < 0.001$) over treatment (Al: alfalfa and Straw: strawberry) and time with sample size n = 126.

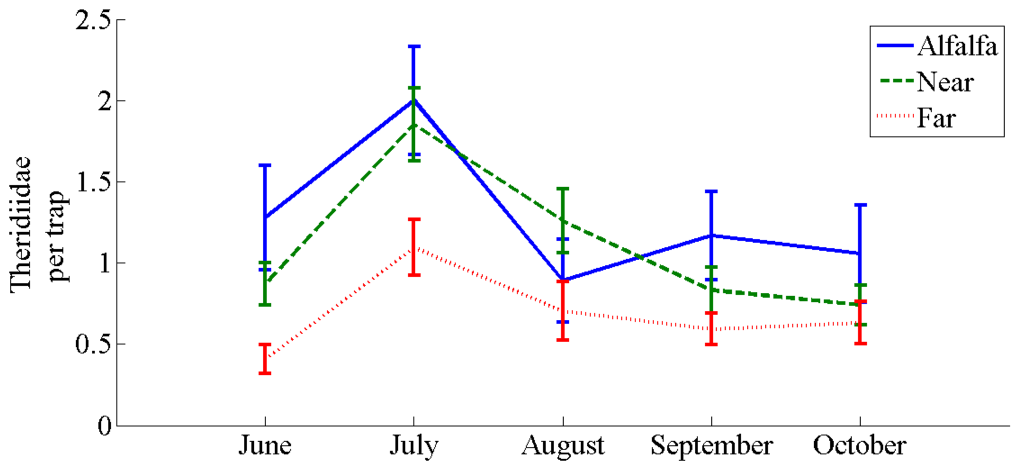

Figure 22 Abundance (mean ± SE) patterns across dominant spider family Theridiidae ($p < 0.001$) over location (alfalfa, near strawberry, and far strawberry) and time with sample size n = 126.

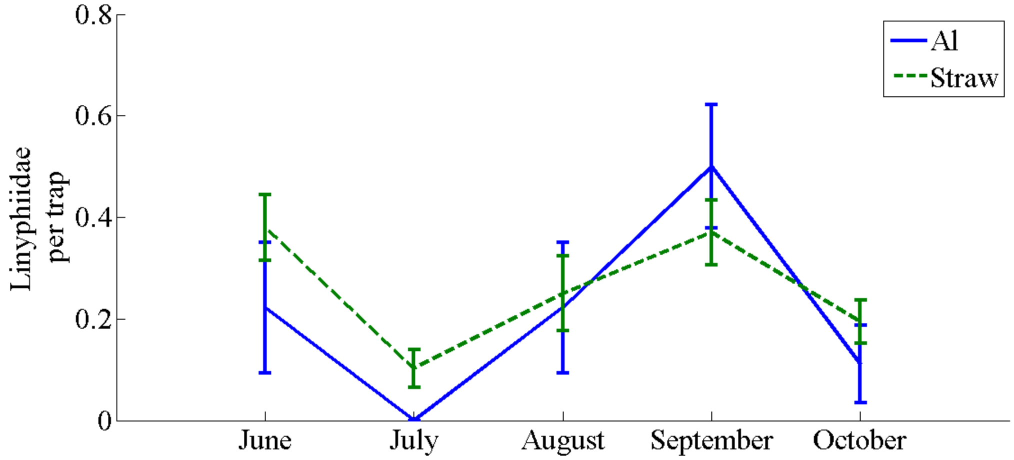

Figure 23 Abundance (mean ± SE) patterns across dominant spider family Linyphiidae ($p > 0.001$) over treatment (Al: alfalfa and Starw: strawberry) and time with sample size n = 126.

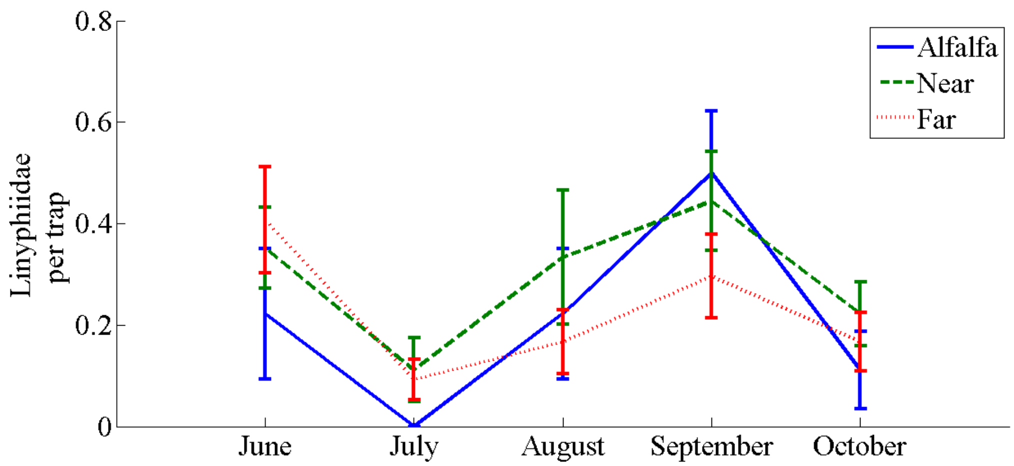

Figure 24 Abundance (mean ± SE) patterns across dominant spider family Linyphiidae ($p > 0.001$) over location (alfalfa, near strawberry, and far strawberry) and time with sample size n = 126.

All three families (Lycosidae, Clubionidae, and Theridiidae) were more abundant in alfalfa and less abundant in strawberry. Linyphiidae did not vary by vegetation structure ($p = 0.954$).

Opiliones (Harvestmen)

A total of 301 Opiliones (Table 1) were captured: 183 males, 110 females, and 8 immature individuals. The abundance of Opiliones over time demonstrated two peaks one around June and the other in September. Opiliones were common in both alfalfa and strawberry, with greater numbers in alfalfa relative to strawberry ($p < 0.001$)(Figure 25). The abundance of Opiliones decreased with distance with a major drop-off in between rows that were near and far from the alfalfa ($p < 0.001$)(Figure 26).

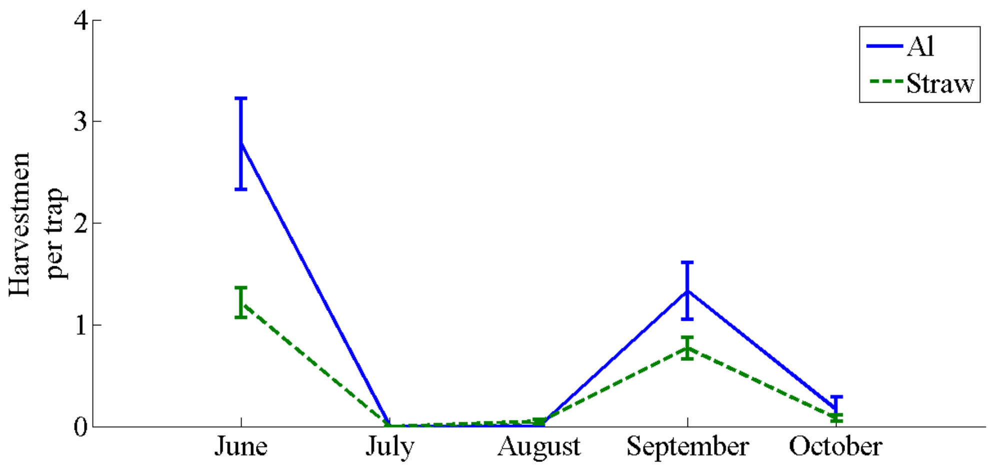

Figure 25 Abundance (mean ± SE) of harvestmen ($p < 0.001$) by treatment (Al: alfalfa and Starw: strawberry) with sample size n = 126.

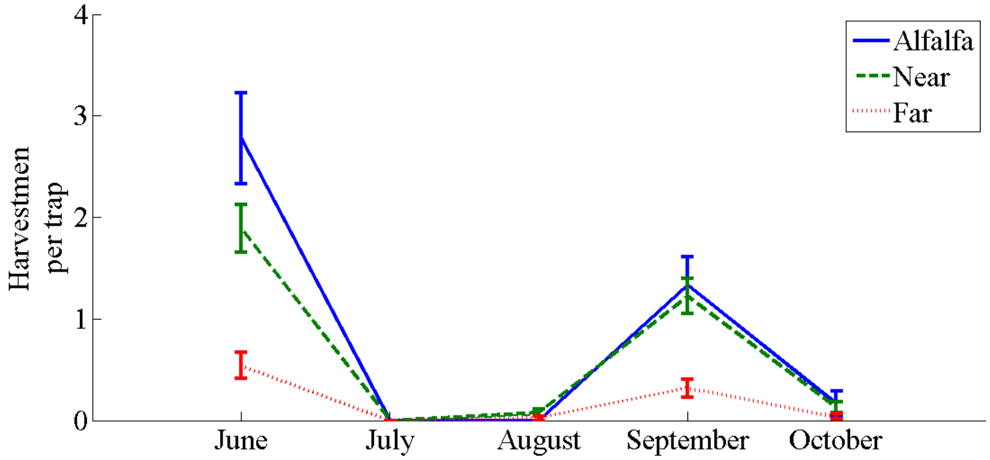

Figure 26 Abundance (mean ± SE) of harvestmen ($p < 0.001$) by location (alfalfa, near strawberry, and far strawberry) with sample size $n = 126$.

DISCUSSION

This study is one of only a few on arachnid communities in organically managed strawberry fields in the United States. In this study, abundance and distribution of spiders and harvestmen at an organic trap-cropped strawberry field in Prunedale, California were compared. The spider fauna documented in northern European field crops are dominated by a single spider guild of small linyphiids (Nyffeler and Sunderland 2003). In the US, spider guild structure is more complex and is comprised of hunters (mainly Oxyopidae, Salticidae, Clubionidae, Thomisidae, and Lycosidae), which have more diverse diets (Nyffeler and Sunderland 2003). Some cropping systems in the US have been shown to contain a greater diversity of fauna, with hunters comprising over 50% of the total spider population, with a relatively lower abundance of linyphiidae (17%) (Nyffeler and Sunderland 2003). In this study, the organic strawberry crop in California supported a wide diversity of spider fauna. Young and Edward (1990) found more than 600 spider species (44% web-builders, 56% hunters) were associated with US crop fields. These findings differ from the current study's findings revealed that pitfall trap catches at study sites had a greater abundance of web-building spiders (53%), relative to hunting spiders (47%). This difference may be because previous study findings (Young and Edward 1990) were based on specific field crops without regard for the effects of trap crops.

This study, in contrast to Young and Edward (1990) specifically considered the influence of alfalfa trap crops on the abundance of spider populations in organic strawberry crop fields. The abundance of hunting spiders decreased significantly with distance from alfalfa, while the abundance of web-building spiders remained unchanged (Figure 14). However despite this finding, one possible reason for this result could be that alfalfa trap crop stabilizes the abundance of web-building spider populations in and near these alfalfa trap crop rows. The scope of the current study was limited to the sampling technique used. Other sampling methods, such as D-vac or sweep net, may have yielded a different composition of species and families from both web-building and hunting guilds.

Spider guild structure (proportional abundance) varies among individual crops (Uetz et al. 1999). Based on the guild structure classification proposed by Uetz et al. (1999), two dominant spider guilds, web builders and hunters, were recorded. The family compositions in this study were limited to family compositions in US crop fields (Nyffeler 1999, Young and Edward 1990). The dominant families identified in this study were Clubionidae, Lycosidae from the hunter guild, and Theridiidae, Linyphiidae from the web-builder guild.

Clubionids (Pacific coast sac spiders) are free-living, nocturnal hunters commonly found in foliage on living trees, under bark, stones and logs, grassy fields, and leaf litter (Richman and Ubick 2005). Clubionidae usually have long narrow bodies and range in color from pale yellow to mahogany brown. They are two-clawed spiders, with eight eyes aligned equally in two straight rows. Lycosidae are commonly called wolf spiders because of their method of capturing their prey (Dondale 2005). Many species of lycosidae family are diurnal, wandering hunters, moving mainly on the ground among low-growing foliage or around the margins of lakes and swamps, preying on a wide variety of ground insects. They are three-clawed spiders, usually dark grey or brown in color, with eight eyes arranged in three rows (4:2:2). Theridiidae (comb-footed spiders) are small-to-medium sized spiders with globular abdomen and long legs, the third pair of which is the shortest (Levi 2005). Most genera build three-dimensional, untidy-looking space-webs of different shapes. They are three-clawed spiders with eight eyes divided equally in two transverse rows. Linyphiidae (dwarf spiders) are small spiders that spin delicate sheet webs between branches of trees and shrubs (Draney and Buckle 2005). They are three-clawed spiders with eight eyes equally arranged in two rows. Linyphiids generally feed on soft-bodied insects, especially collembolan and flies.

Research into the role of Opilionids (Harvestmen) as predators of crop pests has been minimal, with their potential as biocontrol agents relatively unexplored. While the existing literature has focused on the role of harvestmen in controlling leafhoppers (Dixon and McKinlay 1989) and lepidopterans, this study reported that harvestmen comprise a major, and numerically dominant presence in both alfalfa trap crop and organic host crop strawberry fields.

Male spiders are generally more mobile than females and may move considerable distances in search of mates; therefore the representation of sexes has been found to be seldom equally distributed in pitfall trap samplings (Jennings et al. 1988). The dominance of male spiders in trap catches was therefore not surprising, as pitfall traps are inherently biased toward capturing samples that are cursorial (i.e. moving) (Utez & Unzicker 1976). The result showed that the numbers of adult males peaked markedly in the months of June and in July, whereas the adult females showed comparatively less abundance during the same period. This difference in abundance may be due to the observed higher density of adult males in June and July, when they exhibit more predatory behavior and actively search for mates. It is also possible that the lower adult female density during June and July can be explained by the drive to maximize energetic intake for purposes of potential reproduction (Kok et al. 2004). In contrast, September yielded a higher abundance of adult females and males, which could be explained as a breeding season. Interestingly immature spiders were captured in significant numbers immediately after the breeding season, during September and October. Sexual differences in spider communities have not been well studied. The results presented here are based on an experimental study that provided a basis for further study of the abundance of ground spider families within different habitats.

This study's experimental procedures for collecting spider data had four major limitations. Thus, the analysis of spider families that follows should not be generalized to others. There are four such limitations. First, spiders are known to be generalist predators that can subsist on a wide variety of prey. The findings reported here may simply reflect the opportunistic meanderings of the extant spiders in search of that prey. Second, although productive with regard to demonstrating the presence of many species, sampling methodology involving the use of pitfall traps may not be the best one for detecting habitat partitioning within a species because this relative measure of density may not accurately reflect of the absolute density occurring in each habitat. Third, the intensity of sampling in space and time may have been insufficient to detect of habitat partitioning. Fourth, the partitioning that may have been occurring may be taking place based on factors other than those used to delineate the habitats originally identified for this study.

Spider diverse assemblages have been found to be effective in stabilizing pest populations (Riechert and Lawrence 1997). The most likely explanation for enhanced spider abundance is the integration of alfalfa trap crops within strawberry. Arachnid abundance was consistently highest within alfalfa rows, with the numbers decreasing in those strawberry rows furthest to alfalfa (Figure 6). These findings suggest that alfalfa trap crops represent excellent habitat for arachnids. This finding is supported by Root's (1973) "enemies' hypothesis," which states that natural enemies are more abundant in diversified agricultural systems. More specifically, the diversity of spider species is positively affected by habitat structure complexity (Rypstra et al. 1999). The structure of the vegetation and the microclimatic conditions play an important role in spider selection of microhabitat (Biere and Uetz 1981). High levels of leaf and branch density, in combination with greater complexity of twigs in alfalfa, represent an ideal habitat for canopy-dwelling spiders. The physical structure and the density of alfalfa provide optimum web-building conditions. The plants also serve as a safe hiding place, with prey availability and microclimatic conditions such as temperature and humidity that are favorable to spiders.

Perennial crops and degree of heterogeneity in surrounding landscapes has been demonstrated to have a positive effect on spider abundance and species richness on arable land (Schmidt and Tscharntke 2005). Though alfalfa and strawberries are both perennial crops, in California strawberries are planted as an annual. Farmers remove strawberry plants after one year in order avoid pest build-up and to maintain fruit quality. The more diversified the crop, the more positive the effect with regard to natural enemies (Samu et al. 1999). Thus the establishment of alfalfa trap crop rows in an organic strawberry field can enhance diversification and increase the overall abundance of arachnid populations in the crop field.

The role of spiders in a food chain and their potential in biological control has been extensively investigated during the last few decades. Spiders' potential as biological control agents has been consistently agreed upon in the published literature (Riechert and Lockley 1984, Riechert and Bishop 1990, Young and Edwards 1990). Conventional management of agricultural fields leads to a structurally homogeneous environment, which is likely to result in low abundance and diversity of arachnids. Previous studies conducted at the same study site showed that adult lygus bugs were much more abundant in alfalfa trap crops compared to strawberries (Swezey et al. 2007; Swezey et al. 2013). Swezey et al. (2007) also identified a reduced abundance of lygus bugs in the month of August. The same seasonal decline was observed in this study, which found a sharp drop in the abundance of arachnids during the month of August (Figure 6). This particular finding points to an important new research direction. This study revealed that arachnid abundance was consistently highest in alfalfa, rather than strawberries. Moreover, Hagler et al. (In Prep) confirmed spider predation of lygus bugs in trap crops and strawberry through a gut content analysis (polymerase chain reaction), Linyphiidae, Theridiidae, Thomisidae, Oxyopidae, and Harvestmen were all shown to feed on lygus bugs. Also Mostafa et al. (2011) found that the spider family Thomosidae functions to control numerous insect pests, including whiteflies and lygus bugs, in Arizona crop fields. The results of this study lend support to the presence of these lygus-eating families in alfalfa trap crops in large numbers. This finding is supported by Symondson et al. (2002), who demonstrated that spiders can play a key role in suppressing agricultural pests.

The results reported in this study suggest that the use of trap crops offers one strategy for habitat diversification which may be effective for enhancing arachnid populations. The presence of trap crops within the main crop system can provide a level of connectivity between habitats, which can be important for maintaining natural enemy populations. Moreover, alfalfa, as a preferred host of lygus bugs, represents a favorable habitat type for arachnids. If arachnids feed on lygus bugs, then planting alfalfa trap crop with strawberry may even serve as an effective strategy for enhanced biological control through the action of arachnids.

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