Spider Family Response to Changes in Habitat Diversity at the Field and Landscape Scales of Wine Grape Vineyards in Napa and Sonoma Counties

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ABSTRACT

Vineyards and their surrounding landscapes provide habitats for beneficial predators that play a crucial role in biological control. Spiders can be important beneficial predators in vineyards due to their abundance and feeding habits. No previous study has addressed the effects that changes in habitat diversity both within and surrounding vineyards have on spider family diversity in vineyards. The purpose of this study was to provide insight into biological control of vineyards by investigating family specific response of spiders to changes in habitat diversity at multiple spatial scales. Between 2010 and 2013 members of Altieri lab sampled spiders annually from monoculture vineyards, vineyards with flowering cover crops, and vineyards with surrounding riparian habitat. The percentage of natural habitat in the surrounding landscape was quantified at distances of 0.5 km to 6 km surrounding each vineyard. Spiders were collected from 32 different vineyards and 1092 spiders were identified, representing 13 families. Vineyards with flowering cover crops consistently had slightly higher spider diversity than vineyards without flowering cover crops, though the difference was not statistically significant. Additionally, findings suggest that dispersal corridors of non-crop habitat are needed for spiders to enter vineyards from surrounding landscapes. Findings also suggest that flowering cover crops can best enhance spider diversity within vineyards when landscape diversity is increased at 6 km (or possibly more) from vineyards. Finally, a relationship between the family Anyphaenidae and increased landscape diversity surrounding the vineyards highlights the need for further research into the role of Anyphaenidae in biological control of vineyards.

KEYWORDS

floral resource provisioning (FRP), landscape diversity, biodiversity, biological control, flowering cover crops

INTRODUCTION

Biodiversity provides many benefits to agricultural practices, specifically the ecosystem service known as biological control (Beddington et al. 1978, Altieri 1999). Biological control is characterized as a persistent reduction in pest populations due to the presence of a natural enemy, either in the form of a parasitoid or a beneficial predator (Beddington et al. 1978). This is a valuable ecosystem service that is currently threatened because the monoculture cropping systems of modern agricultural practices do not provide hospitable environments for beneficial predators (Andow 1991, Schmidt et al. 2005). Increasing plant biodiversity within individual crops, across entire farms, and throughout surrounding landscapes can make agroecosystems, such as vineyards, more hospitable to beneficial predators (Landis et al. 2000). Progress has been made in California to increase plant biodiversity within vineyards by using intercropping methods so that beneficial predators will flourish, thus enhancing biological control of pest populations (Nicholls et al. 2001).

Vineyards and their surrounding landscapes provide habitats that are essential for the existence of beneficial predators at the field scale, which is the habitat within vineyards, and at the landscape scale, which is the habitat surrounding vineyards (Daane and Costello 1998, Nicholls et al. 2001). Planting cover crops is the most common method of increasing plant biodiversity within vineyards and it has been found to attract beneficial predators such as spiders at the field scale (Daane and Costello 1998). This attraction is most likely because the added variety of vegetation provides additional habitat and food for such beneficials (Daane and Costello 1998), an array of microclimate features, as well as increased retreat sites, which can encourage spider colonization (Rypstra et al. 1999). Additionally, the composition of surrounding landscapes may affect the benefits of beneficial predators at the field scale (Clough et al. 2005). This is because promotion of locally rare beneficial predators is difficult in areas of agricultural intensification at the landscape scale (Tscharntke et al. 2007). Furthermore, in landscapes of low plant and animal biodiversity, limited movement of beneficial predators into crop fields may result in decreased species richness at the field scale (Tscharntke et al. 2007). In order to maximize biological control in vineyards it is critical to identify the most important predators.

Spiders can play a crucial role in biological control of pest populations in vineyards (Marc and Canard 1997, Roltsch et al. 1998) due to their abundance and feeding habits (Isaia et al. 2006). Compared to insect predators, spiders are more prevalent and more effective predators in the

vineyards of California's Central Valley (Costello and Daane 1999). Additionally, the majority of beneficial predators in vineyards may be spiders because they are able to overwinter within the vineyard and therefore never need to leave the field (Costello and Daane 1999). Furthermore, high densities of *Erythroneura elegantula,* which is a common pest in California vineyards, have been found to correlate with low spider abundance (Roltsch et al. 1998). Finally, spiders feed almost exclusively on insects (Riechert and Lockley 1984), which can be at varying stages of maturity and in different locations within the environment (Marc and Canard 1997). As a result, it is critical to better understand spider family specific response to changes in habitat diversity so that spider populations can be managed in a way that most benefits biological control in vineyards. No previous study has addressed the effects that changes in habitat diversity at both the field and landscape scales have on spider family diversity in vineyards.

In this study I assessed spider family diversity within selected vineyards of Napa and Sonoma counties in California. In some of the vineyards, flowering cover crops had previously been sown in an effort to increase habitat diversity at the field scale, through a process called floral resource provisioning (FRP). My research question was *how do changes in habitat diversity at both the field and landscape scales influence diversity of spiders in vineyards of Napa and Sonoma counties?* My null hypothesis was that spider family diversity would be the same in all vineyard plots surrounded by all landscape types. My alternative hypothesis was that spider family diversity would *not* be the same in all vineyard plots surrounded by all landscape types. Based on the primary literature, I expected to find greater spider family diversity in vineyard plots with FRP. The data that I obtained from study sites with and without FRP allowed me to calculate differences between spider family diversity of sites with and without habitat diversity at the field scale. Additionally, I assessed how spider family diversity within the vineyards differed with respect to varying levels of habitat diversity at the landscape scale. I also assessed spider diversity within vineyards bordering riparian habitat to understand how proximity to riparian habitat affected spider family diversity. Finally, I assessed individual spider family response to changes in habitat diversity at the landscape scale. I was able to use previously quantified values of landscape diversity, represented by percentage of natural habitat, that were produced using GIS technology in Altieri Lab. By investigating family specific response of spiders to changes in habitat diversity at the field and landscape scales, the purpose of this study was to provide further insight into

biological control of vineyards, and therefore help to improve the future of ecologically based pest management in viticulture.

METHODS

Study system

Description

Between 2010 and 2013 members of Altieri Lab collected spiders from 32 different vineyards in Napa and Sonoma counties. These vineyards differed in the agricultural methods used, the variety of plant life within the vineyards, and the surrounding habitat types. Study sites were evenly distributed between vineyards with low, medium, and high levels of habitat diversity in the surrounding landscapes. All study plots, consisting of red wine grape vines at least 5 years old, received drip irrigation, and were not treated with pesticides for the duration of the study (with the exception of mandatory Bt spraying for moths in 2009, 2010, and 2011).

Three categories of vineyard sites

Members of Altieri Lab collected spiders from monoculture vineyards, vineyards with floral resource provisioning (FRP), and vineyards with bordering riparian habitat to determine the spider family diversity of each study site (Table 1).

Table 1. Categories of vineyards sampled in each year of experiment.

Year	2010	2011	2012	2013
Monoculture sites	14	17	16	3
FRP sites	0	0	6	2
Riparian sites	3	4	0	0
Total	17	21	22	5

All study sites were managed using conventional, organic or biodynamic farming methods. Neither organic nor biodynamic farming methods use chemical inputs, and the biodynamic farming method incorporates additional composting practices (Reganold 2009). The monoculture sites contained only grape vines within the vineyards. In the FRP sites, plant diversity within the vineyards was manipulated by the planting of three fall-sown flowering cover crops: purple tansy (*Phacelia tanacetifolia*), bishop's flower (*Ammi majus*), and wild carrot (*Daucus carota*). These specific flowers were selected in collaboration with commercial wine grape growers in order to ensure ease of integration with standard vineyard management practices (Wilson 2010). The selected flowers were planted from the edge of the grape vine rows to a distance of approximately 330 ft down the pathways, between alternating rows of grape vines. At each FRP site there was a treatment plot, with the flowering cover crops sown, and a comparable control plot without flowering cover crops. The treatment and control plots each spanned an average of 30 rows wide (approximately 240 ft) and extended approximately 330 ft into the vineyards (length down the rows), with distances between rows averaging 8 ft. The riparian sites all had a stream running along the entire length of one or more borders of the vineyard.

Data collection methods

Following the spider collection methods of Wilson (2010), members of Altieri Lab gathered spider samples annually during the end of the grape growing season in August, September, or October. After joining Altieri Lab in the summer of 2013, I assisted in the final year of spider collection. I shook the vine canopies for 30 seconds over a large funnel to collect any spiders that fell. I attached a plastic bag to the bottom opening of the funnel so that all of the spider specimens could be sealed inside. This funneling method has been found to be the most accurate

spider collecting method when compared to other techniques because it gathers a sample that is most representative of the local spider population (Costello and Daane 1997). At the monoculture sites and FRP sites I selected each vine to be shaken by first walking a minimum of 10 vines down each vineyard row in order to ensure that I was sampling well within the designated study plots. Once inside the vineyard plots to the minimum distance, I randomly selected vines by walking down the rows and randomly stopping in front of any vine. However, this does present a level of bias in my sampling method, because it is impossible to truly sample randomly when hand selecting vines. When sampling at the riparian sites, I shook vine canopies at distances of 10m, 50m, 100m, 150m, and 200m away from the streams by walking down the rows to those specific distances and then randomly selecting vines located at each approximate distance. After I collected the spiders I brought them back to Altieri Lab where they were preserved inside vials of 70% ethanol solution. I identified the family of each spider because that is the most specific level that I am capable of identifying spiders to. I relied heavily on the identification key found within *Spiders of North America, an identification manual*, edited by Ubick et al.

Data analysis methods

I first calculated the Shannon diversity index for each study site (Eq.1), which produced an *H*-value representative of the spider diversity of each vineyard plot. A higher *H*-value corresponded to a more diverse and equally distributed spider family community, while a lower *H*-value corresponded to a less diverse and less equally distributed spider family community. The Shannon diversity index was ideal for this analysis because it took into account both spider family abundance and spider family evenness within the vineyards.

$$H = -\sum (P_i * \ln P_i) \qquad \text{Eq.1}$$

In the above equation, the *H* value is the Shannon diversity index and the P_i value represents the fraction of all spiders identified from one vineyard plot comprised of family *i.*

Natural habitat percentage was previously quantified by members of Altieri Lab at distances ranging from 0.5 km to 6 km surrounding each study site (in increments of 0.5 km) using ArcGIS, which is produced by the Environmental Systems Research Institute. This produced

natural habitat percentages at a total of 12 distances around each vineyard site, which I used as a representation of habitat diversity at the landscape scale.

Before beginning any regression analyses I first assessed the histograms, boxplots, quantile comparison plots, as well as the results from the Shapiro-Wilk test for normality, to test whether my data was normally distributed. If the data sets were not normally distributed I performed transformations on them, or performed non-parametric tests in my data analysis.

Analysis of monoculture sites

After assessing my data for normality, I transformed the Shannon diversity indices from the 2010 and 2012 monoculture sites by squaring them. I then used multidimensional scaling to assess which monoculture vineyard sites contained similar spider families. Next, I ran regression analysis on the continuous data produced from the monoculture sites to test for a relationship between the Shannon diversity index of each monoculture site and the natural habitat percentage at the 12 distances around each vineyard. In each regression analysis the natural habitat percentages were on the x-axis and the Shannon diversity indices were on the y-axis.

Analysis of FRP sites

I performed the Welch Two Sample t-test to assess whether the Shannon diversity indices of the treatment and control plots of the FRP sites differed significantly. I also performed the non-parametric test called the Wilcoxon rank sum test with continuity correction, because the boxplots for this data were only fairly normal. The null hypothesis was that the Shannon diversity indices of the treatment and control plots were equal, while the alternative hypothesis was that the Shannon diversity indices of the treatment and control plots differed. Next, I calculated the differences between the Shannon diversity indices of the treatment and control plots of the FRP sites. I was then able to I run regression analyses on the continuous data produced from the difference calculations to test for any relationships between these differences and the natural habitat percentages at all 12 distances from each study site. In each regression analysis the natural habitat percentages were on the x-axis and the difference in Shannon diversity indices were on the y-axis.

Analysis of riparian sites

To determine if spider family diversity differed at five distances from the neighboring streams, I performed ANOVA (analysis of variance) on the sites with bordering riparian habitat. I also performed the non-parametric test called the Kruskal-Wallace test because the boxplots were not normal for the 2010 data and only fairly normal for the 2011 data. I used the Shannon diversity indices calculated at distances of 10 m, 50 m, 100 m, 150 m, and 200 m from the riparian habitat of each site to run these tests. Using ANOVA and the Kruskal-Wallace test allowed me to determine if spider family diversity differed at five distances in one test, which reduced the chances of a type I error that can result from running multiple paired t-tests. The null hypothesis was that the Shannon diversity indices of all five distances were equal, while the alternative hypothesis was that the Shannon diversity indices of one or more of the distances differed.

Analysis of individual family response

To determine whether individual spider families responded to changes in habitat diversity at the landscape scale, I ran an additional series of regression analysis. I first calculated the frequency that each spider family was identified from both the treatment and control plots of the FRP sites. I then ran regression analysis on the discrete data produced from the family frequencies to test for a relationship between the frequency of each spider family identified and the natural habitat percentage at the 12 distances around each vineyard. In each regression analysis the natural habitat percentages were on the x-axis and the frequency that each family was identified was on the y-axis.

RESULTS

Data Collection

After members of Altieri lab and I collected spider samples from 32 different vineyards between 2010 and 2013, I identified 1092 spiders representing 13 families (Table 2).

Table 2. Total spiders identified from each family in all years of experiment.

Family	2010	2011	2012	2013	Total
Agelenidae	7	5	1	0	13
Anyphaenidae	25	24	36	36	121
Corinnidae	22	19	33	15	89
Desidae	0	0	1	0	1
Dictynidae	18	18	15	1	52
Gnaphosidae	1	1	1	0	3
Linyphiidea	1	0	0	1	2
Lycosidae	0	1	1	0	2
Miturgidae	39	62	139	9	249
Oxyopidae	28	87	52	6	173
Salticidae	25	59	62	1	147
Theridiidae	48	94	78	4	224
Thomisidae	12	21	15	0	48
Total	226	391	434	41	1092

The most abundant family was Miturgidae (22.8%), followed by Theridiidae (20.5%), Oxyopidae (15.8%), and Salticidae (13.5%). The number of spiders identified varied between each year and type of study site: monoculture sites, FRP sites, and riparian sites (Table 3).

Table 3. Total number of spiders identified from each type of study site.

Site type	2010	2011	2012	2013	Total
Monoculture	150	244	284	14	692
FRP (control)			60	8	68
FRP (treatment)			90	19	109
Riparian	76	147			223
Total	226	391	434	41	1092

Data Analysis

Analysis of monoculture sites

Multidimensional scaling. Multidimensional scaling of the monoculture sites in all four years showed that several sites contained Thomisidae, Linyphiidae, and Anyphaenidae, while the remaining families were collected from fewer sites (Fig. 1).

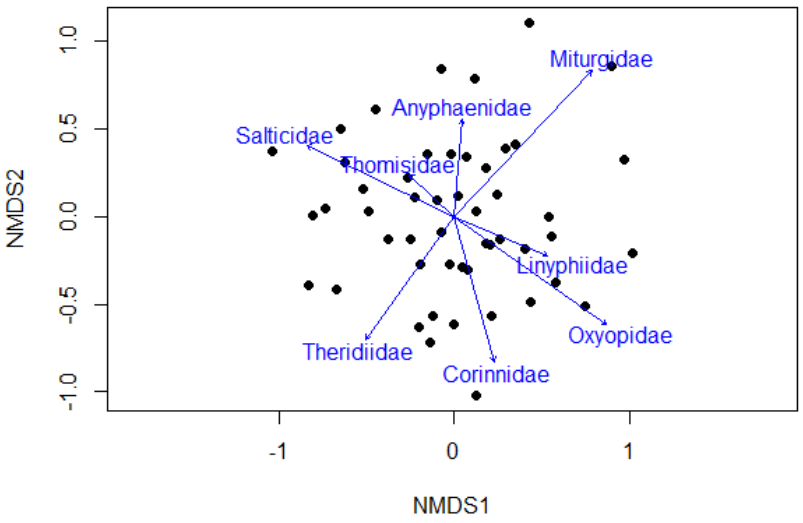

Figure 1. Multidimensional scaling of spider family correlations with all monoculture sites from 2010-2013. The dots in this figure represent the different monoculture vineyards in all four years of the study. They are arranged throughout the figure according to their shared spider families. Dots closer to one another represent vineyards that contained similar spider families. Dots farther from each other represent vineyards that did not share many spider families. The names of the different spider families presented in the figure indicate which families the different vineyards had in common.

Shannon diversity indices vs. changes in landscape diversity. I found multiple relationships between the Shannon diversity indices of the monoculture sites and the percentage of natural

habitat in the surrounding landscapes. Specifically, I found a positive relationship between the Shannon diversity indices of the monoculture sites from 2011 and the percentage of natural habitat in the surrounding landscape at a distance of 0.5 km from the vineyards ($R^2 = 0.2332$, $F(1, 15) = 4.563$, $p = 0.04956$; Fig. 2).

Diversity Index = (0.86 ± 0.40)*pct_NatHab_0.5 + (1.15 ± 0.10)

Figure 2. 2011 Shannon diversity indices of monoculture sites vs. the percentage of natural habitat at a distance of 0.5 km. The Shannon diversity indices of the monoculture vineyards from 2011 are on the y-axis and the percentage of natural habitat at a distance of 0.5 km from each vineyard is on the x-axis.

This figure shows that as the percentage of natural habitat increased at a distance of 0.5 km around the vineyard sites, the Shannon diversity indices of the vineyards also increased. There were additional weak relationships found between the Shannon diversity indices of monoculture sites from 2012 and the percentage of natural habitat surrounding the vineyards, indicated by p-values slightly higher than 0.5. In four instances, a weak negative relationship was found between the Shannon diversity indices of the monoculture vineyards and the percentage of natural habitat in the surrounding landscape (Table 4).

Table 4. 2012 Shannon diversity indices of monoculture sites vs. the percentage of natural habitat at different distances. These four regression analyses showed nearly significant results.

Year	Site type	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value	Direction of relationship
2012	Monoculture	4.0	0.2079	1, 14	3.674	0.07589	Negative
2012	Monoculture	4.5	0.2274	1, 14	4.12	0.06184	Negative
2012	Monoculture	5.0	0.2228	1, 14	4.014	0.06488	Negative
2012	Monoculture	5.5	0.2202	1, 14	3.952	0.06672	Negative

The above table shows that as the percentage of natural habitat increased at distances of 4.0 km, 4.5 km, 5.0 km, and 5.5 km around the vineyard sites, the Shannon diversity indices of the vineyards decreased. The remaining regression analyses did not show any relationships between the Shannon diversity indices and changes in percentage of natural habitat in the surrounding landscape (Appendix A).

Analysis of FRP sites

Comparison of treatment and control Shannon diversity indices. After running both the Welch Two Sample t-test and the non-parametric Wilcoxon rank sum test with continuity correction, no significant difference was found between the Shannon diversity indices of the sites with and without FRP (two sample t-test: t = -0.7315, df = 13.124, p = 0.4773; Appendix B). As a result, I did not reject the null hypothesis that the Shannon diversity indices of the treatment and control plots from the FRP sites were the same. However, regression analyses of the FRP sites visually showed that the Shannon diversity indices of the plots with FRP were consistently higher than the comparable control plots without FRP, even though the differences were never statistically significant (R^2 = 0.03283, F (1, 4) = 0.1358, p = 0.7312; Fig. 3).

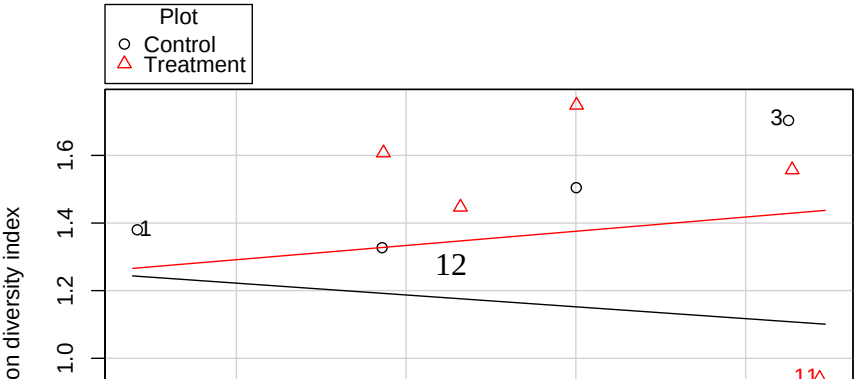

Figure 3. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 2.0 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 2.0 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

Though the difference between the Shannon diversity indices of plots with and without FRP was not statistically significant, visual representation shows that the Shannon diversity indices of the FRP plots were slightly higher than the plots without FRP at all 12 distances from the vineyards (Appendix C).

Differences in Shannon diversity indices of plots with and without FRP vs. changes in landscape diversity. Though no significant relationship was found between differences in Shannon diversity indices of plots with and without FRP, an interesting trend was observed (Appendix D). The combined data from 2012 and 2013 showed that at closer distances to the vineyards, the differences between Shannon diversity indices were greatest when the percentage of natural habitat was lowest ($R^2 = 0.0008146$, $F(1, 6) = 0.004892$, $p = 0.9465$; Fig. 4).

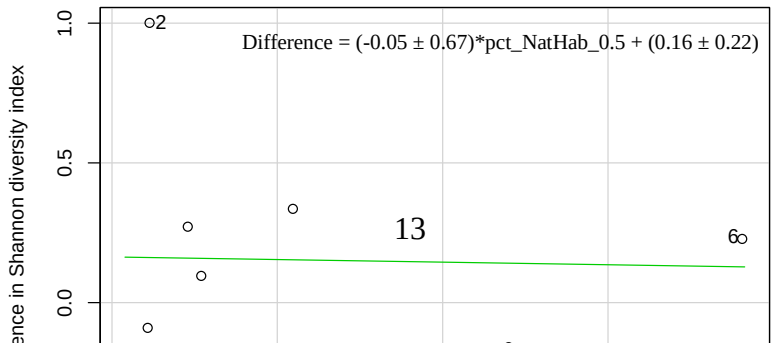

Figure 4. Differences in Shannon diversity indices vs. the percentage of natural habitat at 0.5 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 0.5 km from the vineyards.

Moving away from the vineyards, the differences in Shannon diversity indices were largest at increasing percentages of natural habitat ($R^2 = 0.0927$, $F(1, 6) = 0.613$, $p = 0.4634$; Fig. 5).

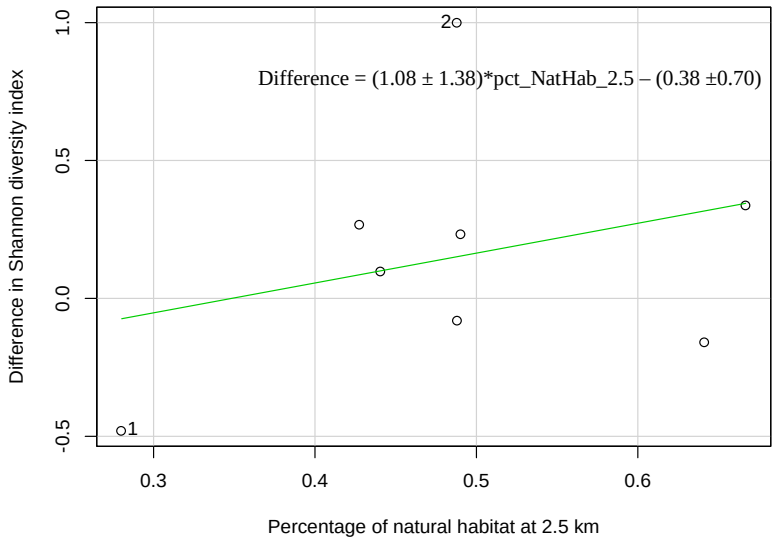

Figure 5. Differences in Shannon diversity indices vs. the percentage of natural habitat at 2.5 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 2.5 km from the vineyards.

At the farthest distance from the vineyards, the differences in Shannon diversity indices were largest when the percentage of natural habitat was greatest ($R^2 = 0.07072$, $F(1, 6) = 0.4566$, $p = 0.5244$; Fig. 6).

Difference = (0.93 ± 1.38)*pct_NatHab_6.0 – (0.45 ± 0.91)

Figure 6. Differences in Shannon diversity indices vs. the percentage of natural habitat at 6.0 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 6.0 km from the vineyards.

Analysis of riparian sites

On the sites bordering riparian habitat I did not find that the Shannon diversity indices differed significantly at increasing distances from the riparian habitat (Appendix E). As a result, I did not reject the null hypothesis that the Shannon diversity indices were equal at all five distances from the riparian habitat.

Analysis of individual family response

Regression analysis of individual family response to changes in landscape diversity revealed Anyphaenidae to be the only family that showed a relationship to changes in percentage of natural habitat surrounding the vineyards (Appendix F). I found a significant relationship between the family Anyphaenidae and changes in percentage of natural habitat at three distances closest to the vineyards (Table 5).

Table 5. Frequency of Anyphaenidae identified vs. the percentage of natural habitat at different distances. These three regression analyses showed significant results. These analyses assessed the spiders identified from the FRP sites only (both treatment and control plots combined). The asterisk (*) indicates a significant result.

Year	Site type	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value	Direction of relationship
2012-2013	FRP	0.5	0.3505	1, 14	7.556	0.01568*	Positive
2012-2013	FRP	1.0	0.3199	1, 14	6.548	0.02242*	Positive
2012-2013	FRP	1.5	0.278	1, 14	5.391	0.03584*	Positive

The results in the table above indicate a positive relationship between the frequency of Anyphaenidae identified and an increase in percentage of natural habitat at distances of 0.5 km, 1.0 km, and 1.5 km from the vineyards.

DISCUSSION

The results of my study provide limited insight into how changes in habitat diversity at both the field and landscape scales affect spider family diversity within vineyards. My study answered my research question: *how do changes in habitat diversity at both the field and landscape scales influence diversity of spiders in vineyards of Napa and Sonoma counties?* I did not reject my null hypothesis that spider family diversity would be the same in all vineyard plots surrounded by all landscape types. Though I did find one significant relationship between spider family diversity and changes in habitat diversity at the landscape scale, contradictory results limit this finding. I found that plots with FRP consistently had slightly higher Shannon diversity indices than the corresponding control plots, but the differences were not statistically significant. However, I did find an interesting trend in the way that these differences related to changes in habitat diversity at the landscape scale. While I did not find that proximity to riparian habitat had a significant effect on spider diversity, analysis of individual spider family response found a relationship between the family Anyphaenidae and changes in habitat diversity at the landscape scale. This finding highlights the importance of researching the role of this specific family in biological control within vineyards.

Habitat diversity at the landscape scale

Findings of a relationship between spider diversity within vineyards and changes in habitat diversity in the surrounding landscape were contradictory. Though one significant finding showed a clear positive relationship between spider diversity and changes in landscape diversity at a distance of 0.5 km from the vineyards, a weak negative relationship was also observed between spider diversity and changes in landscape diversity at distances of 4.0 km, 4.5 km, 5.0 km, and 5.5 km from the vineyards. These contradictory findings suggest that it is possible that spider diversity had a positive relationship to an increase in natural habitat near the vineyards and a negative relationship to an increase in natural habitat farther from the vineyards. This shifting relationship is surprising because studies have clearly shown that the diversity of landscapes surrounding vineyards is an important factor in determining spider assemblages (Isaia et al. 2006), and that the species richness and diversity of spiders within crop lands requires heterogeneous landscapes with a large amount of non-crop habitat (Schmidt et al. 2008). Furthermore, it is possible that spider community composition depends on the shading and moisture of habitats in the surrounding landscape, which results in a relationship between spider community composition and environmental gradients along a spatial scale (Entling et al. 2007). In contrast, my results suggest that spider diversity within the vineyards actually increased when there was less habitat diversity at farther distances from the vineyards. It is possible that the vineyards with greater landscape diversity at distances of 4.0 km, 4.5 km, 5.0 km, and 5.5 km had very low landscape diversity at distances closer to the vineyards. Since non-crop habitat is crucial in providing dispersal corridors for organisms in agricultural landscapes (Holzschuh et al. 2006), it makes sense that a lack of landscape diversity closest to the vineyards could reduce the travel of spiders into the vineyards from farther distances.

Habitat diversity at the field scale

Findings of differences between the Shannon diversity indices of vineyard plots with and without FRP were not significantly different, and the null hypothesis that Shannon diversity indices of vineyard plots with and without FRP were equal was not rejected as a result. However,

visual representation provided by regression analysis of the FRP sites showed that the Shannon diversity indices of plots with FRP were consistently higher than those without, though by a slight amount. I had expected FRP plots to have higher spider diversity than plots without FRP because previous research indicates that growing ground covers between vine rows can support spider communities within vineyards (Isaia et al. 2006). Additionally, planting a cover crop mixture within vineyards has been shown to enhance spider species density (Hanna et al. 2003) as well as alter individual spider species abundance (Costello and Daane 1998). Furthermore, cover crops might help to increase spider abundance in vineyards because they provide both habitat and alternate food sources for spiders (Daane and Costello 1998). Assessing potential relationships between differences in spider diversity of plots with and without FRP and changes in landscape diversity revealed a possible theme.

Findings show an interesting trend in the way that the differences between the Shannon diversity indices of plots with and without FRP related to changes in habitat diversity at the landscape scale. Results suggest that at distances closest to the vineyards differences in diversity indices were greatest when the percentage of natural habitat was lowest, while at distances farthest from the vineyards, differences in diversity indices were greatest when the percentage of natural habitat was highest. This observation suggests that the enhancement of spider diversity by flowering cover crops corresponded to increased landscape diversity at distances farthest from the vineyards, but did not depend on landscape diversity at distances closest to the vineyards. While studies have acknowledged the ability of flowering cover crops to enhance spider community composition within vineyards (Daane and Costello 1998, Hanna et al. 2003), as well as suggested the importance of surrounding landscape diversity in supporting spider diversity within agroecosystems (Entling et al. 2007, Isaia et al. 2006, Schmidt et al. 2008), no study has assessed the interaction between these two scales of habitat diversity and the resulting effects on spider diversity. Furthermore, no study has assessed the extent to which landscape diversity at specific distances from vineyards can enhance the effects of flowering cover crops on spider diversity within vineyards.

Proximity to riparian habitat

Findings of Shannon diversity indices at five distances from riparian habitat were not significantly different, and the null hypothesis that the Shannon diversity indices of all five distances were equal was therefore not rejected. This suggests that spider diversity did not increase with closer proximity to riparian habitat. This finding is unexpected because spider species diversity has been associated with litter depth, vegetation diversity, and the overall complexity of the habitat (Moring and Stewart 1994), all of which are factors that likely characterize riparian regions. Given that distinct spider fauna has previously been associated with the stream edge of riparian habitats (Buddle et al. 2004), it is possible that while spider diversity did not significantly increase with proximity to riparian habitat, the composition of the spider population shifted. However, fewer spider species and reduced total spider abundance have been associated with flood plain areas (Uetz 1976), which could possibly account for the lack of spider diversity with increased proximity to riparian habitat. Additionally, though riparian zones have been thought to alter the climate of adjacent vineyards, they may play a limited role in promoting spider diversity within vineyards because they usually occupy a relatively small area of habitat along the vineyard edge (Hogg and Daane 2011).

Response of Anyphaenidae to changes in landscape diversity

Findings that the abundance of the family Anyphaenidae increased as the percentage of natural habitat in the surrounding landscape increased suggest a relationship between the abundance of Anyphaenidae and changes in habitat diversity at the landscape scale. This finding suggests that the Anyphaenidae population can be manipulated by changes in habitat diversity at the landscape scale, and thus highlights the importance of understanding the role that this particular spider family may play in biological control of vineyards. The role of spiders in biological control has long lacked thorough investigation in the USA, largely because spiders are primarily generalist (polyphagous) predators and research has focused on specialist predators that target specific pest populations (Riechert and Lockley 1984). However, research of spiders in apple orchards has shown that spider prey preference may be species specific, which indicates that spiders can be effective biological control agents in agroecosystems (Marc and Canard 1997). Studies have shown that spider prey preference may also be family specific (Amalin and Pena 1999, Michaud 2002), but further research is needed in this area. The family Anyphaenidae have been found to

aid in biological control of one pest, *Diaphorina citri* nymphs, in Florida citrus groves (Michaud 2002). Additionally, research has shown Anyphaenidae to feed on the larvae of another pest, *Phyllocnistis citrella*, in Florida lime orchards (Amalin and Pena 1999). These examples show that Anyphaenidae has played a role in biological control of citrus crops, but no study has assessed the capacity of Anyphaenidae to assist in the biological control of wine grape vineyards. Research in this area could provide crucial insight into the future of integrated pest management in vineyards.

Limitations and Future Directions

My study design suffered from limited repetition, especially in the FRP sites, likely could have benefited from more frequent sampling throughout different seasons, and presented the challenge of identifying many juvenile spiders. Though I was able to analyze four years of data from the monoculture sites, I was only able to analyze two years of data from the riparian sites, and only one year of data from the FRP sites. Since we only sampled spiders once each year, this meant that all of the data for the FRP sites came from only one day of sampling. It is possible that my results would have differed if sites were sampled over four or five years. Furthermore, since we only sampled spiders at the end of the growing season, it is possible that we collected an inaccurate representation of spider distribution throughout the vineyards and their surrounding landscapes throughout the year. Most spiders inhabit vineyards seasonally because they do not overwinter within vineyards, and most likely enter from neighboring natural habitat areas (Hogg and Daane 2010, Hogg and Daane 2011). Spider abundance within vineyards has been found to be highest during late summer and early fall, because most spiders do not enter the vineyards early in the spring (Hogg and Daane 2010). Therefore, it makes sense that by August, September and October, when we collected our samples, most spiders would have already dispersed relatively evenly throughout the vineyards. In contrast, if we had instead sampled multiple times throughout the year we may have found a wider variation in spider family distribution as the spiders slowly moved from the surrounding natural habitat to areas within the vineyards. Finally, I encountered a similar problem as Costello and Daane 1995, because many of the spiders that I needed to identify were juveniles. It is extremely difficult to accurately identify juvenile spiders, and there are probably errors in my final data as a result. Despite the limitations of my study, it does provide a base from which more extensive studies may build upon in the future.

While this study only assessed how habitat diversification influences spider family diversity, future studies may assess how spider diversity may be further manipulated to best contribute to biological control of pest populations within vineyards. Since certain spiders found in agricultural landscapes have been known to drink the nectar of *Daucus carota* (Pollard et al. 1994), it would be interesting to try planting more of this flower in the FRP sites. It would also be helpful to address which families of spiders contribute most to the suppression of specific pest populations. This would be especially interesting in the case of Anyphaenidae, as this family responded to changes in landscape diversity and can therefore be manipulated by simply increasing the percentage of natural habitat in the surrounding landscapes of vineyards.

Broader Implications/Conclusions

This study has investigated how spider family diversity of vineyards can be influenced by changes in habitat diversity at multiple spatial scales, in an effort to provide insight into ways to maximize biological control within vineyards. Spiders have been found to play a crucial role in biological control of pest populations in vineyards (Roltsch et al. 1998, Colstello and Daane 1999). Additionally, the planting of flowering cover crops between rows of vines within vineyards has been shown to support spider communities (Isaia et al. 2006), increase spider density (Hanna et al. 2003), as well as alter spider species abundance (Costello and Daane 1998). While this study did not show a significant difference between the spider diversity of sites with and without FRP, it did indicate that the spider diversity of sites with FRP was consistently higher than sites without FRP by a slight amount. This study suggests that spiders may require dispersal corridors composed of non-crop habitat through which to enter vineyards from surrounding natural habitat areas, as shown by previous research (Holzschuh et al. 2006). Additionally, this study suggests that the enhancement of spider diversity by sowing flowering cover crops can be best augmented by increased landscape diversity at distances of 6 km (or possibly more) from the vineyards, as apposed to increased landscape diversity at distances closest to the vineyards. Finally, though this study presents mixed results regarding the previously shown trend that increased habitat diversity of the surrounding landscape results in increased spider diversity within vineyards (Tscharntke et al. 2007), it did highlight the response of the family Anyphaenidae to changes in habitat diversity at the landscape scale. While the family Anyphaenidae has been found to participate in the

biological control of certain pests of citrus crops in Florida (Amalin and Peña 1999, Michaud 2002), further research into the specific role of Anyphaenidae in biological control of vineyards is needed. Such research could provide family specific insight into the field of biological control, and therefore help to usher in a new era of ecologically based pest management in viticulture.

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APPENDIX A

Table 1. 2010 Shannon diversity indices of monoculture sites vs. the percentage of natural habitat at different distances.

Year	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value
2010	0.5	0.1948	1, 12	2.903	0.1142
2010	1.0	0.1641	1, 12	2.356	0.1508
2010	1.5	0.2001	1, 12	3.002	0.1088
2010	2.0	0.2223	1, 12	3.43	0.08876
2010	2.5	0.2026	1, 12	3.049	0.1063
2010	3.0	0.1856	1, 12	2.736	0.124
2010	3.5	0.1786	1, 12	2.609	0.1322
2010	4.0	0.1725	1, 12	2.502	0.1397
2010	4.5	0.1795	1, 12	2.624	0.1312
2010	5.0	0.1725	1, 12	2.502	0.1397
2010	5.5	0.1618	1, 12	2.317	0.1539
2010	6.0	0.1539	1, 12	2.025	0.1802

Table 2. 2011 Shannon diversity indices of monoculture sites vs. the percentage of natural habitat at different distances. The asterisk (*) indicates a significant result.

Year	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value
2011	0.5	0.2332	1, 15	4.563	0.04956*
2011	1.0	0.1493	1, 15	2.632	0.1256
2011	1.5	0.1117	1, 15	1.886	0.1899
2011	2.0	0.06157	1, 15	0.9842	0.3369
2011	2.5	0.04168	1, 15	0.6525	0.4319
2011	3.0	0.03211	1, 15	0.4976	0.4914
2011	3.5	0.03271	1, 15	0.5073	0.4873
2011	4.0	0.05974	1, 15	0.9531	0.3444
2011	4.5	0.09364	1, 15	1.55	0.2323
2011	5.0	0.1232	1, 15	2.108	0.1672
2011	5.5	0.1455	1, 15	2.554	0.1309
2011	6.0	0.1706	1, 15	3.085	0.0994

Table 3. 2012 Shannon diversity indices of monoculture sites vs. the percentage of natural habitat at different distances.

	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value
2012	0.5	0.008504	1, 14	0.1201	0.7341
2012	1.0	0.02467	1, 14	0.3542	0.5613
2012	1.5	0.04835	1, 14	0.7114	0.4132
2012	2.0	0.08022	1, 14	1.221	0.2878
2012	2.5	0.08299	1, 14	1.267	0.2793
2012	3.0	0.09608	1, 14	1.488	0.2427
2012	3.5	0.1515	1, 14	2.5	0.1362
2012	4.0	0.2079	1, 14	3.674	0.07589
2012	4.5	0.2274	1, 14	4.12	0.06184
2012	5.0	0.2228	1, 14	4.014	0.06488
2012	5.5	0.2202	1, 14	3.952	0.06672
2012	6.0	0.1965	1, 14	3.423	0.08552

APPENDIX B

Table 1. Welch Two Sample t-test results. This test was performed on data from all FRP sites (2012 and 2013 combined).

Year	t-result	Degrees of freedom	p-value
2012-2013	-0.7315	13.124	0.4773

Table 2. Wilcoxon rank sum test with continuity correction (non-parametric test). This test was performed on data from all FRP sites (2012 and 2013 combined).

Year	W	p-value
2012-2013	24	0.4306

APPENDIX C

Table 1. 2012 Shannon diversity indices of plots with FRP (treatment) vs. the percentage of natural habitat at different distances.

Year	Plot type	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value
2012	Treatment	0.5	0.3328	1, 4	1.995	0.2307
2012	Treatment	1.0	0.1353	1, 4	0.6258	0.4732
2012	Treatment	1.5	0.04615	1, 4	0.1935	0.6827
2012	Treatment	2.0	0.03283	1, 4	0.1358	0.7312
2012	Treatment	2.5	0.01937	1, 4	0.079	0.7926
2012	Treatment	3.0	0.03956	1, 4	0.1648	0.7056
2012	Treatment	3.5	0.07057	1, 4	0.3037	0.6109
2012	Treatment	4.0	0.07873	1, 4	0.3418	0.5902
2012	Treatment	4.5	0.0712	1, 4	0.3066	0.6092
2012	Treatment	5.0	0.05475	1, 4	0.2317	0.6554
2012	Treatment	5.5	0.03333	1, 4	0.1379	0.7292
2012	Treatment	6.0	0.0182	1, 4	0.07413	0.7989

Table 2. 2012 Shannon diversity indices of comparable monoculture plots from the FRP sites (control) vs. the percentage of natural habitat at different distances.

Year	Plot type	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value
2012	Control	0.5	0.2639	1, 4	1.434	0.2972
2012	Control	1.0	0.005185	1, 4	0.02085	0.8922
2012	Control	1.5	0.01063	1, 4	0.04299	0.8459
2012	Control	2.0	0.01096	1, 4	0.04433	0.8435
2012	Control	2.5	0.03904	1, 4	0.1625	0.7075
2012	Control	3.0	0.04675	1, 4	0.1962	0.6807
2012	Control	3.5	0.04245	1, 4	0.1773	0.6953
2012	Control	4.0	0.03795	1, 4	0.1578	0.7115
2012	Control	4.5	0.04428	1, 4	0.1853	0.689
2012	Control	5.0	0.03929	1, 4	0.1636	0.7066
2012	Control	5.5	0.04247	1, 4	0.1774	0.6952
2012	Control	6.0	0.04158	1, 4	0.1736	0.6984

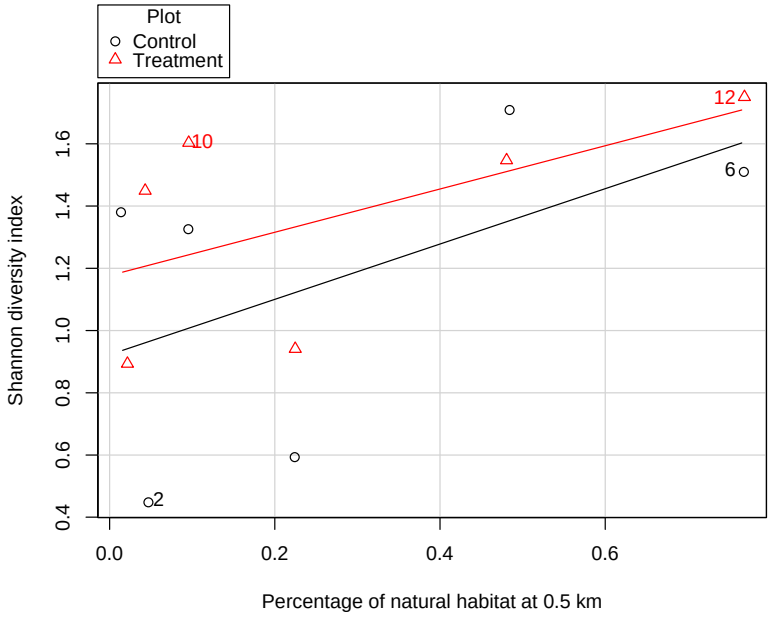

Figure 1. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 0.5 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 0.5 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

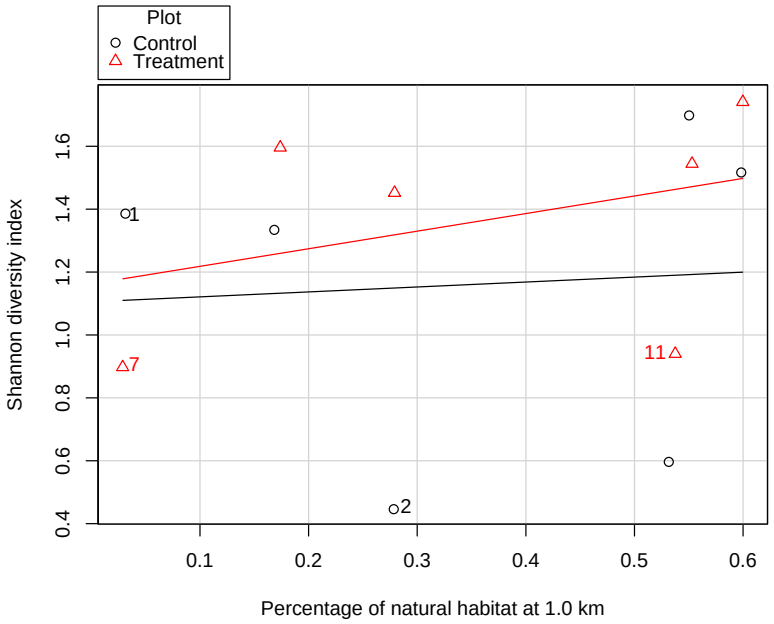

Figure 2. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 1.0 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 1.0 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

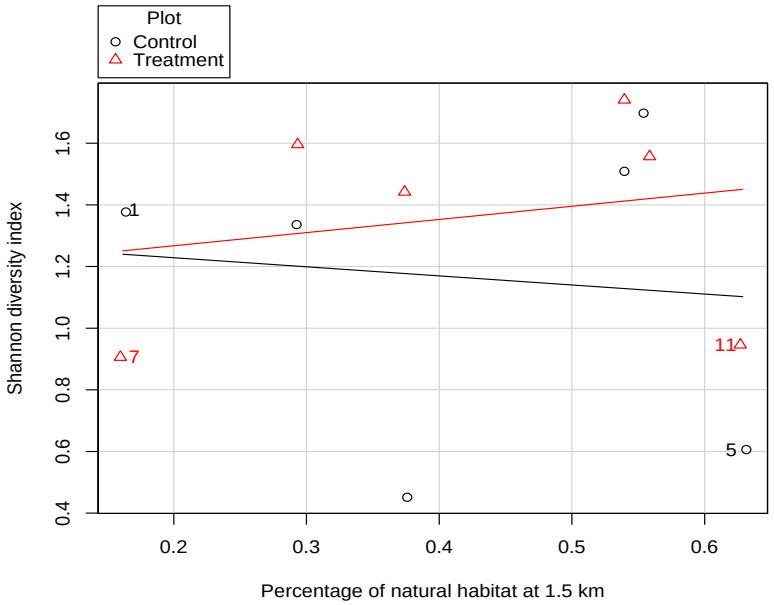

Figure 3. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 1.5 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 1.5 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

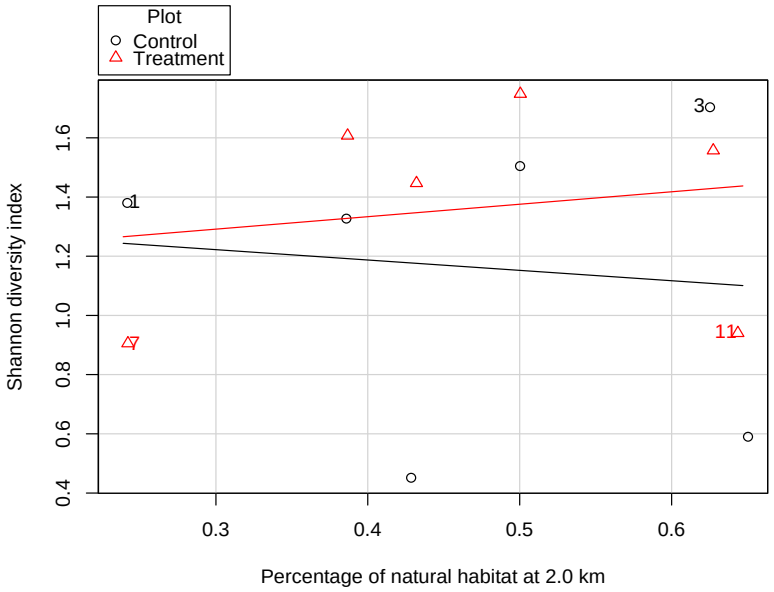

Figure 4. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 2.0 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 2.0 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

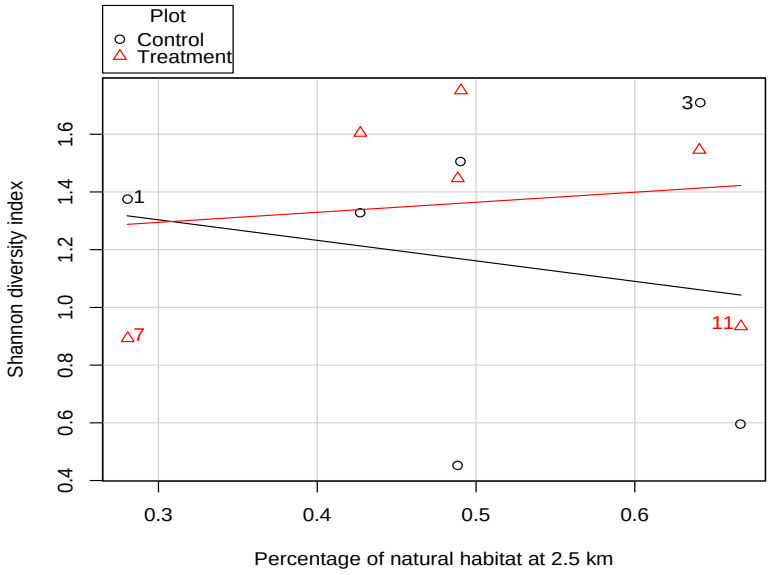

Figure 5. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 2.5 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 2.5 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

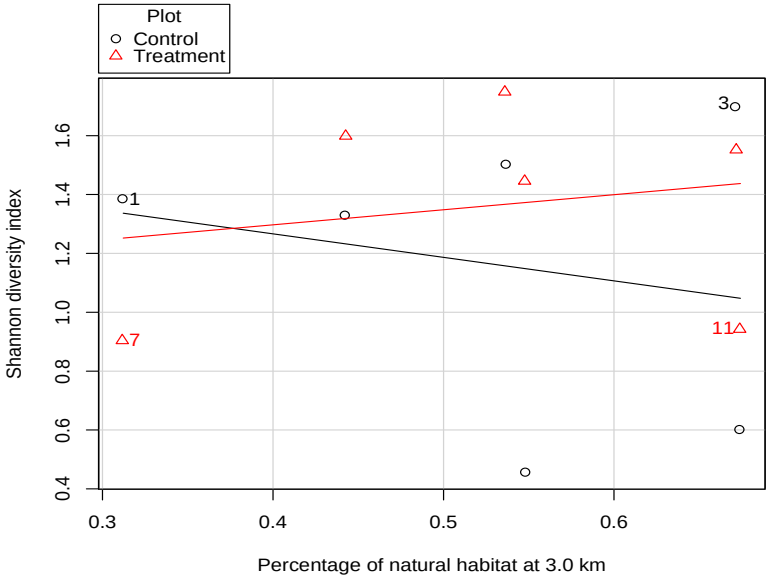

Figure 6. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 3.0 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 3.0 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

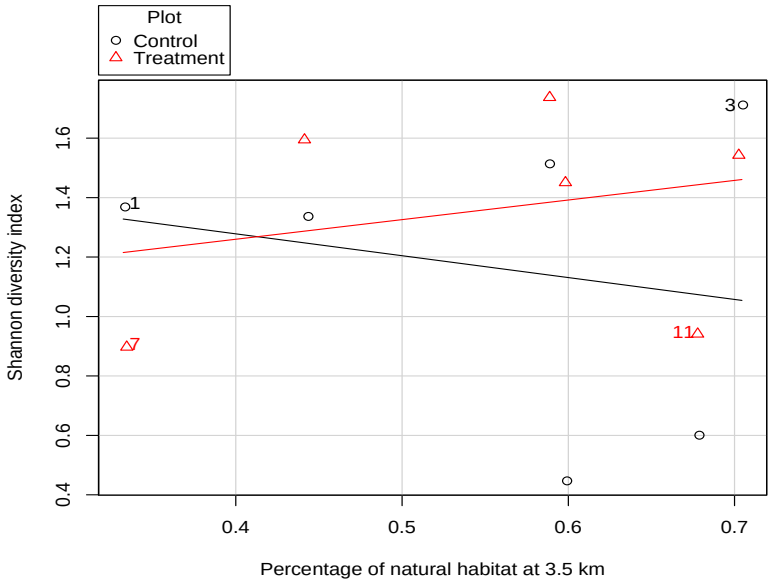

Figure 7. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 3.5 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 3.5 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

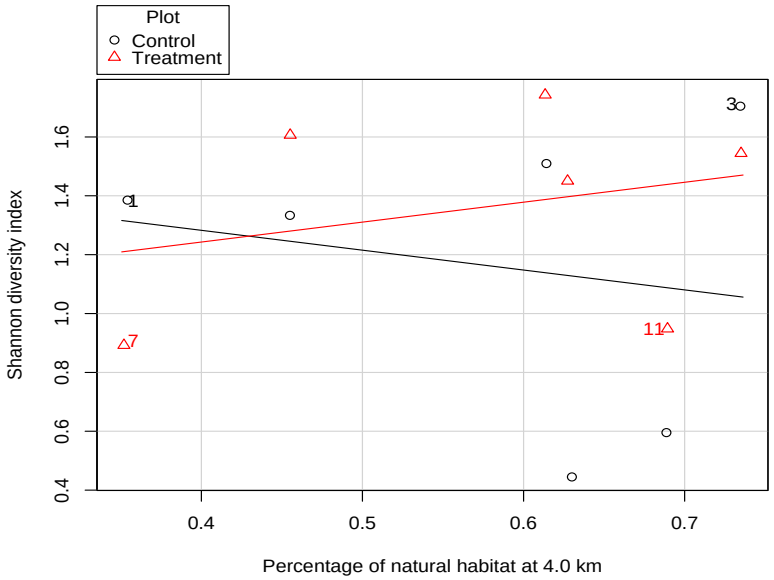

Figure 8. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 4.0 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 4.0 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

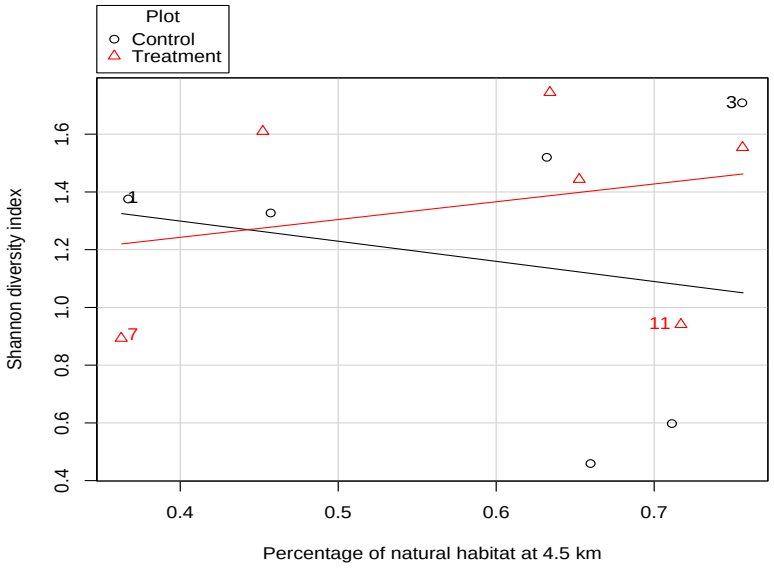

Figure 9. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 4.5 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 4.5 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

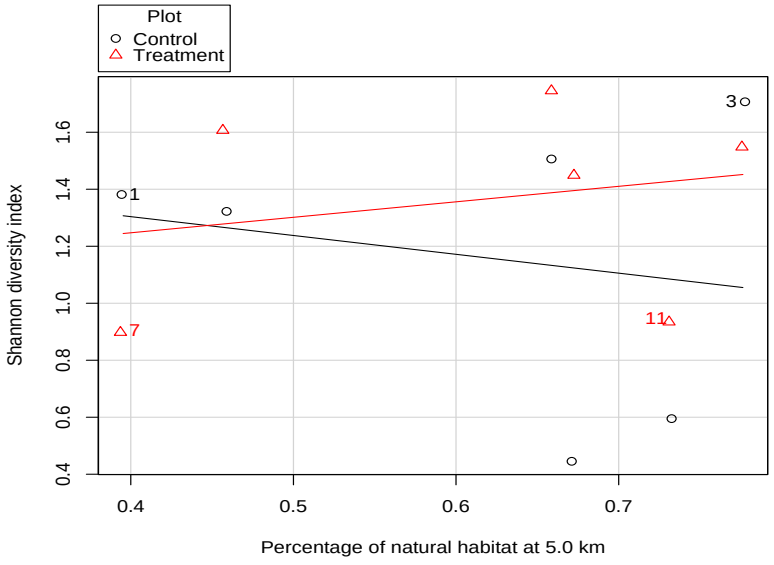

Figure 10. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 5.0 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 5.0 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

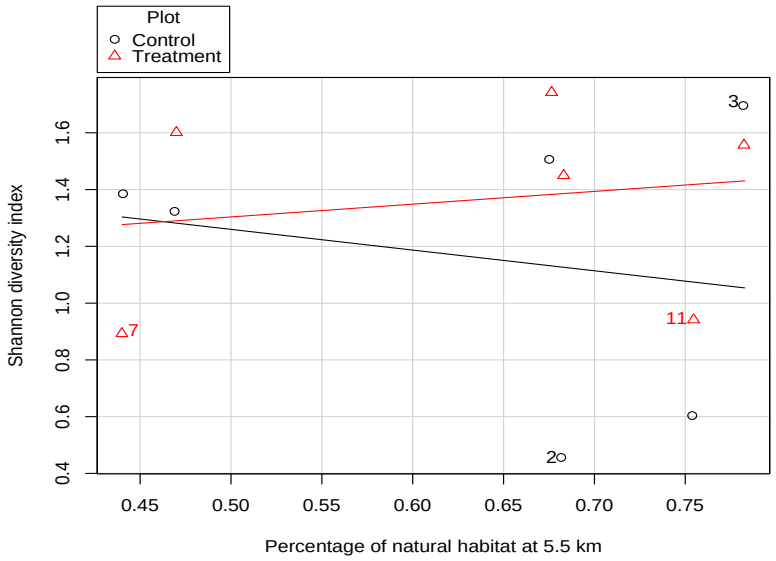

Figure 11. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 5.5 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 5.5 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

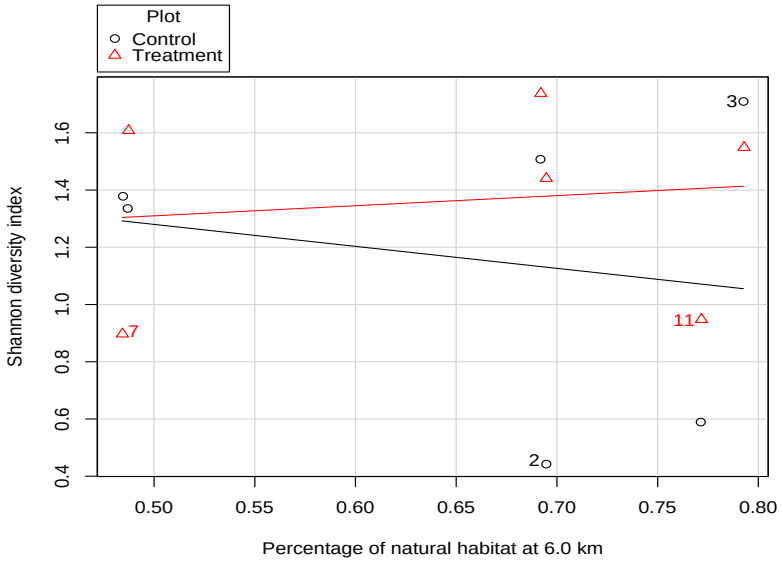

Figure 12. 2012 Shannon diversity indices of FRP plots (treatment) and comparable monoculture plots (control) vs. the percentage of natural habitat at a distance of 6.0 km. The Shannon diversity indices of the plots with and without FRP from 2012 are on the y-axis. The percentage of natural habitat at a distance of 6.0 km from each vineyard is on the x-axis. The plots with FRP are the treatment plots and are indicated by red triangles. The comparable plots without FRP are the control plots and are indicated by black circles.

APPENDIX D

Table 1. Differences in Shannon diversity indices vs. the percentage of natural habitat at different distances. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

Year	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value
2012-2013	0.5	0.0008146	1, 6	0.004892	0.9465
2012-2013	1.0	0.04832	1, 6	0.3046	0.6009
2012-2013	1.5	0.07708	1, 6	0.5011	0.5056
2012-2013	2.0	0.06609	1, 6	0.4246	0.5388
2012-2013	2.5	0.0927	1, 6	0.613	0.4634
2012-2013	3.0	0.1179	1, 6	0.8019	0.405
2012-2013	3.5	0.1287	1, 6	0.8864	0.3828
2012-2013	4.0	0.1217	1, 6	0.8316	0.397
2012-2013	4.5	0.1231	1, 6	0.8422	0.3942
2012-2013	5.0	0.1024	1, 6	0.6843	0.4398
2012-2013	5.5	0.08751	1, 6	0.5754	0.4768
2012-2013	6.0	0.07072	1, 6	0.4566	0.5244

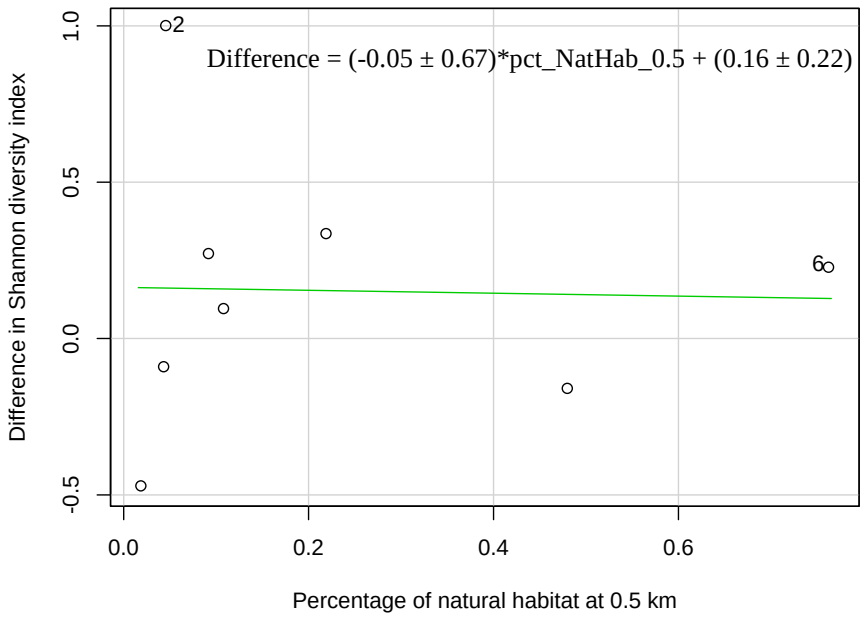

Figure 1. Differences in Shannon diversity indices vs. the percentage of natural habitat at 0.5 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 0.5 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

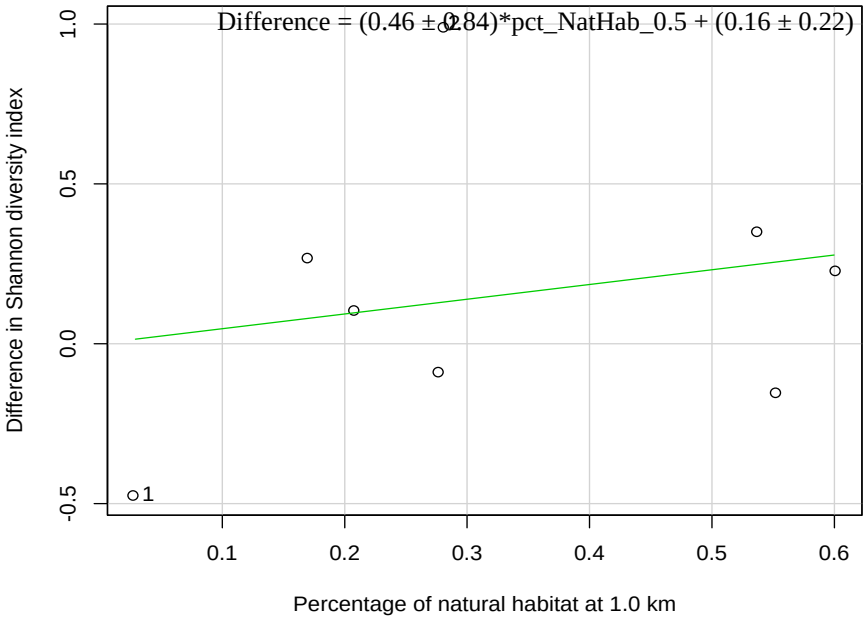

Figure 2. Differences in Shannon diversity indices vs. the percentage of natural habitat at 1.0 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 1.0 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

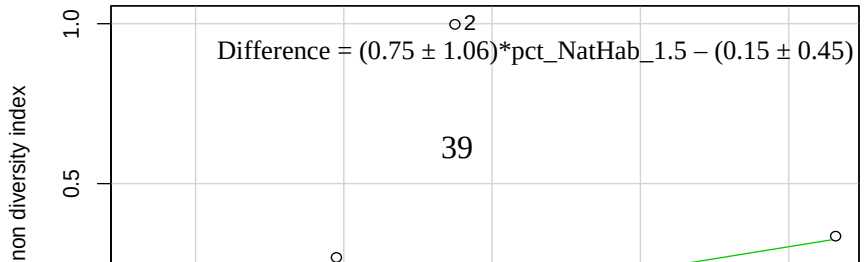

Figure 3. Differences in Shannon diversity indices vs. the percentage of natural habitat at 1.5 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 1.5 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

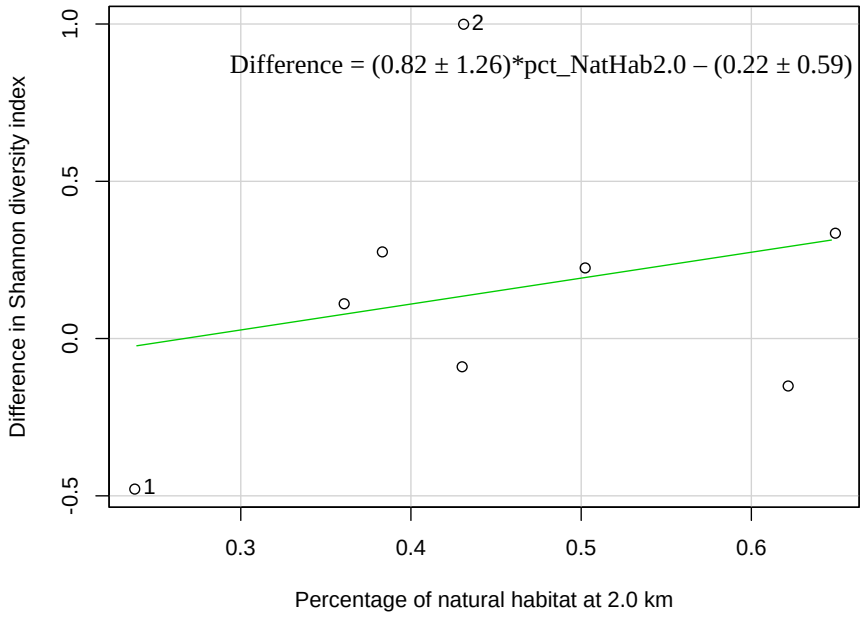

Figure 4. Differences in Shannon diversity indices vs. the percentage of natural habitat at 2.0 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 2.0 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

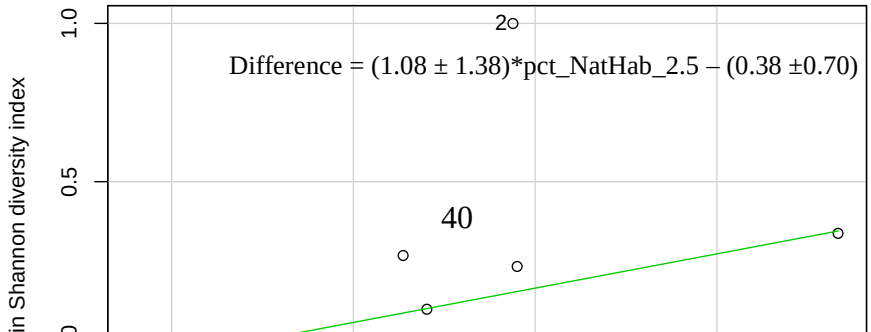

Figure 5. Differences in Shannon diversity indices vs. the percentage of natural habitat at 2.5 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 2.5 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

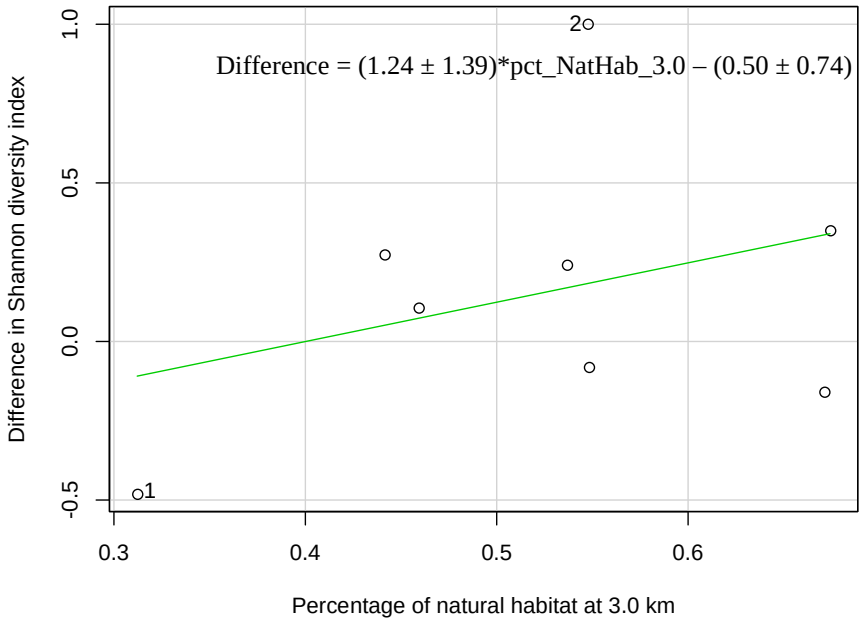

Figure 6. Differences in Shannon diversity indices vs. the percentage of natural habitat at 3.0 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 3.0 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

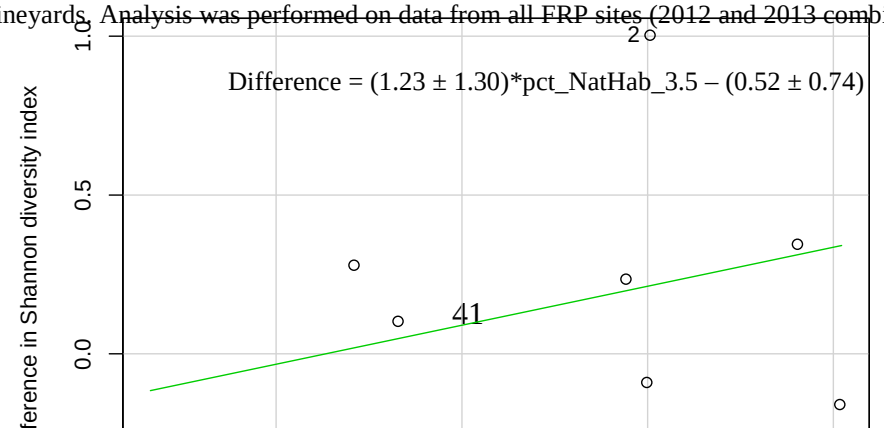

Figure 7. Differences in Shannon diversity indices vs. the percentage of natural habitat at 3.5 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 3.5 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

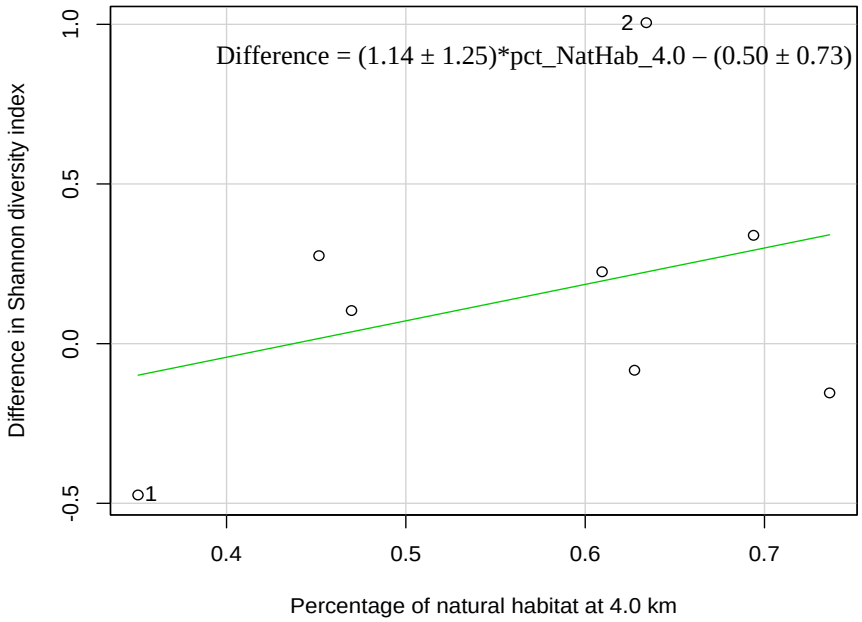

Figure 8. Differences in Shannon diversity indices vs. the percentage of natural habitat at 4.0 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 4.0 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

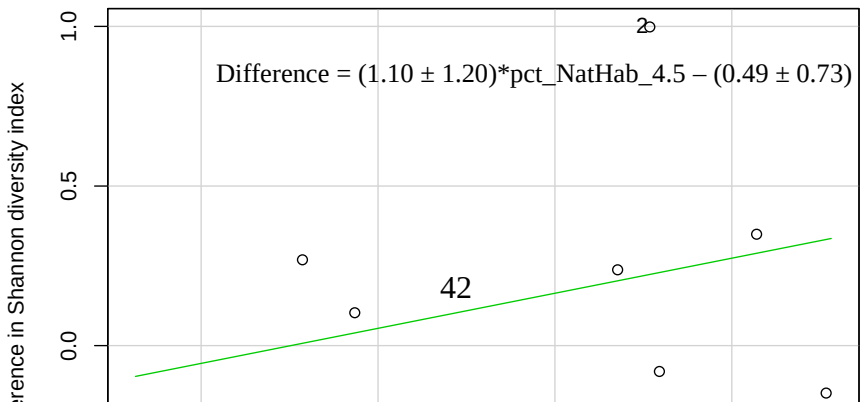

Figure 9. Differences in Shannon diversity indices vs. the percentage of natural habitat at 4.5 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 4.5 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

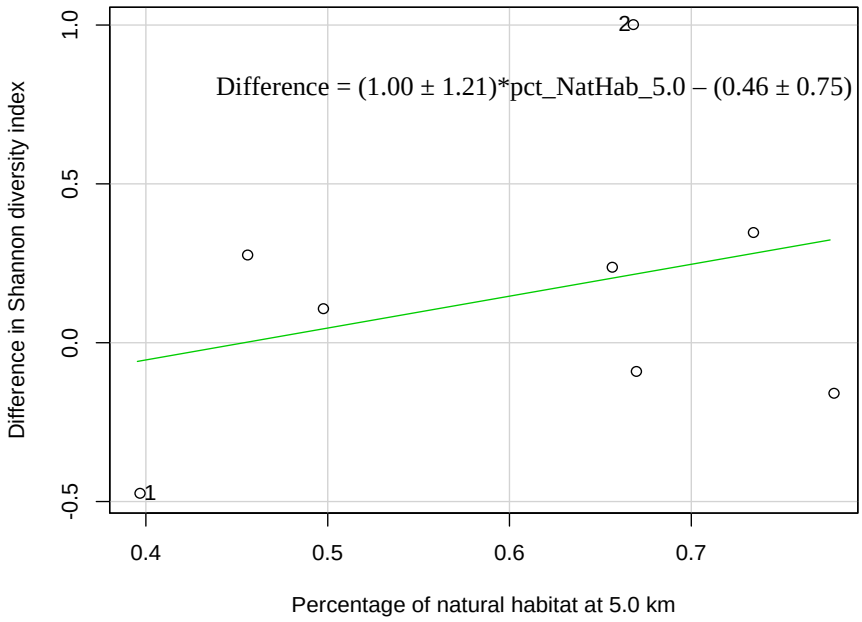

Figure 10. Differences in Shannon diversity indices vs. the percentage of natural habitat at 5.0 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 5.0 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

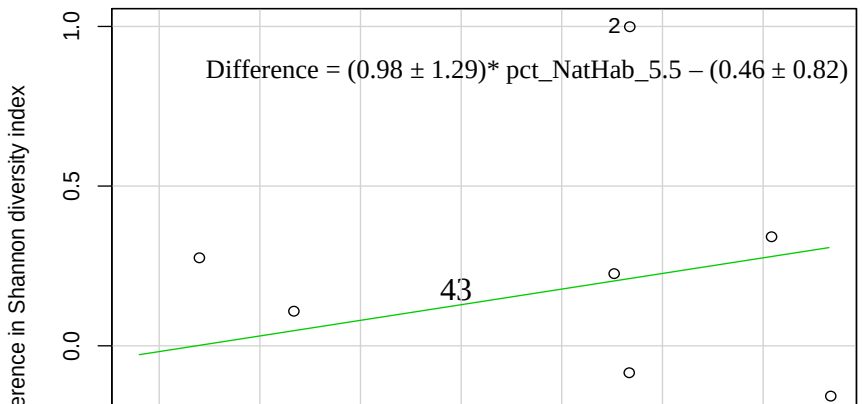

Figure 11. Differences in Shannon diversity indices vs. the percentage of natural habitat at 5.5 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 5.5 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

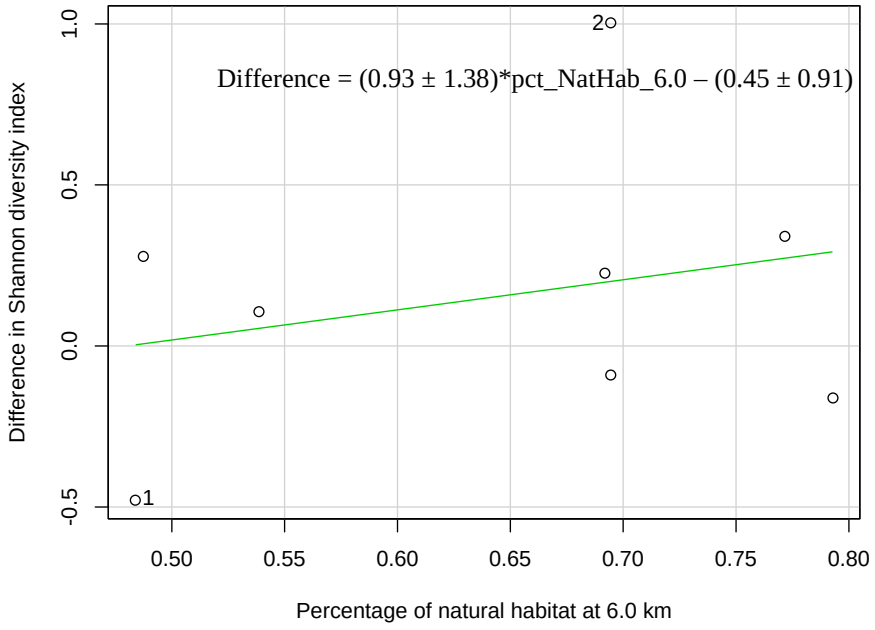

Figure 12. Differences in Shannon diversity indices vs. the percentage of natural habitat at 6.0 km. Along the y-axis are the calculated differences between Shannon diversity indices of the FRP plots and comparable plots without FRP. Along the x-axis is the change in percentage of natural habitat in the surrounding landscape at a distance of 6.0 km from the vineyards. Analysis was performed on data from all FRP sites (2012 and 2013 combined).

APPENDIX E

Table 1. Kruskal-Wallace test results (non-parametric test).

Year	Degrees of freedom	chi-squared	p-value
2010	2	1.8056	0.4054

Table 2. ANOVA results.

Year	Degrees of freedom	F-value	p-value
2011	4	2.372	0.0989

Table 3. Kruskal-Wallace test results (non-parametric test).

Year	Degrees of freedom	chi-squared	p-value
2011	4	7.15	0.1282

APPENDIX F

Table 1. Frequency of Anyphaenidae identified vs. the percentage of natural habitat at different distances. These analyses assessed the spiders identified from the FRP sites only (both treatment and control plots combined). No significant results were found when running analysis on other spider families identified. As a result, only results from analysis of Anyphaenidae are shown below. The asterisk (*) indicates a significant result.

Year	Site type	Family	Distance from vineyard (km)	R^2	Degrees of freedom	F-statistic	p-value
2012-2013	FRP	Anyphaenidae	0.5	0.3505	1, 14	7.556	0.01568*
2012-2013	FRP	Anyphaenidae	1.0	0.3199	1, 14	6.584	0.02242*
2012-2013	FRP	Anyphaenidae	1.5	0.278	1, 14	5.391	0.03584*
2012-2013	FRP	Anyphaenidae	2.0	0.153	1, 14	2.528	0.1341
2012-2013	FRP	Anyphaenidae	2.5	0.08515	1, 14	1.303	0.2728
2012-2013	FRP	Anyphaenidae	3.0	0.08423	1, 14	1.288	0.2755
2012-2013	FRP	Anyphaenidae	3.5	0.09052	1, 14	1.393	0.2575
2012-2013	FRP	Anyphaenidae	4.0	0.08233	1, 14	1.256	0.2813
2012-2013	FRP	Anyphaenidae	4.5	0.08166	1, 14	1.245	0.2833
2012-2013	FRP	Anyphaenidae	5.0	0.08479	1, 4	1.297	0.2739
2012-2013	FRP	Anyphaenidae	5.5	0.0912	1, 14	1.405	0.2556
2012-2013	FRP	Anyphaenidae	6.0	0.09238	1, 14	1.425	0.2524