**Full Title**

Does Semi-Natural Habitat Amplify Beneficial Spider Populations in a California Organic Vineyard?

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**Short version of title**

Vineyard SNH and Beneficial Spiders?

**Abstract**

Semi-natural habitats (SNH), areas characterized by reduced management activity and the presence of native vegetation, are thought to represent a persistent reservoir of beneficial insect populations. Faced with an array pest management challenges, the organic wine grape industry and research institutions have studied the potential contribution of SNH to biological control strategies. However, conclusions are often contradictory and qualitative. Here, we track the spatial occurrence of spiders over the course of the growing season, comparing a transect supported by a native oak grove and a transect bordered by an empty field.

To evaluate the density of insect populations, we collect samples from non-lethal vane traps suspended in the canopy. We find that species abundance is higher by 30% in the SNH transect early in the growing season, while species diversity is always comparable for the two transects. Three distinct population clusters persist throughout the season in both transects. Contrary to our initial assumptions, we conclude that, for a California Central Coast organic vineyard, SNH dominated by mature oak trees promotes populations of the generalist spiders *Thomisidae* beyond the first 15 meters of the transect. This result suggests that producers could consider reinforcing SNH effects by emphasizing under-trellis cover crop strategies for the initial 15 meters of the rows.

**Key words:** semi-natural habitat, beneficial insects, spiders

**Introduction**

Biological control of vineyard pests represents economic, as well as environmental, value for the competitive wine industry. While overall cultural cost is higher (Wheeler, 2009) and production is lower (Döring, 2015), growers who use organic methods (Provost 2016) and emphasize the role of beneficial insects as antagonists of phytophagous pests reduce insecticide material and operations cost, reduce the uptake of herbicide residuals by vines (Bettiga 2013), and may reduce vineyard tractor emissions and ground compaction (Polge de Combret‐Champart 2013) as compared to those using traditional methods. Often, organic growers can achieve further leverage up the value chain by commanding higher prices for an “organic” product (Kirby 2018).

The vineyard habitat in the California Central Coast experiences significant change during vine dormancy and throughout the growing season. Overwintering pest larvae survive in the soil, under vine bark, in pruning debris, and in dessicated clusters to form a nucleus of subsequent arthropod populations. The annual redevelopment of the vineyard canopy provides resources for the existing inhabitants and also for colonists emigrating from other crops or natural habitat (Wilson 2016). Row cover crops relying on soil moisture provided by winter rains die well before harvest, subsequent mowing and/or tillage (Nicholls 2000) change the predator-prey dynamic. Cultural operations in the vineyard canopy can also be interpreted as habitat perturbations and have been noted to cause adaptive responses by the diverse spider assemblages (Chatterjee 2008). Pruning and leaf pulling change the canopy microclimate (Norton 2008).

Researchers have examined the role of the “field margin” as a source of insects that could control vineyard pests (Altieri 2005, Hogg 2010, Hogg 2018, Nichols 2001, Ponti 2005, Thomson 2009, Wilson 2015). However, the general response of agricultural systems to the composition of surrounding landscape is inconsistent (Karp 2018).

The specification of “semi-natural habitat” (SNH) itself is vague and not easily compared between regions, crop systems, or researchers (Duflot 2014). The European Union defines SNH as “any habitat within or outside of the crop containing a community of non-crop plant species” Holland 2017). The research context of SNH is often related to any “non-crop habitats such as cropland boundaries, fallows, grasslands, woodlands, wetlands, and forests” (Tscharntke 2016).

Because complex trophic level interactions are influenced by spatial and temporal variables, researchers have warned that the effect of SNH cannot be generalized (Rusch 2010). In California vineyard systems, some agricultural ecologists view “semi-natural habitats” as “areas characterized by reduced management activity and the presence of native vegetation” (Fuller 2016). These zones are thought to represent a persistent reservoir of beneficial insect populations.

This project’s primary purpose is to develop some insight into spatial and temporal patterns of beneficial insect penetration of organic vineyard rows supported by semi-natural habitat typical of the California Central Coast. Existing research has identified the contribution of SNH to organic vineyard ecology, but statements about the extent, or reach, and duration of these effects is often unavailable. Clarifying these questions could lead not only to more thoughtful use of chemical materials, but may inform next-generation vineyard architectures through a better understanding of the relationship between beneficial insect populations and the native habitat bordering the vineyard.

**Materials and Methods**

**The Study Site**

The study was conducted at Ampelos Vineyards in the Central Coast wine grape growing region of California, USA during June, July, and August of 2018. Ampelos is situated west of the town of Buellton in the Sta. Rita Hills American Viticultural Area. This area is known for its persistent night and morning marine layer, a cool air mass usually visible as fog, that originates over the ocean. Gradually increasing east winds usually push this saturated air back over the ocean by mid-day.

Daily climate data was obtained from data published by the California Department of Water Resources via its California Irrigation Management Information System (CIMIS). CIMIS weather station #231 is the closest station to Ampelos, situated 22 km (14 miles) west of the Ampelos North Block. We identify the Ampelos GPS coordinates as -120° 16' 49.7208" longitude and 34° 37' 30.4782" latitude (Buellton 2018), and those for CIMIS #231 as -120° 30' 47.0154" longitude and 34° 40' 19.9986" latitude.

The Ampelos North Block is bordered on the south west by a dense cluster of mature, native coast live oak trees (Quercus agrifolia). 100 meters to the north, this same block is bordered by a vacant, un-irrigated field. The eastern edge of the block borders a typical field of native grass. The striking variation in the borders of these two sections of the Ampelos North Block allowed us to delineate an SNH and Control transect containing identical plants managed using identical operational procedures.

**Transect Positioning, Design, and Layout**

Each of the two transects were defined as including 10 adjacent rows. For each week, 10 traps were alternately distributed in three rows according to a pattern intended to be most sensitive closest to the vineyard edge. This pattern begins, from the vineyard edge, with seven traps spaced 16 foot intervals. The next two traps are placed at 30 foot intervals with the tenth and final trap placed 40 feet beyond the ninth trap. Each row of 10 traps was separated by an un-trapped row. These trap patterns were shifted one row laterally for observation in the following week.

**Sampling**

Blue vane traps (SpringStar Inc., Woodinville, Washington, USA) were suspended from a trellis wire such that the collecting bowl was positioned in the trellis fruit zone. Vane traps are designed to attract pollinators, floral simulation geometry of the vanes induce investigation by *Diptera* and *Lepidoptera*. Positioned in the canopy, vane traps also restrain other wandering arthropods that investigate the trap and, once inside, are unable to exit the bowl. Three days per week, individual traps were opened twice per day at roughly 0800 and 1700 by unscrewing the bowl from the vanes, then examining, recording, and releasing the contents. No chemical attractants were used. It took roughly 45 minutes to complete the examination of the 60 traps in two transects.

**Insect Identification**

We attempted to classify individual trapped insects according to their taxonometric Order, and occasionally to their species. Most insects were categorized into one of five taxonometric Orders, those with uncertain taxonomy were assigned to the category “other”. Identifications were made without visual assist tools. The smallest insect that we could occasionally identify in the field was a species of pirate bug (family *Anthocoridae*), roughly 3 mm in length. This is an extremely problematic dimension for reliable visual identification and candidates were undoubtedly overlooked. In practice, any trapped insect smaller than about 10 mm in length was ignored. During the course of a the sampling season, certain commonly recognized insects of unknown species, were collected in plastic bags and taken to an entomologist for identification.

**Sub-population Identification**

Noting the appearance of spider sub-populations along the length of the transects, we used clustering algorithms to examine the relationship between certain transect positions. Proposing to identify 3 clusters, the observations in each transect position were partitioned via R’s kmeans algorithm which “aims to partition the points into k groups such that the sum of squares from points to the assigned cluster centres is minimized” (R Core Team 2017).

**Spider Population by Cluster and by Transect - Variations in Temporal and Seasonal Presence**

Expecting variation in the number of trapped spiders from week-to-week, we used graphs of spiders trapped per week plotted across the growing season to anticipate effects associated both with time-of-day and with the season, between clusters, and/or between the transects.

**Data Analysis**

We use a generalized multilevel model to produce a probability distribution representing the uncertainty about the outcome variable “trapped spiders” and compare the modelled rate of trapped spiders per unit time between two transects of equivalent spider population. The distribution was analyzed using the R Package brms (Bürkner 2018).

**Results**

S**pecies Composition**

Over the course of the survey period, 4,679 insects were collected and classified. Hymenoptera were found to be abundant apparently due to the presence of mustard weeds (family *Brassicaceae*) between the rows. The vane traps collected very few beneficial wasps, 73 wasps (1.56% of the total insects) were identified. Flies (order *Diptera*) were also numerous (Table 1).

**Insect Diversity and Abundance in the Canopy**

Subject to the sensitivity of the sampling method, the SNH and Control transects maintained similar insect diversity levels (Table 2), but the SNH transect shows higher overall population abundance (Table 3) early in the survey period.

**Crab Spider Abundance and Composition**

Several species of spider were encountered. Spiders of the taxonometric family *Thomisidae*, “Crab Spiders”, were most prevalent throughout the sampling period. Other wandering spiders were also found in the traps, but at a lower frequency (Table 4).

**Crab Spider Spatial Distribution**

For both transects, crab spiders were most frequently found in traps between 15 meters and 25 meters from the vineyard edge (Table 5).

**Crab Spider Population Clusters and Seasonal Presence**

For both transects, clusters occur in a similar pattern throughout the survey period (Table 6, Table 7). Based on this analysis, trap positions 1-4 were assigned to “cluster 1”, trap positions 5-7 were assigned to “cluster 2”, and trap positions 8-10 were assigned to “cluster 3”. The crab spider populations were found to peak in June (week 24) and to begin a gradual decline through August (week 34). Seasonal population patterns for each cluster in the SNH transect (Table 8) and the Control transect (Table 9) increased and declined in a similar way.

**The Plausibility of SNH Influencing Crab Spider Populations**

Seasonal time frame 1 (weeks 23-25) results indicate that it is very implausible that the population of crab spiders in cluster 1 is positively influenced by the presence of SNH (Table 10). In addition, it is plausible that the spider population in cluster 2 is positively influenced by the presence of SNH. The seasonal SNH effect converges to the center (0.50 plausibility) as the populations move into later seasonal stages.

**Discussion**

This study begins with an interest in evaluating conjectures about the influence of SNH on beneficial bug populations in a vineyard. Some researchers have noted that SNH promotes these populations, but the extent of the reach, or penetration, of this effect into the core of the vineyard is not well discussed. In addition, possible inter-seasonal effects are not consistently evaluated. Our transect layout involved a pattern of 30 traps, with a trap density biased toward the transect-SNH interface as we suspected that any effect would be strongest at the edge and decline gradually moving into the center of the vineyard. We chose an unusual, unproven, trapping technique, suspending vane traps in the canopy for high frequency sampling of pollinators and other moderate sized, canopy dwelling insects. This approach allowed very general categorization of trapped animals as they were promptly released, mostly unharmed, without expert entomology support onsite.

Our environment, a classic California Central Coast oak savanna, showed that the most conspicuous beneficial predator in the vineyard canopy is the crab spider. These arachnids were commonly found in the vane traps throughout the growing season. Other beneficials, notably parasitic and parasitoid wasps, were encountered, but in very low numbers. These wasps are difficult to see and identify, and perhaps appeared infrequently as the traps were not baited with pheromones. We did not try and assess their populations relative to the arachnids.

The adult crab spiders themselves were present in low numbers. They averaged 0.18 spiders per trap throughout the growing season, no more than 4 individuals were ever encountered in a single trap. These numbers yielded “count data” that may be characterized by a Poisson distribution (Rodríguez 2007).

We decided not to use traditional, destructive sampling methods to estimate the actual spider populations as their use appeared to clash with the organic/biodynamic posture of the grower. As a result, we did not attempt to directly estimate the overall spider population or the trapping efficiency of the vane traps.

**The Influence of Semi-Natural Habitat on Transect Crab Spider Populations**

Our twice daily, 3 days per week, sampling protocol produced 3,270 observations, a stream of count data that allows us to compare the numbers of trapped spiders in 3 different transect zones across 3 different growing season time periods and two transects. Probabilistic Data Analysis, so called “Bayesian Analysis”, allows us to make statements about the uncertainty of values of unobservable quantities given known facts. Bayesian theorems utilize inference axioms that enable patterns of observed data to adjust an assumed, but informed, prior probability distribution of model parameters to a more accurate posterior probability distribution of those same parameters.

In the Bayesian sense, “probability” is a value between 0 and 1 that represents the uncertainty about the occurrence of an outcome. We use a generalized linear model to produce a probability distribution representing the uncertainty about the outcome variable “trapped spiders” and compare the modelled rate of trapped spiders per unit time between two transects of equivalent spider population.

**A Generalized Multilevel Model**

We constructed a generalized linear model of the populations for each cluster and for each seasonal time frame, creating 9 individual models tuned to specific population parameters. “Trapped spiders” are defined to be the response variable with spider population and SNH presence, or “SNH contact”, as the predictor variables.

**Model Concepts**

We proposed that the number of trapped spiders would be a function of the general population of spiders in the canopy, and that the number of trapped spiders would be sensitive to the order of magnitude of the general population rather than the absolute population level. Secondly, our model expects that natural habitat on the vineyard edge increases the population of beneficial insects in the canopy. Finally, our model also expects that the effect of the general population on the number of trapped spiders is amplified by the presence of semi-natural habitat on the vineyard edge.

We then constrained the model to those follow specific ecosystem assumptions (Table 13). These constraints are equivalent to those used in Kline’s Oceanic Tool Complexity (OTC) research (Kline 2010) where λ, the probability distribution of the rate of tool development in two islands of equivalent human population are found to be determined by the combined effect of log(population) and the intensity of human exchange between those islands. OTC theories predict that "larger island populations develop and sustain more complex tool kits" and that "contact rates" between island populations "effectively increase population size" (McElreath section 10.2.1). Noting similarity in the model assumptions above and Kline’s study, we viewed the expected count of Ampelos transect “trapped spiders” as directly analogous to OTC island expected counts of “tools”. Both are proposed to be a function of the size of the local population and a contact variable that amplifies the effect of population.

The expectation, or distribution, of the trapped spider count was proposed to follow a poisson distribution of the average trapped spider rate (λ) for the sample unit time period:

E(Trapped Spiders) ~ Poisson(λ) (1)

And the model takes the form:

log (λ) = α + (2)

β1 × log (population) +

β2 × SNH\_contact +

β3 × SNH\_contact × log (population)

Where SNH\_contact, or “contact rate”, is a boolean variable with ‘1’ representing the presence of SNH (the Oak Margin transect) and ‘0’ representing the absence of SNH (the Control Transect). From the perspective of the model, SNH\_contact is either “on” or “off”.

Given the similarity of our model requirements and those of the OTC Model, the model structure (Equations 1 and 2) were adapted from McElreath’s specification (McElreath pg 333). In our case, we accommodate wide variation in seasonal spider population by partitioning the data into 3 seasonal time frames. Each of these model instances requires its own set of Bayesian “priors”, the informed probability distribution of model variables. We also normalize the observations to reflect the number of traps present in 3 distinct physical clusters in the transects.

The current specification includes a parameter that allows the predictor “contact rate” to be adjusted for various SNH border geometries, SNH composition, SNH distance, management regimes, or climate conditions. Our model does not engage this dimension of granularity, SNH\_contact is either “on” or “off”.

The updated parameter distribution (the “posterior”) is proportional to the probability distribution (the “likelihood”) and the parameter distribution before (the “prior”) new observations were accounted for.

In order to generate “reasonable” values for log(population) as an input to the model, we estimated vane trap efficiency, the ratio of trapped spiders to the total canopy population. Our estimate is based on our (un-recorded) canopy observations and intuition developed over the course of the sampling period. The canopy, a 3 dimensional shape, was imagined to be divided into 9 volumes, each contributing a percentage of its population to the number of trapped spiders. traps are positioned in the center of the lower part of the canopy and receive varying contributions from each of the canopy domains. Assuming a uniform distribution of the spider population in the canopy, we propose a 1% weekly trap efficiency (Table 11). We then calculated normal distribution parameters and log(population) for each of the three seasonal periods (Table 12).



**Evaluation of Model Results and Analytics**

The distribution of the plausible difference in average trapped spiders should show a bias indicating an effect of SNH as compared to the control transect. A positive bias indicates a positive effect. The model results were evaluated by plotting the probability density against the difference in the average rate of trapped spiders (λ) for the two transects. (McElreath pg 316, Figure 10.8 (a))

Additionally, the joint posterior distribution of the model parameters ‘bpc’, the combined effect of population and contact rate, and ‘bc’, the effect of contact rate are expected to give confidence in the precision of the model during each of the three seasonal timeframes (McElreath pg 316, Figure 10.8 (b)). A tight linear relationship across the sample space adds credibility to the model predictions.

**Conclusion**

We conclude that, for a California Central Coast organic vineyard, SNH dominated by mature oak trees promotes populations of the generalist spiders *Thomisidae* beyond the first 15 meters of the transect. This result suggests that producers could consider reinforcing SNH effects by emphasizing under-trellis cover crop strategies for the initial 15 meters of the rows.

The Ampelos SNH effect experiences a wave-like shift during the seasonal transition from time frame 1 to time frame 2. Spider counts of cluster 2 becomes less plausibly influenced by SNH and counts of cluster 3 become more plausibly influenced by Ampelos SNH.

Ampelos SNH effects, positive and negative as evaluated with vane traps, narrow in the second seasonal time frame and disappear in the third seasonal time frame.

The sensitivity of the model to seasonal effects suggests that SNH evaluation that relies on insect population sampling should carefully consider the pattern of trophic interactions and sampling should target specific insects during the growing season.

Vane traps appear to be a viable tool for coarse, high frequency sampling of insect diversity and abundance in a vineyard canopy.

**Literature Cited** Limit literature to 35 of the most salient peer-reviewed articles. List all references cited in the text. See the AJEV Guide to Authors for required format of literature and see published AJEV articles for examples. Check all literature against original publications.

**Tables**

| Table 1  **Table 1**  Population Percentages - All Observed Insects | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **week** | **Araneae** | **Diptera** | **Hymenoptera** | **Hemiptera** | **Lepidoptera** | **Other** |
| 23 | 21.56 | 36.97 | 25.36 | 0.71 | 2.14 | 13.27 |
| 24 | 27.82 | 26.03 | 19.22 | 2.24 | 2.12 | 22.58 |
| 25 | 15.38 | 32.31 | 32.65 | 0.68 | 0.68 | 18.29 |
| 26 | 14.29 | 11.90 | 42.85 | 1.59 | 1.19 | 28.18 |
| 27 | 12.99 | 17.75 | 29.45 | 0.43 | 0.87 | 38.52 |
| 28 | 16.12 | 3.23 | 28.63 | 1.01 | 0.00 | 51.01 |
| 29 | 19.44 | 5.62 | 30.92 | 1.41 | 0.00 | 42.63 |
| 30 | 16.78 | 14.09 | 36.91 | 0.34 | 0.00 | 31.87 |
| 31 | 16.55 | 23.99 | 32.43 | 1.01 | 0.68 | 25.35 |
| 32 | 16.81 | 12.30 | 36.89 | 0.00 | 0.41 | 33.61 |
| 34 | 5.69 | 11.03 | 60.14 | 0.36 | 0.36 | 22.42 |

| Table 2  **Table 2**  Apparent Diversity - species counts | | |
| --- | --- | --- |
| **week** | **SNH**  **Transect** | **Control**  **Transect** |
| 23 | 14 | 15 |
| 24 | 15 | 16 |
| 25 | 13 | 15 |
| 26 | 14 | 15 |
| 27 | 11 | 9 |
| 28 | 13 | 12 |
| 29 | 13 | 14 |
| 30 | 10 | 12 |
| 31 | 10 | 12 |
| 32 | 10 | 13 |
| 34 | 12 | 10 |

| Table 3  **Table 3**  Apparent Abundance - insect counts | | |
| --- | --- | --- |
| **week** | **SNH**  **Transect** | **Control**  **Transect** |
| 23 | 244 | 178 |
| 24 | 484 | 411 |
| 25 | 335 | 250 |
| 26 | 299 | 205 |
| 27 | 134 | 97 |
| 28 | 260 | 236 |
| 29 | 225 | 202 |
| 30 | 143 | 155 |
| 31 | 143 | 153 |
| 32 | 104 | 140 |
| 34 | 119 | 162 |

| Table 4  **Table 4**  Araneae Occurrence (percent) | | | |
| --- | --- | --- | --- |
| **week** | **Thomisidae** | **other** | **Araneae**  **Total** |
| 23 | 19.19 | 2.37 | 21.56 |
| 24 | 27.71 | 0.11 | 27.82 |
| 25 | 14.70 | 0.68 | 15.38 |
| 26 | 9.92 | 4.37 | 14.29 |
| 27 | 8.66 | 4.33 | 12.99 |
| 28 | 13.10 | 3.02 | 16.12 |
| 29 | 10.07 | 9.37 | 19.44 |
| 30 | 11.41 | 5.37 | 16.78 |
| 31 | 9.12 | 7.43 | 16.55 |
| 32 | 8.61 | 8.20 | 16.81 |
| 34 | 1.78 | 3.91 | 5.69 |

| Table 5  **Table 5**  **Crab Spider Spatial Distribution:** Seasonal Occurrence by trap position | | | |
| --- | --- | --- | --- |
| **Trap position (ft)** | **Trap position (m)** | **SNH Transect**  **Occurrences** | **Control Transect**  **Occurrences** |
| 4 | 1 | 11 | 10 |
| 16 | 5 | 15 | 12 |
| 32 | 10 | 14 | 16 |
| 48 | 15 | 17 | 11 |
| 64 | 20 | 20 | 18 |
| 80 | 24 | 13 | 19 |
| 100 | 30 | 19 | 17 |
| 130 | 40 | 17 | 28 |
| 160 | 49 | 22 | 16 |
| 200 | 61 | 8 | 21 |

| Table 6  **Table 6**  calculated cluster identifiers for each trap position by week - SNH transect | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **position** | **Week**  **23** | **Week**  **24** | **Week**  **25** | **Week**  **26** | **Week**  **27** | **Week**  **28** | **Week**  **29** | **Week**  **30** | **Week**  **31** | **Week**  **32** |
| 1 | one | one | — | one | — | one | — | one | — | one |
| 2 | one | one | one | one | one | one | one | — | one | — |
| 3 | one | one | one | — | one | one | one | — | one | — |
| 4 | two | two | one | one | one | one | one | — | one | one |
| 5 | two | two | two | two | — | two | one | two | one | — |
| 7 | three | three | two | two | — | two | two | two | two | two |
| 8 | three | three | three | three | three | three | two | — | two | — |
| 9 | three | three | three | three | three | three | three | three | — | three |
| 10 | three | three | three | three | three | — | three | three | three | — |

| Table 7  **Table 7**  calculated cluster identifiers for each trap position by week - control transect | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **position** | **Week**  **23** | **Week**  **24** | **Week**  **25** | **Week**  **26** | **Week**  **27** | **Week**  **28** | **Week**  **29** | **Week**  **30** | **Week**  **31** | **Week**  **32** |
| 1 | one | one | one | one | one | one | one | one | — | one |
| 2 | one | one | one | — | — | one | one | — | one | one |
| 3 | two | one | one | — | — | one | one | one | one | one |
| 4 | two | two | two | two | — | two | two | one | — | — |
| 5 | two | two | two | two | — | two | two | one | two | — |
| 6 | three | two | two | two | two | two | two | two | two | — |
| 7 | three | three | two | three | two | three | — | two | — | two |
| 8 | three | three | three | three | three | three | three | two | three | two |
| 9 | three | three | three | three | three | — | — | three | three | — |
| 10 | three | three | three | three | — | three | three | three | three | three |

| Table 8  **Table 8**  Crab Spider Observations by Cluster - SNH transect | | | |  |
| --- | --- | --- | --- | --- |
| **week** | **Cluster One**  **Spider Counts** | **Cluster Two**  **Spider Counts** | **Cluster Three**  **Spider Counts** | **Assigned Seasonal**  **Time Frame** |
| 23 | 9 | 8 | 10 | one |
| 24 | 27 | 19 | 29 | one |
| 25 | 12 | 5 | 3 | one |
| 26 | 4 | 3 | 5 | two |
| 27 | 2 | 0 | 5 | two |
| 28 | 6 | 7 | 5 | two |
| 29 | 5 | 5 | 6 | two |
| 30 | 0 | 6 | 0 | two |
| 31 | 4 | 2 | 1 | two |
| 32 | 3 | 5 | 1 | three |
| 34 | 1 | 0 | 0 | three |

| Table 9  **Table 9**  Crab Spider Observations by Cluster – control transect | | | |  |
| --- | --- | --- | --- | --- |
| **week** | **Cluster One**  **Spider Counts** | **Cluster Two**  **Spider Counts** | **Cluster Three**  **Spider Counts** | **Assigned Seasonal**  **Time Frame** |
| 23 | 13 | 12 | 10 | one |
| 24 | 27 | 27 | 34 | one |
| 25 | 5 | 16 | 9 | one |
| 26 | 5 | 6 | 7 | two |
| 27 | 1 | 2 | 1 | two |
| 28 | 9 | 2 | 6 | two |
| 29 | 1 | 3 | 6 | two |
| 30 | 2 | 4 | 5 | two |
| 31 | 0 | 3 | 1 | two |
| 32 | 1 | 0 | 5 | three |
| 34 | 1 | 0 | 2 | three |

| Table 10  **Table 10**  ‘plausibility’ of SNH effect on crap spider populations | | |
| --- | --- | --- |
| **Cluster** | **Seasonal**  **Timeframe** | **Plausibility** |
| one | one | 0.1412 |
| one | two | 0.4396 |
| one | three | 0.2741 |
| two | one | 0.9106 |
| two | two | 0.3031 |
| two | three | 0.0384 |
| three | one | 0.5394 |
| three | two | 0.7124 |
| three | three | 0.9056 |

Table 11

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 11**  Canopy Spider Trapping Efficiency | | | |
|  | Canopy Left | Canopy Center | Canopy Right |
| Canopy Upper Domain Efficiency | .01 | .01 | .01 |
| Canopy Center Domain Efficiency | .02 | .03 | .02 |
| Canopy Lower Domain Efficiency | .02 | .04 | .02 |

Table 12

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Table 12**  Model Baseline Population Distribution Variables | | | | | | |
|  |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |

Table 13

|  |  |
| --- | --- |
| **Table 13**  specific ecosystem assumptions | |
| 1 | The numbers of trapped spiders are always “small” integers >= 0 |
| 2 | The rate of trapped spiders increases with log(population). |
| 3 | The rate of trapped spiders increases with increased natural habitat (SNH) support   * SNH drives arthropod abundance and diversity (Pfiffner 2000),   + we assume spider abundance increases with general arthropod abundance   + we assume trapped spider rates are constant with increasing spider abundance |
| 4 | The rate of trapped spiders is amplified by the interaction effect between population and SNH.   * SNH drives arthropod abundance and diversity (Pfiffner 2000)   + And therefore, SNH implies higher prey abundance and diversity   + And therefore, SNH implies higher abundance and diversity of alternative prey   + And therefore increased prey implies increased predator populations * “We assume the predator is cannibalistic but has a preference, p, for eating prey, as opposed to conspecifics” (Kindlmann 2000)   + And therefore, higher prey availability implies reduced cannibalism and higher predator population * “alternative food can increase predator abundance and survival” (Frank 2010)   + And therefore, higher alternative prey availability implies reduced cannibalism and higher predator population   + Spiders are valuable biocontrol agents as they can subsist on alternative prey (Harwood 2005) |

**Figures** (graphs, charts, line drawings, photographs)

See the AJEV Guide to Authors for sizing and format. Place each figure on a separate page, number each one (1, 2, 3, etc.), and include descriptive captions for all figures after the Literature Cited.

**Supplemental Data**

If you have supplemental material that is ancillary to your article, then it may be published in the online version. Submit supplemental data as separate table or figure files after the main tables and figures and label as such (Supplemental Table 1, Supplemental Figure 1). All supplemental data must be peer-reviewed with the manuscript. There may be an extra fee for supplemental data, based on file size and editing needs.