Relative importance of patch area, plant diversity, and habitat heterogeneity on species richness for Lepidoptera, Trichoptera, and Neuroptera in a glaciated second-growth Northern mesic hardwood forest

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Abstract

The use of arthropod species richness and biodiversity are increasingly being used to as a measure of habitat quality on a smaller scale. These values can be used to more precisely determine which areas are more important to target for conservation management programs within the larger landscape. This study focused on nocturnal members of three orders of insects (Lepidoptera, Trichoptera, and Neuroptera),divided into two functional groupings based on larval habitat, and sought to determine which factors (patch area, woody plant biodiversity, habitat heterogeneity, or diversity of proximal aquatic habitats) were more important in supporting greater species richness within early successional areas(unforested) of a northern mesic hardwood forest. Specifically, I predicted that terrestrial Lepidoptera would show increased species richness as a result of greater plant biodiversity and habitat heterogeneity, while the aquatic-immature orders Trichoptera and Neuroptera would show increases in species richness due to greater patch area and diversity of aquatic habitats. Contrary to my expectations, the total species richness actually decreased as the habitat heterogeneity increased (p=0.034); the obfuscation of the results could be attributed to sampling methods in relation to scale or misidentification of relevant variables in determining habitat heterogeneity values.

Introduction

Preserving biodiversity has been the aim of many conservation movements over the last decade, as the number of species either threatened or driven extinct has continued to rise. Relative rates of biodiversity over time has been used as a litmus test for the health of ecosystems on local, regional, and global scales, and has been applied to many taxa. Some of the larger sized groups such as mammals and birds are effectively and easily censused, but insects have proven more challenging as only about a third (or less) of all estimated taxa have even been described, and the variation in their communities can be much greater across a smaller scale (Tews *et al.* 2004;Spence *et al.* 2008) The reasons for this are not yet fully understood, but in general insects have been shown to respond more intensely to changes in microhabitats due to biotic and abiotic factors like seasonal temperature, shelter, and food availability(Hill *et al.* 1995; Summerville and Crist 2008; Pérez-Guerrero *et al.* 2011). With a seemingly exhaustive array of species, the possibility has been put forth that perhaps not all of them are vital members of a community (Walker 1992). The question then becomes, are some of these species playing "redundant" roles in their ecosystem, and does conserving every insect species even matter? The problem with assuming that our inability to discover the importance of a species indicates its relative role in the health of a community is that without proper surveys of where and when species occur we cannot predict what might happen if they were removed from a system. Holometabolous insects are different from many terrestrial vertebrates in segregating their juvenile and mature life stages, allowing them to occupy and

exploit two different habitats and food sources-two species so to speak- so that often the stage we most readily associate with them only represents half of their ecological role.

Moths (Lepidoptera) perform important functions in forest ecosystems as both herbivorous feeders and food for insectivores and their recorded biodiversity is remarkably high with tree stands of around 50ha supporting up to 200 species of macrolepidopterans (Summerville *et al.* 2008; Summerville 2011). They are also relatively easy to sample with UV-light traps at night, and thus are the most extensively catalogued order to date; however, the number of moths described in northern forests is likely still only a small fraction of those present (Summerville and Crist 2008). Most moth larvae (caterpillars) are terrestrial herbivores and a few species are periodically destructive, although many adult moths are nectivorous and are important as pollinators (Summerville 2011). Trichopterans and Neuropterans both have aquatic larval stages; caddisfly larvae are well studied for their role in nutrient cycling in stream systems, and along with the predaceous Neuropteran larvae are used as bioindicators of water quality (Patrick and Palavage 1994). Like moths, many adult caddisflies are nectivorous or do not feed, nor do the Neuropteran suborder that includes dobsonflies and fishflies (Jackson and Resh 1991; Johnson and Triplehorn 2004). Subsequently, it can be assumed that the winged adult phase of all of their life cycles will primarily function for mate location, ovipositional site selection by the females, and/or more general dispersal.

For decades, MacArthur and Wilson's (1963) theory of island biogeography was interpreted to relate number of species found in an isolated habitat patch to its area, as well as its distance from a "mainland" source of colonizers. More recently, other measures to predict species richness have further developed this idea, including the importance of habitat heterogeneity for species on multiple spatial scales (Hortal *et al.* 2009; Tews *et al.* 2004; Spence *et al.* 2008). Studies to determine the relative importance of each have been applied in a limited fashion to insects, but the diversity of life histories and feeding strategies among different taxa within the class have yielded mixed results, often when the habitat sampled falls in the grey area between an increase in habitat heterogeneity and habitat fragmentation (Fahrig 2003, Hill *et al.* 1995, Rainio & Niemela 2003) Deciding which are important variables within a

habitat to the taxa measured can help to alleviate the confusion. For instance, many herbivorous insects have adapted specialist relationships with their host plants allowing them to overcome the plant toxic defenses, reducing interspecific competition and increasing the number of feeding niches per unit area (Ehrlich and Raven 1964; Case 1981). In this case, loss of the plant would likely result in loss of the insect. When studying a group with diverse feeding strategies, a broader use of vegetation type as a measure of habitat heterogeneity would be most useful, but a second measure of plant diversity as a driver of insect species richness would also help determine effects of a habitat patch especially for groups like the moths that include many specialists (Ober and Hayes 2010). In this case, the measure of insect species richness is sufficient to show presence of more rare species that rely on specific host plants.

The University of Notre Dame Environmental Research Center (UNDERC) field station in MI Gogebic Co is a second-growth Northern mesic hardwoods forest with a topography formed from the Wisconsin event glaciation, producing multiple lakes and bogs. Several patches of fields and meadows also occur representing a contrasting microhabitat within the larger landscape. The regular precipitation throughout the year forms vernal ponds and feeds streams; many types of water bodies are represented. Because the biotic and abiotic variability of the landscape presents an effective model site, one of the objectives of this study will be testing the effects of habitat heterogeneity, plant diversity, and habitat patch area on species richness. Unfortunately, although the plant and vertebrate species occurring at UNDERC have been thoroughly and commendably surveyed, the many of the invertebrates making up a substantial, and arguably integral, proportion of community members still need identification. Therefore, another objective of this study will be to provide another insect census to increase the body of knowledge here at UNDERC.

I believe the fields and meadows of this property are more likely to represent an increase in habitat heterogeneity rather than habitat fragmentation. Because the variability in vegetation represents increased potential food for terrestrial herbivorous caterpillars, I hypothesize that moths will show increased species richness as habitat heterogeneity and plant biodiversity increases. With aquatic larvae, adult Trichopterans and Neuropterans will likely respond less to changes in vegetation, instead using open

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patches for other reasons like mate location, so I predict that they will show increased species richness as patch area increases. I also believe that the nearer the patch is to various types of water bodies, the more likely taxa whose larvae develop in different aquatic systems will occur, so I predict that the more types of aquatic habitats are located near the habitat patch, the greater the species richness of Trichoptera and Neuroptera.

Materials and Methods

I sampled three sites on UNDERC property classified as early successional open areas (non-forested) by UV-light trapping during the week of 7/9/11 through 7/15/11. The sites, colloquially named Naked Kitty Field, Grasshopper Nation, and Tick Site, were located at least 2km from each other to maximize separation of communities. Each site was sampled nightly for macro-Lepidopterans, Trichopterans, and Neuropterans between the hours of 9pm and 2am,and I collected the insects after at least 30 minutes and no more than 1 hour of light exposure. I identified specimens collected to the lowest taxon I was able utilizing Borror and Delong's Study of Insects (Johnson and Triplehorn 2004) and the online key maintained by David Hembry and the University of California at Berkeley.

To characterize the plant diversity at each site, I identified and recorded abundances for all woody trees and shrubs, and identified herbaceous plants as either forb (with flowering status) or graminaceous plant. I took three 50 m transects at each site, and estimated the proportion of each type of vegetation I found at every meter (lichen, grass, forb, or woody), and proportion of bare soil. I categorized each meter based on dominant (>70%) vegetation, or mixed composition if no type dominated to create microhabitat "species" for calculating habitat heterogeneity. I recorded types of aquatic habitats located within 500m of each site (bog, vernal pond, lake, or stream) using topographical maps located on the UNDERC website. I determined the area of each site using Google earth (imagery date 5/14/2011).

Statistics

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I compared the total species richness represented by Lepidoptera, Trichoptera, and Neuroptera, and the Trichoptera/Neuroptera species richness between sites using the Jaccard Index to determine degree of species similarity between sites, and used SYSTAT to perform a linear regression test for each to determine effects of patch area, plant diversity, number of proximal aquatic habitat types, and habitat heterogeneity on total and functional levels of night flying insects. I determined plant diversity and habitat heterogeneity using the Shannon-Weiner index (H').

Results

I recorded the insect species collected at the light trap for each site as well as the area, plant diversity, habitat heterogeneity, and proximal aquatic habitats, and summarized the results in Appendix 1. A cluster analysis using Jaccard Index showed that all three sites were very dissimilar in their relative species richness collected (Fig 1), and separate analyses using the Jaccard Index also showed a relatively low percent similarity in both Trichoptera/Neuroptera species assemblages (Table 1), and woody plant species composition between sites (Table 2).

Patch Area

The species richness does not appear to be impacted by the relative size of a habitat patch. The Naked Kitty site ($15598.15m^2$) had over 1.5 times greater area than the Grasshopper Nation site ($9551.89m^2$), and more than 3 times greater than the Tick site ($4954.38m^2$). Multiple linear regressions showed no significant relationship between patch area and total species richness ($F_{(1,1)}=0.472, p=0.616, R^2=0.321$). Neither the Lepidoptera ($F_{(1,1)}=0.016, p=0.920, R^2=0.016$), nor the combined Neuroptera and Trichoptera ($F_{(1,1)}=5.468, p=0.257, R^2=0.845$) showed any significant effects by area on their relative species richness.

Plant Diversity

I identified and 21 woody trees and shrubs among all three sites sampled, and measured their relative biodiversity using the Shannon-Weiner Index. Contrary to my expectations, linear regression analyses showed that relative diversity in woody plants of each site had no significant impact on the overall ($F_{(1,1)}=3.259, p=0.322, R^2=0.765$) or Lepidoptera richness of species collected

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($F_{(1,1)}=32.059,p=0.111,R^2=0.970$). As expected, the Trichoptera and Neuroptera grouping did not show any significant changes in their species richness as plant diversity varied between sites($F_{(1,1)}=0.137,p=0.774,R^2=0.120$).

Habitat Heterogeneity

Surprisingly, greater habitat heterogeneity on the measured scale significantly decreased the total species richness found by linear regression ($F_{(1,1)}=349.570,p=0.034,R^2=0.997$). When separately analyzed neither the sub-grouping Lepidoptera ($F_{(1,1)}=1.228,p=0.467 R^2=0.551$) nor Trichoptera and Neuroptera ($F_{(1,1)}=0.0432,p=0.870,R^2=0.041$) showed any significant relationship between the habitat heterogeneity and species richness.

Aquatic Habitat

As predicted, proximity to varying types of aquatic habitats had no significant impact on total species richness ($F_{(1,1)}=0.159,p=0.758,R^2=0.137$) or Lepidoptera species richness($F_{(1,1)}=3.191,p=0.325,R^2=0.761$) by linear regression. An unexpected result was the lack of a significant interaction between the abundance of various types of aquatic habitats within 500m of each site and the Trichoptera and Neuroptera species richness collected ($F_{(1,1)}=2.895,p=0.338, R^2=0.743$).

Discussion

The purpose of this study was two-fold; to elucidate the factors that determined the species richness of two different insect functional groups occurring in an open habitat patch within a Northern mesic hardwood forest as a guideline for conservation management, and to potentially add to the list of insects found at the UNDERC field station. Over the course of the sampling period I found 58 different species of moths, caddisflies, and Neuropterans, hopefully making a useful contribution to the insect collection. Because the species composition of each site was so dissimilar measured by the Jaccard Index, there were likely underlying ecological factors that govern where species occur. As a result of the study, I identified that patch area of early successional fields, their diversity of woody trees and shrubs, and proximity to varied aquatic habitats did not have a significant effect on species richness. Habitat heterogeneity of the variables selected, and at the scale I chose to measure did appear to significantly alter

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the total species richness found, although there was no effect on the functional grouping level. More studies are needed to determine which factors are important for developing conservation management practices.

The nonsignificant impact of patch area on total and Lepidoptera species richness was expected, and most likely reflects the growing consensus that other factors are more important drivers of insect biodiversity (Spence *et al.* 2008; Summerville *et al.* 2008; Tews *et al.* 2004). The data did not support my hypothesis that patch area would have an effect on Trichoptera and Neuroptera species richness, but the species dissimilarity between sites indicates it is likely that there is an important environmental influence that varies across the field station. Whether the data supports the theory of island biodiversity in any way is not really possible to determine without sampling over an extended period of time to identify extinction and immigration rates.

A more surprising finding is that the plant diversity at each site has no significant impact on the total and particularly the Lepidoptera species richness. Although the lack of a significant relationship between plant diversity and the Trichoptera/Neuroptera group with aquatic larvae was as predicted, I expected that a diverse plant assemblage would be reflected by increases in moth species richness, as they would constitute host plants for the ovipositing female moths (Knops *et al.*1999; Haddad *et al.* 2001). The underlying factor is impossible to determine with the data I collected, but one possible correlation could be made with the relative dominance of coniferous species at each site. Coniferous trees are more likely than deciduous hardwoods to have a greater proportion of their herbivore assemblage be specialists rather than generalists (Futuyma and Gould 1979; Zovi *et al.* 2008). Multiple previous studies have found a very uneven pattern of distribution in moth species richness and diversity in forest ecosystems, where a very small percentage of generalist species constitute a high number of individuals present (Pérez-Guerrero *et al.* 2011; Summerville and Crist 2008; Summerville *et al.*2008; Summerville 2011). To illustrate, Ober and Hayes (2010) found that of the 9514 individuals captured over a three year period in a northern coniferous forest, more than 50% consisted of the same twelve species (eight being known deciduous generalist herbivores as larvae), although they only accounted for 5% of the species richness.

Because my sample period was so short, it is likely that many of the specialist species that occur at very low abundances were not captured. For instance, at Grasshopper Nation, three of the four most abundant woody plants were coniferous, and although conifers only made up half of the individual plants counted, relative biomass was not taken into account when I recorded the data. I counted all trees if they were greater than 1.5m tall with the same weight as I recorded a 9m tall tree, and it is possible that if biomass was a factor in the diversity calculation the conifers would dominate the site. If they are host to low-frequency specialist moths, the likelihood of collecting a truly representative sample would diminish, as the generalists found on the deciduous hardwoods would likely be overrepresented, while at the same time the likelihood of collecting at least some of the rare species would balance out the trend. However, without further data collection, this possibility is not verifiable and so should not be used to make management decisions.

Habitat heterogeneity as I calculated it did not have an appreciable effect on Lepidoptera and Trichoptera/Neuroptera species richness, but the most unexpected result of the study showed a significantly negative correlation between high habitat heterogeneity and overall species richness (p=0.034). Although previous studies have shown contradictory results in correlating habitat diversity with species richness or biodiversity, the difference is often attributed to how the variation in the habitat affects the greater landscape; if the variation has an additive effect on total niches and therefore species it can support, it is habitat heterogeneity, but if it splits the landscape and hinders dispersal or migration of organisms, it is considered habitat fragmentation (Ewers and Didham 2006; Fahrig 2003; Debinski and Holt 2000). Each of my sites was too small within the larger forest landscape to likely induce the effects of habitat fragmentation, and so I believe that either the factors I chose to measure were of little significance to the insects studied, the way I collected the floral data was not specific enough, or the scale that I measured was inappropriate for accurately measuring habitat heterogeneity.

Choosing biologically relevant variables to measure the habitat heterogeneity for any set of organisms requires an understanding of their behaviors and life histories. This can present a problem for ecologists working with insects as many have only been cursorily described unless they present some

great harm or benefit to human enterprise (Spence *et al.* 2008). Overall, the more innocuous arthropods have not been the focus of many studies to determine how they respond to diversity in their habitats, and thus part of this study was to identify which variables mattered for moths as terrestrial herbivores and nectarivores, and caddisflies and Neuropterans with aquatic immature stages. Based on the feeding guilds most Lepidopterans occupy, I assumed that diversity in woody plants and forbs would be most important for their larvae although both graminivorous and lichenivorous species are known, and abundance of flowering forbs as sources of nectar would matter most for the adults. Thus, I weighted equally the proportion of forbs, graminaceous plants, woody plants, and lichens, as well as proportion of bare ground to account for differences in density. I also graphed the relationship between the number of transect points with flowering forbs against species richness, but found no clear trend. In future studies, I would account for the diversity in species of flowering forbs, as different moth species are known to utilize various nectar sources. Lack of variation in flowering species present might decrease overall heterogeneity, and thereby possibly increase interspecific competition. The important factors may also not yet be identified; Tews *et al.* (2004) proposed the existence of "keystone structures" whose absence or presence alone is the driving factor within the habitat that determines the community biodiversity, like a certain type of tree in a grassland landscape, or a temporary wetland within the forest. Identifying the presence of these structures is only possible when surveying the landscape at the correct scale, however, so that to narrow or wide of a view will obscure its importance. Due to the diminutive size of my study organisms, I chose to measure habitat heterogeneity at the scale of square meters. The greater mobility afforded the insects I studied may allow them to exploit a wider range of habitat so that the controlling structural variables might only be apparent with a broader view of the landscape.

Variability in proximity to diverse aquatic habitats also had a puzzling lack of significance for species richness of the aquatic Trichoptera and Neuroptera, as well as on total and Lepidoptera species richness although this was as expected. My inability to uncover a significant relationship between the aquatic group and variety of aquatic habitats may simply be due to a failure of omission based on my trapping methods. Although many Trichoptera and Neuroptera are nocturnal, they often temporally

segregate flight activity throughout the night (Jackson and Resh 1991). Although I trapped over a 5 hour period (9pm through 2am), each site was only sampled for a short fraction of that time because I was limited to only one light trap that had to be moved between each site nightly. In an attempt to control for this I rotated the order in which I sampled sites so that I would trap insects at each time interval over the course of the week, but if species assemblage differed between the intervals then the likelihood of collecting a particular species may have dropped by up to two-thirds. In addition, some Trichoptera are crepuscular or even diurnal, and these species would not have been accounted for (Jackson and Resh 1991).

In light of these findings, I suggest further studies to determine predictors of insect diversity on multiple scales, as a means of quantifying and monitoring habitat quality for conservation purposes. Areas of focus should incorporate more taxa with mixed mobility for understanding how to measure habitat diversity through different landscape structures and levels of scale. . I encourage future researchers to conduct a more systematic and comprehensive survey of insects found at the UNDERC field station as it would provide an invaluable baseline for monitoring impacts of any future conservation management programs.

Acknowledgements

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Figures

Cluster Tree
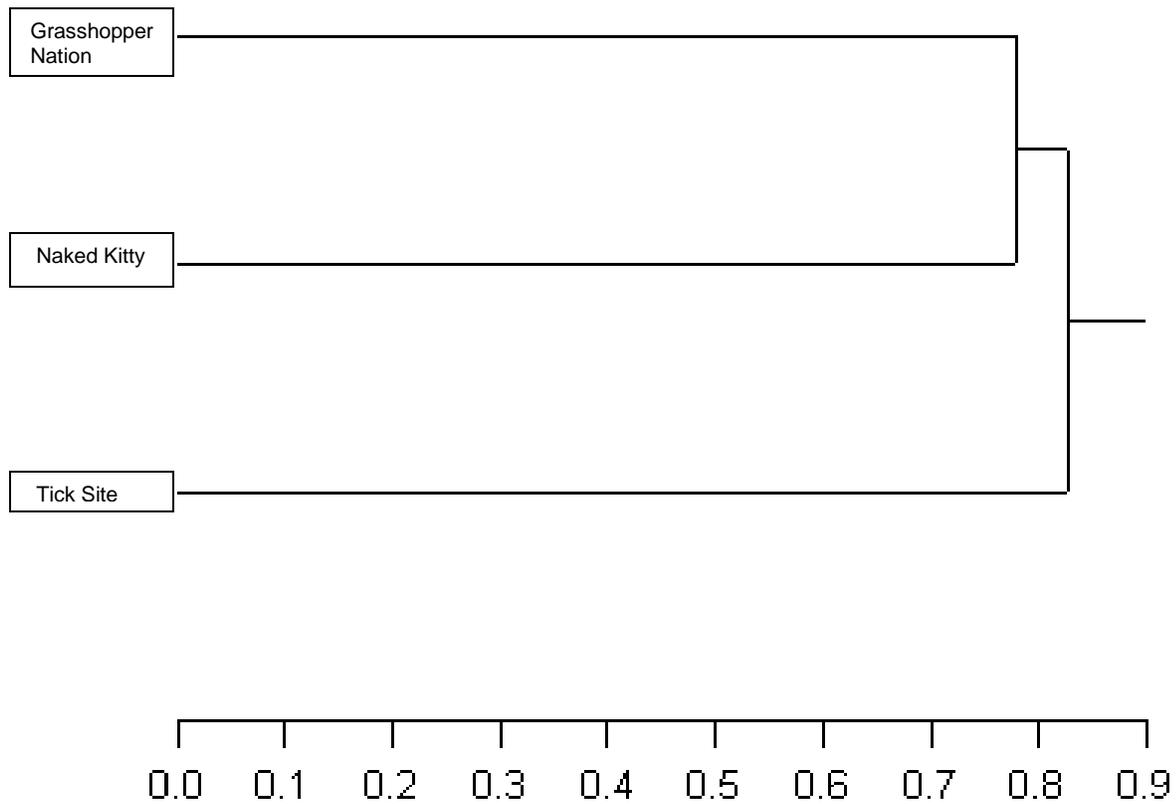
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

Fig. **1 Cluster analysis (Jaccard Index) showing percent similarity between sites based on total species richness of insects collected-**Grasshopper Nation and Naked Kitty sites were most similar (21.95%), while Grasshopper Nation and Tick sites were least similar (12.2%).

Tables

Table 1. Jaccard Index showing percent similarity of Trichoptera and Neuroptera species richness between sites

Sites Compared	j	r	J(%similarity)
NK/GN	9	41	0.219512195
NK/TS	8	46	0.173913043
GN/TS	5	41	0.12195122

Table 2. Jaccard Index showing percent similarity of woody plant species between sites

Sites Compared	j	r	J(% similar)
NK/GN	3	11	0.272727273
NK/TS	1	9	0.111111111
GN/TS	1	7	0.142857143

Appendix A-Grasshopper Nation

Insect Species Collected	Area
Arctiidae A	9551.89
Arctiidae/Ctenucha spp.	
Arctiidae/Haploa spp. A	Plant Diversity (H')
Arctiidae/Haploa spp. B	15598.15
Arctiidae/Hypoprepia fucosa	
Chrysopidae	Habitat Heterogeneity (H')
Geometridae/Geometrinae A	-2.303183007
Lasiocampidae/Malacasoma spp.	
Leptoceridae A	Proportional Diversity of Aquatic Habitats
Leptoceridae B	0.2
Leptoceridae/Leptocerus	
Noctuidae A	
Phryganeidae A	
Phryganeidae B	
Sphingidae A	
Unknown 13	
Unknown 14	
Unknown 15	
Unknown 2	
Unknown 27	
Unknown 28	

Appendix B-Naked Kitty

Insect Species Collected	Area
Arctiidae/Ctenucha spp.	15598.15
Arctiidae/Haploa spp. A	
Arctiidae/Haploa spp. B	Plant Diversity (H')
Arctiidae/Hypoprepia fucosa	-1.747944295
Chrysopidae	
Corydalidae/Chauliodes	Habitat Heterogeneity (H')
Geometridae A	-1.105816859
Geometridae/Cyclophora spp.	
Geometridae/Ennominae A	Proportional Diversity of Aquatic Habitats
Hydropsychidae	0.4
Lasiocampidae/Malacosoma disstria	
Leptoceridae/Leptocerus spp.	
Leptoceridae/Triaenodes spp.	
Noctuidae A	
Noctuidae B	
Noctuidae C	
Noctuidae D	
Noctuidae E	
Phryganeidae A	
Phryganeidae C	
Pterophoridae	
Unknown 16	
Unknown 17	
Unknown 18	
Unknown 19	
Unknown 2	
Unknown 4	
Unknown 6	
Unknown Trich A	

Appendix C- Tick Site

Insect Species Collected	Area
Arctiidae/Ctenucha spp.	4954.38
Arctiidae/Haploa spp. A	
Geometridae B	Plant Diversity (H')
Geometridae C	-1.729294984
Geometridae/Ennominae B	
Geometridae/Sicya spp.	Habitat Heterogeneity (H')
Geometridae/Xanthotype spp.	-1.626854046
Lasiocampidae/Malacasoma disstria	
Microlep A	Proportional Diversity of Aquatic Habitats
Microlep B	0.8
Noctuidae A	
Phryganeidae A	
Pterophoridae	
Sphingidae B	
Unknown 11	
Unknown 12	
Unknown 16	
Unknown 2	
Unknown 21	
Unknown 22	
Unknown 24	
Unknown 7	
Unknown 8	
Unknown 9	
Unknown Trich B	