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Arthropod Abundance and Diversity in Restored Longleaf Pine Savannas at Abita Creek
Flatwoods Preserve

A Thesis

To be submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Science
In Biological Sciences

By

Cara B. Nighohossian

B.A. Saint Louis University St. Louis, MO 2004

May 16, 2014

Dedication

I would like to dedicate this thesis to my family who have instilled me with a passion for learning and education and have supported me with their love, help, and understanding through all of my endeavors.

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I would like to thank my advisor Dr. Jerome Howard for all of his help and advice, his patience, and his encouragement throughout this master's project. I would also like to thank my committee members, Dr. Nicola Anthony and Dr. Chuck Bell who have been a source of great advice and inspiration. Thank you to The Nature Conservancy for allowing to use and sample from the Abita Creek Flatwoods Preserve. Thanks to Dr. Philip J. DeVries for lending me his copy of The Manual of Nearctic Diptera which was absolutely invaluable in identifying the many, many flies I had in my collection.

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Abstract

The objective of this study is to determine whether changes in arthropod community structure in restored longleaf pine savannas corresponds to differences in vegetation structure often associated with burn frequency. Longleaf pine savannas are fire-maintained ecosystems characteristic of the southeastern United States and have experienced severe declines (around 97%) since European settlement. Changes in fire regime have been instrumental in the declines. Restoration of these ecosystems has involved reinstatement of periodic burnings to promote and maintain vegetative characteristics of the savannas. This study investigates trends in arthropod communities from areas heavily invaded by hardwood shrubs against those dominated by longleaf pines and associated vegetation. These data suggest that herb-dominated sites have higher overall diversity. While overall abundance differences were not found, significant differences have been detected at the order and family level, indicating that vegetation structure and periodic burning are important factors in maintaining arthropod communities characteristic of these savannas.

Keywords: Longleaf pine savanna, arthropods, prescribed fire, vegetation structure

Introduction

Longleaf pine savannas

Longleaf pine (*Pinus palustris* Mill.) savannas are characteristic of the lower coastal plains of the southeastern United States. These savannas, once a ubiquitous part of the landscape, have become a severely diminished and endangered ecosystem. Prior to European settlement, this ecosystem historically extended from Virginia, south to Florida, and west to Texas (Barnett 2013) and spanned approximately 37 million hectares (Aschenbach *et al.* 2010; Frost 1993). Now, only 1.3 million hectares remain and the land that does remain is often patchy and degraded in large part due to human-mediated changes in historic fire regimes (Barnett 2013; Aschenbach *et al.* 2010; Gilliam & Platt 1999).

European colonization of the U.S. led to rapid and dramatic change and/or reduction in native ecosystems. In the Southeastern U.S., declines in longleaf pine savannas, have been so steep that they have become one of the most endangered ecosystems in the country (Aschenbach *et al.* 2010). Approximately 97% of this ecosystem has been decimated by logging, conversion to agricultural lands, urbanization, and fire suppression (Barnett 2013; Aschenbach *et al.* 2010).

Such heavy losses of habitat coupled with the degraded nature of the remaining patches have negatively impacted many organisms that rely on this ecosystem for survival. Examples include a broad range of rare and endangered plants, as well vertebrate species such as the red-cockaded woodpecker, the Louisiana pine snake, the gopher tortoise, and the southern fox squirrel (Aschenbach *et al.* 2010; Van Lear *et al.*

2005; Barnett 2013). The decline in longleaf pine savannas coupled with changes in fire regime have had and will continue to have severe consequences for these at-risk plants and animals as well as a variety of others that rely primarily on this ecosystem for survival.

Longleaf pine savanna characteristics

Longleaf pine (*Pinus palustris*) savannas are fire-structured habitats and typically have an open, park-like vista structure. They are characterized by intermittent trees in the overstory (primarily longleaf pines), a sparse midstory, and a dense herbaceous groundcover made up of wide diversity of plants (Aschenbach *et al.* 2010). These savannas range from xeric sandhills to seasonal wetlands (Aschenbach *et al.* 2010). Longleaf pines and the component grasses and forbs that comprise the herb-layer tend to be shade-intolerant, fire-dependent plants that thrive in the savanna setting with periodic burning. In the absence of periodic fires, however, other hardwoods often out-compete them for resources. Longleaf pines are a long-lived species with an extensive grass stage that lasts several years (Barnett 2013). This lengthy grass stage makes them vulnerable to competition from other woody plant species (Barnett 2013). However, the grass stage is also highly fire-tolerant and thrives in the presence of periodic burning which controls other woody plant species.

Fire Suppression

Although timber harvesting and conversion of longleaf pine savannas into agricultural land or urban areas have all played important roles in the declines of this ecosystem type, fire suppression has been a major factor in savanna loss and continues to be a cause for concern and potential ecosystem loss in the tracts of longleaf pine savanna that remain today (Steen 2013). Fire has proven to be an important evolutionary driver of ecosystem adaptation throughout history (Nowacki & Abrams 2008). Naturally occurring fires (e.g. those caused by lightning), in conjunction with fires started by humans (i.e. burnings implemented by Native Americans before European settlement), have resulted in a plethora of fire-adapted species that depend on regular burning for establishment and/or persistence (Nowacki & Abrams 2008). Since the heavy implementation of fire suppression strategies beginning in the 1920's, fire-dependent plant species that live on these savannas are being out-competed by fire-sensitive species that have taken root and expanded their ranges (Nowacki & Abrams 2008; Barnett 2013).

Without periodic fire, other woody trees and shrubs facilitate each other in a positive feedback loop in which they alter environmental conditions to promote further establishment and reduce conditions required for persistence of savanna plants (Nowacki & Abrams 2008). For instance, they reduce sunlight and soil resources to the plants that are not shade tolerant and need the nutrient cycling associated with burning (Aschenbach *et al.* 2010). As longleaf pine recruitment fails and the herbaceous plants are shaded out, the pine needles and ground layer that provide fuel for the low-

intensity burns necessary to maintain the ecosystem are also lost, thereby reducing fire frequency and reinforcing the dominance of woody plants (Steen 2013).

In addition to excluding woody species that would otherwise encroach into the ecosystem, periodic fires, which are fueled by the herbaceous ground layer and the fallen longleaf pine needles, serve several other purposes (Barnett 2013; Steen 2013). They stimulate production of seeds by native species and release nutrients back into soils that are oftentimes nutrient-poor. By preventing encroachment of woody species, fires may also promote greater longleaf pine recruitment since longleaf pines tend to be more sensitive to competition than most other pines of the Southern U.S. (Loudermilk *et al.* 2011; Vasconcelos 2009; Aschenbach *et al.* 2010; Barnett 2013). Burning is therefore an integral part of maintaining the biological diversity that longleaf pine savannas harbor.

Restoration

As humans continue to damage and change ecosystems, attempts to restore ecosystems and their functions have become increasingly common in an effort to stem loss of important ecosystem services and reduce/reverse pervasive trends of biodiversity loss (Burkhalter 2013; Bullock *et al.* 2011). Reestablishing biodiversity, community structure, and ecosystem processes are all important aspects of trying to restore an area that has been impacted significantly by anthropogenic forces (Burkhalter 2013). Because of the once widespread nature of longleaf pine savannas combined with

their high rates of biodiversity and large numbers of rare species, they have become a popular ecosystem for conservation and restoration attempts (Aschenbach *et al.* 2010).

Restoration projects often focus on reintroduction of or fostering native vegetation, with the assumption that this strategy is sufficient to restore both ecosystem function and other components of the habitat including landscape structure, fauna, etc. (Burkhalter 2013). Strategies for restoring longleaf pine savannas follow the vegetation restoration model. Methods include cutting down or thinning of competing hardwood vegetation (shrubs, other pine species such as slash or loblolly pine, and other trees), replanting of longleaf pine seedlings, and reintroduction of prescribed burning to promote growth of desirable natives. Decisions to restore degraded sites are often based on the degree of degradation and the likelihood that restoration can be successful. For example, a site that was used extensively as farmland may no longer contain a viable native seed bank. Tracts of land with remnant or neighboring populations where the land has not been heavily modified are better candidates for restoration.

Studies on restored mine pits in Australia and *Spartina* marshes in New Jersey have indicated that vegetative structure is a key component in restoring native arthropod assemblages to desired reference conditions (Moir *et al.* 2005; Gratton & Denno 2005). However, it is important to note that dispersal capabilities can have substantial impacts on the restoration trajectory of arthropods for these communities, possibly allowing more mobile taxa to colonize more quickly than those with more limited dispersal capabilities (Moir *et al.* 2005). Despite evidence that vegetation

structure can significantly affect overall arthropod diversity and community composition, there is little information on how vegetation structure in longleaf pine savannas affects arthropod assemblages on a wider scale. Most studies thus far have focused on the effects of vegetation structure on soil-litter arthropods and other specific taxa following fire, rather than on the larger community composition of arthropods in these ecosystems.

Arthropods as Indicators of Restoration Success

Restoration success is commonly assessed by considering vegetative structure of restored sites, but restoration of native fauna is often a preeminent goal and some taxa may be utilized to evaluate restoration as well (Longcore 2003). Arthropods are considered by many to be a useful indicator because they have short generation times, large population sizes, they are relatively easy to collect, and they fill many roles within an environment including the roles of pollinator, decomposer, predator and prey, so significant amounts of information regarding the environment can be garnered fairly easily by collecting insects over relatively short periods of time (Longcore 2003; Burkhalter 2013).

Several studies have demonstrated relationships between vegetation structure and arthropod community observations (Ulyshen *et al.* 2009; Hanula *et al.* 2011; Hanula *et al.* 2011). Collins *et al.* (2002) was able to link an increase in arthropod density in longleaf pine ecosystems with decreasing hardwood mid-story associated with infrequent burning. In that study, they demonstrated that open pine stands contained

significantly higher densities of arthropods than those stands clogged with mid-story hardwoods and indicated that lack of ground vegetation in habitats dominated by a hardwood midstory was responsible for this trend. Other studies suggest that absence or removal of understory shrubs in savannas typically dominated by an herbaceous understory, increases biomass and abundance of arthropods (Ulyshen *et al.* 2010; Hartley *et al.* 2010).

Trap Catch

Trap type is an important determinant of what types of arthropods are caught in an environment. The types of traps used for arthropod sampling are important and will dictate the amount and type of data a researcher can collect. If one is trying to determine overall characteristics of an arthropod community or trying to sample a particular taxonomic group, it is key to choose the right type of traps for the purpose. Ground dwelling arthropods are often caught in pitfall traps buried in the soil, whereas pollinators and flying insects are often attracted to particular colors and scents that might correspond with flowers they visit (Campbell & Hanula 2007). Therefore, gaining an accurate depiction of community structure is dependent on using the right kind of traps to capture the arthropods one would like to collect. In a study of overall community, several types of traps should be employed to ensure adequate sampling of various arthropod taxa that will respond differently to each.

Research objectives

The objective of this study was to determine how insect community structure in restored longleaf pine savannas is affected by vegetation structure. Because the sites sampled in this study had similar burn history but differing vegetative characteristics, effects of relatively recent changes in vegetation structure in a fire-dependent community could be assessed. This study was completed at the Abita Creek Flatwoods Preserve (ACFP). My study compared arthropod community structure in areas that had been heavily invaded by hardwood shrubs against similarly burned areas that were primarily dominated by longleaf pines and an herbaceous understory. While the literature suggests that arthropod numbers and diversity are negatively correlated with increased shrub cover, most studies focus on single insect orders. This study will attempt to create a more complete picture of the differences at the order and family level in arthropod communities inhabiting compartments heavily invaded with shrub-cover versus those with in areas primarily consisting of the herbaceous ground-cover and sparse overstory that are characteristic of traditional longleaf pine savannas.

A secondary objective is to evaluate the effectiveness of trap types and multiple trap colors for attracting particular orders and families of arthropods. Assessing the relative effectiveness of the different traps employed in the study may be relevant for future studies attempting to survey particular arthropod groups. To elucidate which traps are best for which groups, I wanted to compare different types of traps and specimens they collected.

Methods

Study Site

This study was conducted at the Abita Creek Flatwoods Preserve, a 950-acre conservation site (Figure 1) owned by The Nature Conservancy, in St. Tammany Parish, Louisiana, approximately five miles from Abita Springs, Louisiana. The preserve is situated in the Prairie Terrace geologic formation. Its location, variety of soil types, geology, and hydrological conditions provide habitat for a diverse community of plants and animals. Three hundred plants species, including twenty species of rare plants (e.g. parrot pitcher plant, spoon-leaved sundew, bog flame-flower, and the endangered Louisiana quillwort) and several uncommon animal species such as the Bachman's Sparrow and the barking tree frog, live in this relatively small tract of protected land.

The Nature Conservancy (TNC) acquired the land in 1996 because, despite logging in the 20th century, fire suppression and subsequent colonization by slash pines and other hardwoods and shrubs, the native vegetation remained relatively intact. Since then, TNC has been actively engaged in restoring indigenous pine savanna habitat by clearing areas that were formerly dominated by longleaf pine by the use of controlled burns and replanting longleaf pine seedlings. TNC carries out prescribed burning on designated units regularly to maintain the open structure of the longleaf pine savannas (Figure 1).

In addition to the longleaf pine savanna, the preserve also contains slash pine-pond cypress forest, eastern hillside seepage bogs, bayhead forests, and river floodplain

forest (Fig.2). As well as providing habitat for many rare species, this wetland habitat is an important watershed resource for the surrounding communities.

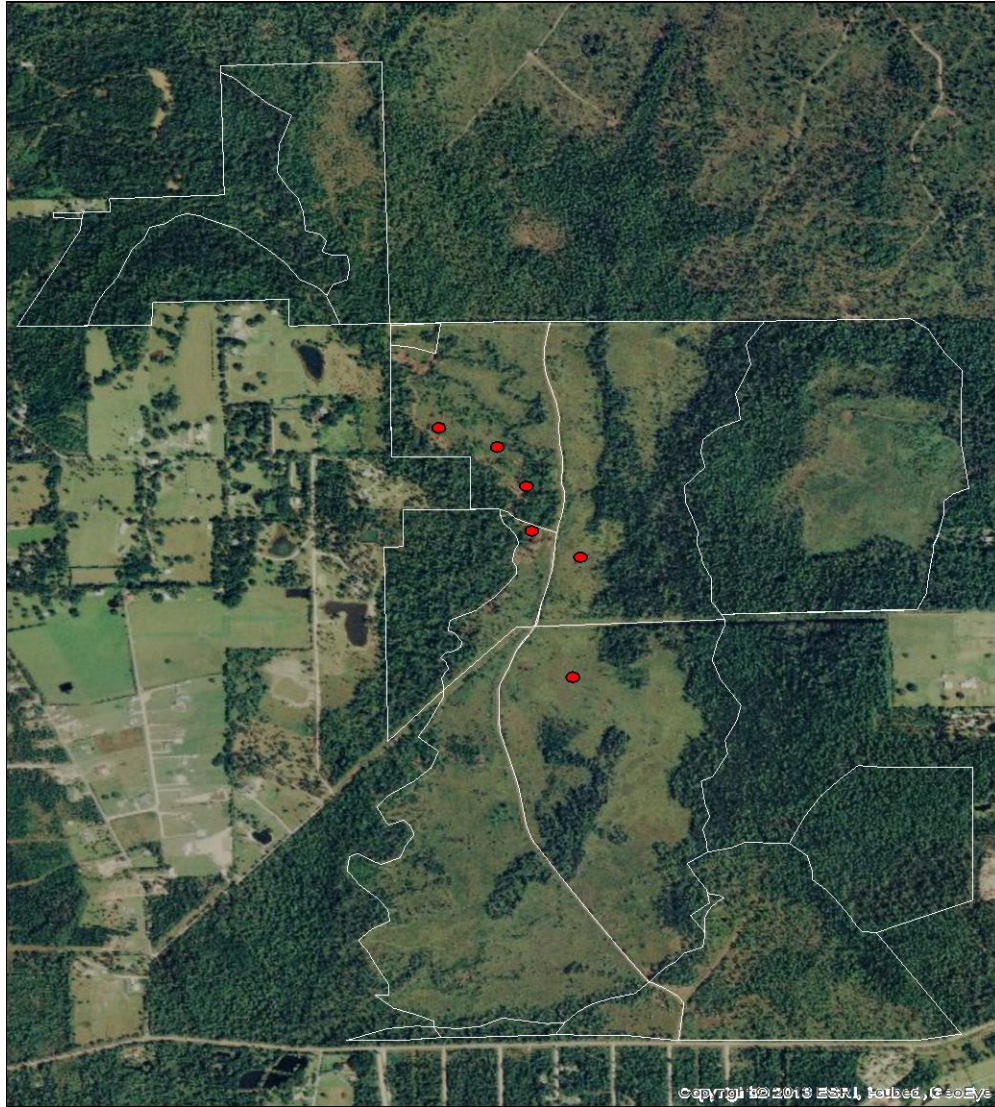


Figure 1. Map of the Abita Creek Flatwoods Preserve showing burn units and approximate sampling sites.

ABITA CREEK FLATWOODS PRESERVE MITIGATION BANK UNIT NATURAL COMMUNITY TYPES

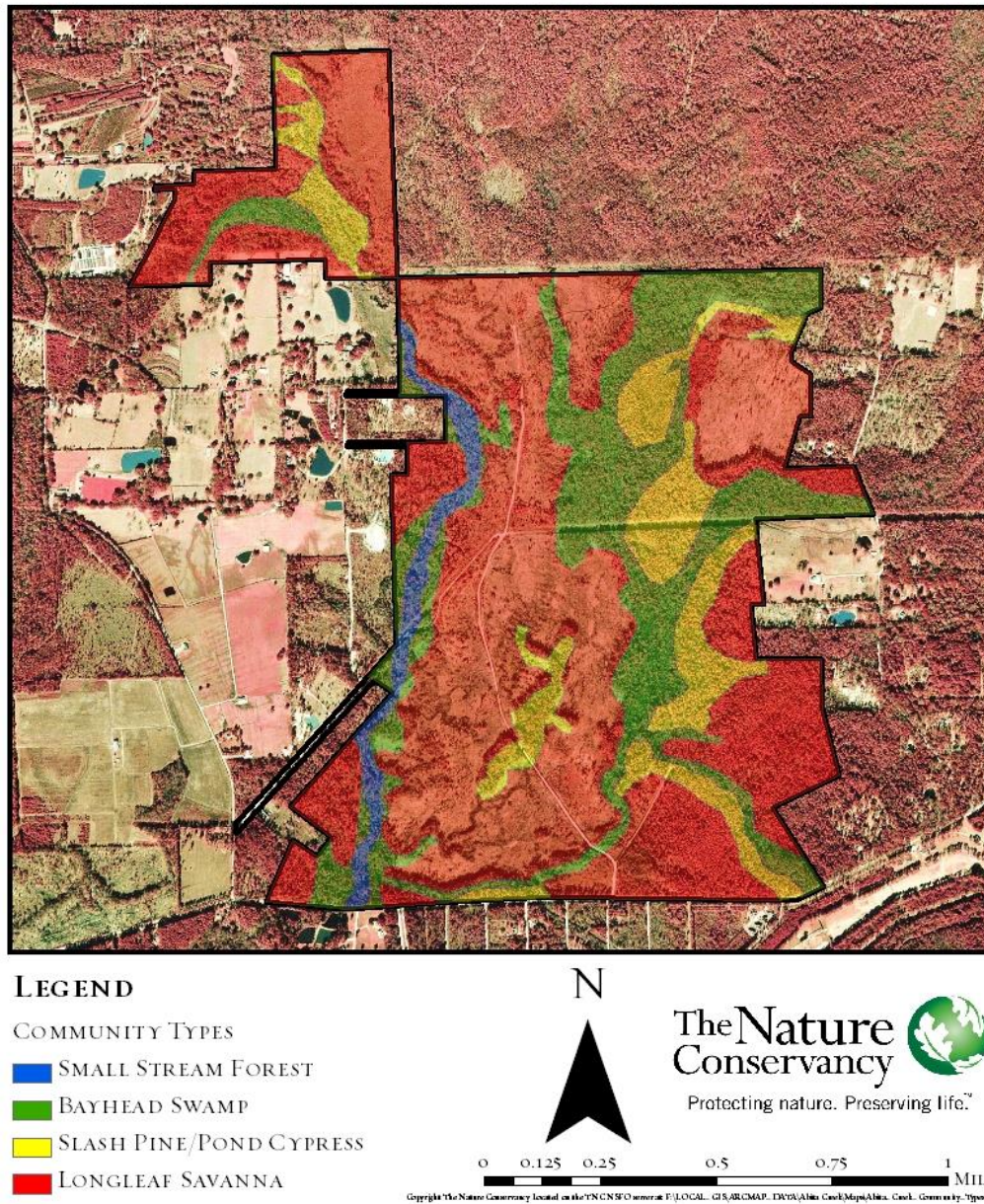


Figure 2. Map of the Abita Creek Flatwoods Preserve showing community types.

Sampling Design

To assess the differences between arthropod communities in shrub-dominated plots versus plots dominated by grasses and forbs, I chose six sites at the Abita Creek

Flatwoods Preserve (Fig.1) that had all had a similar burn history (the most recent burn on the sites had been conducted in 2009 prior to the study); 3 sites were dominated by the herbaceous grass characteristic of traditional longleaf pine savannas and 3 sites were dominated by shrubby undergrowth, predominately titi (*Cyrilla racemiflora*).

After careful review of available plots throughout the preserve, the six sites were chosen carefully to be representative of the vegetative structure found within the preserve. Shrub-dominated sites were set up within larger areas dominated by shrub so as to decrease possible crossover from herb-dominated areas. Herbaceous sites were established within large areas of pine savanna. All plots were circular and 5 m in radius, with insect traps placed within two meters of the center as vegetation on the plot permitted.

Traps

In each plot, I haphazardly distributed three flight interception traps and two pitfall traps. The flight interception traps were constructed using one meter of 4-gauge wire and white, yellow, and blue plastic bowls purchased from a party supply store. I twisted each piece of wire into a stem that I could bury into the ground and a circular portion that would suspend the colored bowls in air. 4-gauge wire was required to support the weight of the bowls when filled with liquid. The pitfall traps were assembled digging a hole large enough that an 8-cm diameter steel can would fit inside flush with the ground. This can prevented the hole from collapsing in or changing shape

throughout my sampling period. For every collection period, nine-ounce plastic cups were placed within the steel cans.

Arthropod Sampling

Twice a month, from July 2011 until July 2012, the traps were set to collect for 24 hours (except November 2011 which only had one sampling period due to weather complications). The traps were set primarily on clear days when possible, in order to maximize the number of arthropods that would encounter the traps. To set the traps, I put a few drops of dish soap in each and half-filled the trap with water to disperse the soap. The soap reduces the surface tension of the water so that arthropods that come into contact with the solution are unable to escape the trap. Filling traps halfway was enough to avoid evaporation of the solution during the sample period and keep the bowls at a weight that was supportable by the wire suspension post. In addition, clothespins were employed to attach the bowls to the wire posts to prevent the bowls from tipping over in windy conditions.

Traps were left open for approximately 24 hours and the contents were collected in labeled Ziploc bags and returned to the lab. The arthropods were then removed from the soapy water solution and placed in labeled cups with a 70% ethanol solution to prevent decay while awaiting identification.

Arthropods were identified by morphological characters using a microscope and a variety of field guides and dichotomous keys (Triplehorn & Johnson 2005; Borror & White 1970; White 1983; Milne & Milne 1980; Eaton & Kaufman 2007; Evans 2008;

McAlpine 1981; McAlpine 1987). All arthropods were identified to order. Most insect orders were identified to family with the exceptions of Thysanoptera and Collembola which were only classified to order.

Statistical Analyses

All statistical analyses were performed using Systat Version 11 (SYSTAT Software Inc., Richmond,CA).

Richness Measures

I calculated family richness as well as the Shannon diversity index (H) and the Shannon equitability index (E_H) for each sampling unit. Shannon diversity index (H) is often used in ecological studies to quantify diversity in a sample or population (equation 1). Higher values of H correspond with higher levels of diversity. The Shannon equitability index (E_H) measures evenness of a sample or population (equation 2). Values range from 0 to 1 where 0 signals that one taxonomic group is overtaking the sample and 1 is complete evenness. After calculating family richness, H and E_H , I ran two-sample t-tests to compare these values between the shrub-covered (covered) and grass-dominated (open) sites.

$$H = - \sum_{i=1}^S p_i \ln p_i$$

Equation 1: Shannon diversity index

$$E_{\mathcal{H}} = H / H_{\max} = H / \ln S$$

Equation 2: Shannon equitability index

Abundance of Orders and Families

To determine if there were overall differences in arthropod community composition between shrub and herb-dominated sites, I analyzed the data at the level of total abundance, abundance of orders, and where identifications were possible, abundance of families. Shapiro-Wilks tests for normality were used to test for deviations from normality in the observation data and the order data. Abundance was calculated per site and that data was analyzed using a two-sample t-test to compare total abundance in covered versus open sites. Two-sample t-tests were then employed to assess any differences between the sites at the level of order. Differences in abundance at the family level were analyzed using two-sample t-tests.

To ensure that significant ecological patterns were not obscured by analyses that focused on a large number of families with relatively small numbers of individuals, I also categorized families in terms of functional group, where known, in order to analyze the representation of trophic guilds by vegetation structure. I pooled families known to be predominantly characterized by six trophic patterns: Predators, flower visitors, herbivores, parasites, wood-inhabiting beetles, and detritivores. Groups with a mixture of trophic habits were excluded from the analysis of functional groups. I used MANOVA to compare abundance patterns between herb and shrub dominated sites for the five groups mentioned above. In this analysis, I also separately included Formicidae and Dolichopodidae, two families sampled in large numbers in this study. They were

not included within the functional groups because their numbers may have overwhelmed other patterns in the data.

Seasonal Trends

In addition to variation in numbers by burn treatment, I also analyzed the data to check for seasonal trends within the herb-dominated and shrub-dominated plots. Due to the patchy occurrence of insect taxa in individual sample dates, samples were pooled into summer (July-August), fall (September-November), winter (December-February), and spring (March-May) for analysis. Mean values for total abundance, abundance by order, and abundance by family were calculated by summing total samples across season and dividing by the number of sample dates. For winter and spring, collections were taken 6 times (twice per month). In the fall sample, only one sample was taken for November due to inclement weather and the summer sample only had 3 sample dates because of a burn that was implemented by TNC in June 2012. Data was collected for June and July 2012, but that data was not comparable to rest of the collected data and was excluded from analysis of diversity, abundance, and seasonal trends. After calculation of seasonal abundance numbers, a Repeated Measures ANOVA (RMA) was used to compare herb-dominated and shrub dominated sites using burn treatment as the among-subjects effect and season as the within-subjects effects. One-way ANOVAs with Tukey's HSD post-hoc tests were then run to evaluate differences by season. RMA were then run for seasonal differences by order. When the RMA produced statistically significant results, I tested for differences between vegetation types or among seasons

using one-way ANOVAs with Tukey's HSD post-hoc tests. One-way ANOVAs with Tukey's HSD post-hoc tests were used to analyze data at the family level.

Trap type catch

I also compared trap success at the order and family level. I calculated totals for the white, blue, and yellow bowls (I excluded the pitfall traps because they are not strictly comparable based on the type of arthropods they sample). First, I ran a two-way ANOVA to check for differences between site type and number of specimens collected by each bowl color. Two-way ANOVAs were used to look at burn and bowl color. The data was then analyzed by order using two-sample t-tests to test for differences between the bowl colors. Lastly, trap collection success was assessed by family using one-way ANOVAs and Tukey's HSD post-hoc analysis. When analyzing trap usefulness by family, I included pitfall traps because at this level of taxonomic analysis, it was illuminating to parse out which families within the orders were caught with each type of trap.

Results

Diversity measures

I collected a total of 9038 arthropods, including 8656 insects from 117 families were collected from sites surveyed from July 2011 until July 2012. The preserve was burned extensively (including five of my six sites) in June 2012, so I excluded samples collected after May 2012 from the analysis of richness and diversity measures as well as

the vegetation-based analyses and seasonal trends, because burning may have affected the collectability of arthropods. For these analyses, I used only the 6152 arthropods trapped between July 2011 and May 2012. T-tests revealed that herb-dominated sites had significantly greater total Shannon diversity over the course of the study than the shrub-dominated sites ($t=-3.34, p=0.029$; Table 1). Neither total family-level richness nor equitability measures differed significantly among shrub and herb-dominated sites (Table 1).

Table 1. Comparison of total family-level richness, Shannon-diversity (H) and equitability (E_H) for shrub- and herb-dominated sites at Abita Creek Flatwoods Preserve.

	Shrub-Dominated	Herb-Dominated	t	P
Richness	61.67±2.517	63.67±2.517	-0.97	0.386
H	2.66±0.148	2.98±0.067	-3.34	0.029*
E_H	0.65±0.039	0.72±0.022	-2.68	0.055

Abundance of Orders and Families

From July 2011 until May 2012, a two-sample t-test detected no difference ($p=.631$) in overall arthropod abundance between the shrub-dominated and herb-dominated sites. All orders of arthropods with more than 50 individuals were analyzed for abundance between the two site types using two-sample t-tests. Coleoptera, Hymenoptera, Hemiptera, Collembola, Thysanoptera, Araneae, Lepidoptera, and Acari demonstrated no significant difference between site type, although Araneae was

marginally significant ($p=0.078$). Diptera was the only order that showed a significant difference in abundance between site types ($p=0.046$); more specimens were caught in the shrub-dominated landscape.

Table 2. Comparison of total abundance and abundance by order for shrub- and herb-dominated sites at Abita Creek Flatwoods Preserve.

	Shrub-Dominated	Herb-Dominated	t	P
Totals	986.00±161.53	1064.67±206.52	-0.520	0.631
Acari	13.33±3.21	34.67±23.76	-1.541	0.198
Araneae	21.00±2.00	33.67±9.07	-2.361	0.078
Coleoptera	41.33±11.59	59.00±19.92	-1.328	0.276
Diptera	315.00±30.27	260.33±13.58	2.854	0.046*
Collembola	215.33±71.16	169.67±37.07	0.986	0.380
Hemiptera	52.00±7.21	90.00±32.74	-1.963	0.121
Hymenoptera	92.33±48.42	106.33±56.13	-0.327	0.760
Lepidoptera	8.00±0.00	10.67±2.52	-1.835	0.140
Thysanoptera	216.67±80.93	288.33±122.35	-0.846	0.445

The abundance of individual families was analyzed for those with sufficient counts to permit statistical analysis (Table3). Within Coleoptera, only Lampyridae demonstrated a significant difference between site type with more individuals found in the herb-dominated areas ($p=0.013$). In Diptera, two families, Anthomyiidae and Ephydriidae, had significantly more individuals in the herb-dominated sites ($p=0.004$ and $p=0.002$ respectively), whereas the shrub-dominated sites supported significantly more

Calliphoridae ($p=0.023$), Dolichopodidae ($p=0.017$), and Mycetophilidae ($p=0.033$).

Phorids occurred with greater frequency in shrub-dominated sites (9.33 ± 4.04 vs. 2.33 ± 2.08), while the Chironomids appeared more frequently in herb-dominated sites (11.00 ± 6.00 vs. 22.00 ± 4.58), but in neither case was this difference significant ($p=0.056$ and $p=0.065$ respectively). Among the Hymenoptera, Halictidae was the only family to demonstrate a significant difference between treatments, with more individuals caught in shrub-dominated areas ($p=0.024$). Of the families in Hemiptera, aphids were significantly more abundant in herb-covered sites ($p=0.028$). The only family of Lepidoptera analyzed, Hesperidae, was non-significant for this measure.

Table 3. Comparison of abundance by family for shrub- and herb-dominated sites at Abita Creek Flatwoods Preserve.

	Shrub-Dominated	Herb-Dominated	t	P
<u>COLEOPTERA</u>				
Buprestidae	3.67±1.53	2.67±1.16	0.905	0.417
Carabidae	1.67±1.16	0.67±1.16	1.061	0.349
Chrysomelidae	1.67±0.58	1.33±0.58	0.707	0.519
Curculionidae	1.00±1.73	2.33±0.58	-1.265	0.275
Lampyridae	0.33±0.58	2.33±0.58	-4.243	0.013*
Mordellidae	19.00±8.72	39.67±27.65	-1.235	0.284
Scolytidae	3.00±3.46	3.00±4.36	0.00	1.000
Staphylinidae	1.00±0.00	3.33±1.16	-----	-----

Table 3. Comparison of abundance by family for shrub- and herb-dominated sites at Abita Creek Flatwoods Preserve.

	Shrub-Dominated	Herb-Dominated	t	P
<u>DIPTERA</u>				
Anthomyiidae	0.68±1.16	10.33±2.517	-6.047	0.004*
Asilidae	2.00±2.00	0.33±0.58	1.387	0.238
Bibionidae	0.68±1.16	1.67±0.58	-1.342	0.251
Calliophoridae	3.33±0.58	0.67±1.16	3.578	0.023*
Cecidomyiidae	8.67±3.22	6.00±3.46	0.977	0.384
Ceratopogonidae	5.67±2.08	5.33±5.86	0.093	0.930
Chironomidae	11.00±6.00	22.00±4.58	-2.524	0.065
Chloropidae	3.00±1.73	2.67±2.52	0.189	0.859
Culicidae	1.33±2.31	1.00±1.00	0.229	0.830
Dolichopodidae	193.00±26.15	123.67±15.18	3.971	0.017*
Drosophilidae	10.00±1.73	7.00±5.00	0.982	0.382
Ephydridae	0.33±0.58	5.00±1.00	-7.000	0.002*
Muscidae	5.33±1.53	4.67±2.08	0.680	0.678
Mycetophilidae	5.33±2.08	1.33±0.58	3.207	0.033*
Phoridae	9.33±4.04	2.33±2.08	2.667	0.056
Sarcophagidae	14.00±6.25	10.67±1.53	0.898	0.420
Scathophagidae	0.67±0.58	3.67±3.79	-1.357	0.246
Scatoposidae	1.67±1.53	1.33±1.53	0.267	0.802

Table 3. Comparison of abundance by family for shrub- and herb-dominated sites at Abita Creek Flatwoods Preserve.

	Shrub-Dominated	Herb-Dominated	t	P
Sciaridae	14.67±7.02	10.00±1.73	1.117	0.326
Sphaeroceridae	2.33±2.31	5.33±1.53	-1.877	0.134
Syrphidae	5.00±1.73	11.33±8.96	-1.202	0.296
Tabanidae	2.00±1.00	1.67±0.58	0.500	0.643
Tachinidae	1.00±1.00	2.67±2.52	-1.066	0.346
<u>HEMIPTERA</u>				
Aphidae	3.00±1.73	33.67±15.63	-3.377	0.028*
Cercopidae	1.33±0.58	5.33±2.52	-2.683	0.055
Cicadellidae	33.33±10.97	40.33±15.18	-0.647	0.553
Coccoidea	1.33±0.58	4.00±2.65	-1.706	0.163
Psyllidae	2.33±3.22	1.33±1.53	0.487	0.652
<u>HYMENOPTERA</u>				
Apidae	6.33±4.04	3.00±2.08	1.143	0.317
Diapriidae	3.67±2.08	2.67±3.06	0.469	0.664
Encyrtidae	1.67±1.53	2.67±1.53	-0.802	0.468
Eulophidae	2.00±2.65	3.67±2.08	-0.857	0.440
Formicidae	56.67±51.59	70.00±53.93	-0.309	0.772
Halictidae	2.33±0.58	0.67±0.58	3.536	0.024*
Mymaridae	3.33±2.89	6.67±2.89	-1.414	0.230

Table 3. Comparison of abundance by family for shrub- and herb-dominated sites at Abita Creek Flatwoods Preserve.

	Shrub-Dominated	Herb-Dominated	t	P
Platygasteridae	1.67±1.53	2.33±2.31	-0.417	0.698
Scelionidae	4.67±1.53	4.67±2.52	0.000	1.000
<u>LEPIDOPTERA</u>				
Hesperiidae	6.33±1.16	5.67±2.31	0.447	0.678

Functional Groups

Combining families into trophic functional groups revealed patterns not apparent from considering family-level data alone (Table 4). When the data was separated and compared by functional groups, MANOVA revealed significantly more predators ($p < 0.001$), flower visitors ($p = 0.019$), herbivores ($p = 0.004$), and parasites ($p = 0.001$) in herb-dominated sites (Table 5). Wood-boring beetles and detritivores were significantly more common in shrub-dominated areas ($p = 0.045$ and $p < 0.001$ respectively) (Table 5).

Table 4. Abundance of functional groups at three shrub- and three herb-dominated sites at Abita Creek Flatwoods Preserve.

Sample Site	Predators	Flower Visitors	Herbivores	Parasites	Borers	Detritivores
Shrub1	2	38	63	24	6	56
Shrub2	4	54	57	17	12	68
Shrub3	3	40	50	19	4	63
Herb1	6	26	69	23	11	41
Herb2	5	102	143	34	3	49
Herb3	8	86	120	29	4	50

Table 5. Multivariate analysis of variance table for functional guild comparisons between shrub- and herb-dominated sites.

Guild	Sum of Squares	df	Mean-Square	F	P
Predators	7104.33	2	3552.17	156.71	<0.001*
Error	90.67	4	22.67		
Flower Vis.	21073.33	2	10536.67	12.53	0.019*
Error	3362.67	4	840.67		
Herbivores	46374.67	2	23187.33	31.41	0.004*
Error	2953.33	4	738.33		
Parasites	3665.33	2	1832.67	84.59	0.001*
Error	86.67	4	21.67		
Boring	269.33	2	134.67	7.41	0.045*
Error	72.67	4	18.17		
Detritivores	18189.67	2	9094.83	299.83	<0.001*
Error	121.33	4	30.33		

Seasonal Trends

With RMA, I found there was a significant effect of season on total arthropod abundance ($p < 0.001$). No significant difference was detected between different vegetation types ($p = 0.252$) or in the interaction between vegetation cover-type and season ($p = 0.860$), meaning that patterns of change over time did not differ significantly between shrub- and herb-dominated sites (Table 6).

Table 6. Repeated Measures Analysis of Variance table for seasonal abundance and vegetation type.

	Sum of Squares	df	Mean-Square	F-ratio	P
Vegetation Type	708.144	1	708.144	1.791	0.252
Error	1581.547	4	395.387		
Season	27295.224	3	9098.408	47.338	<0.001*
Vegetation*Season	143.674	3	47.891	0.249	0.860
Error	2306.426	12	192.202		

After the overall RMA, I ran two-way ANOVAs on each pair of seasons to evaluate differences in abundance and season*vegetation effect. I found significant differences in arthropod abundance between summer and fall ($p=0.003$), summer and spring ($p<0.001$), fall and spring ($p<0.001$), winter and spring ($p<0.001$), and fall and winter ($p=0.035$). Spring and fall had significantly higher arthropod counts than summer and winter. Spring had a significantly higher abundance of arthropods than any other season (Fig. 3). In all comparisons, I found no significant difference in seasonal changes in abundance between shrub-dominated vs. herb-dominated sites.

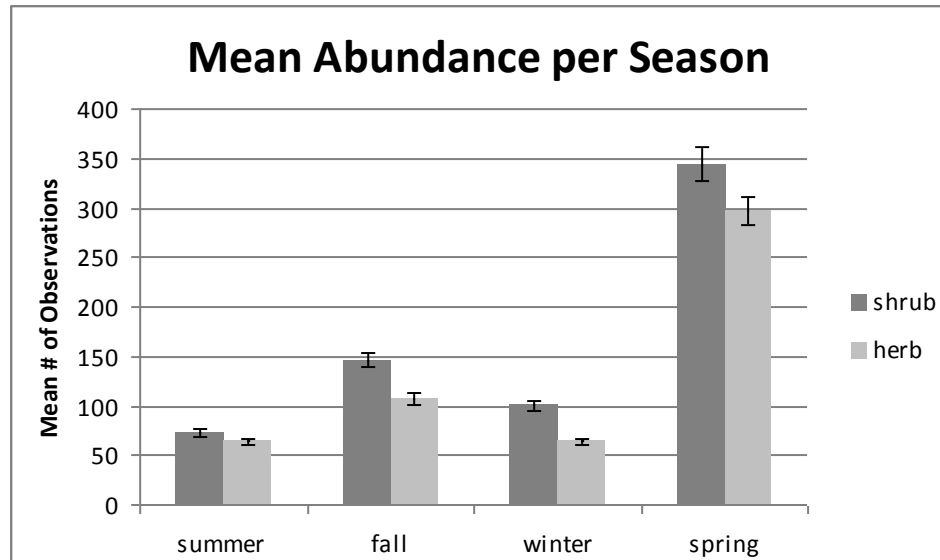


Figure 3. Mean number observations of arthropods per season/per vegetation type.

Using RMA, significant differences in seasonal abundances were found for every order except Collembola ($p=0.364$) (Fig. 4). With Tukey HSD Post-Hoc tests, I determined that Hemipterans were caught significantly more frequently in the spring than in fall ($p=0.019$) or winter ($p=0.002$) (Fig.5). Coleopterans were caught significantly more frequently in the summer than in the fall ($p=0.005$) or winter ($p=0.001$) (Fig.6). Diptera were trapped significantly more often in the spring ($p<0.001$ against all other seasons) (Fig. 7). Hymenopterans were sampled significantly more often in spring than in fall ($p=0.029$) or winter ($p=0.012$) (Fig.8). Significantly lower numbers of Lepidoptera were caught in winter than in fall ($p=0.002$) or spring ($p=0.035$) (Fig. 9). Abundance of Thysanoptera was significantly greater in spring than in any other season (summer, $p=0.001$; fall, 0.002 ;winter, $p=<0.001$) (Fig.10). Araneae were captured least often in winter, but significantly different only from summer ($p=0.031$) (Fig.11).

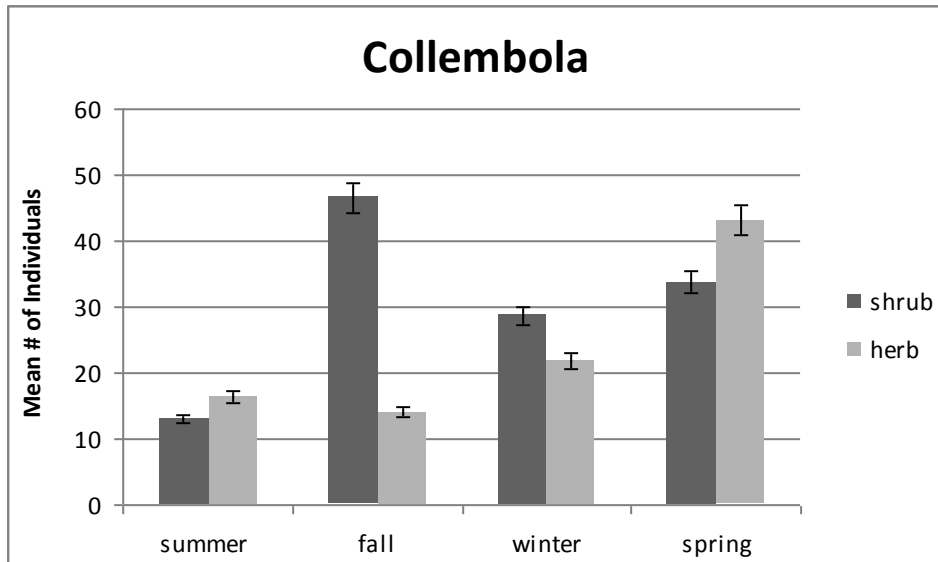


Figure 4. Mean number observations of Collembola per season/per vegetation type.

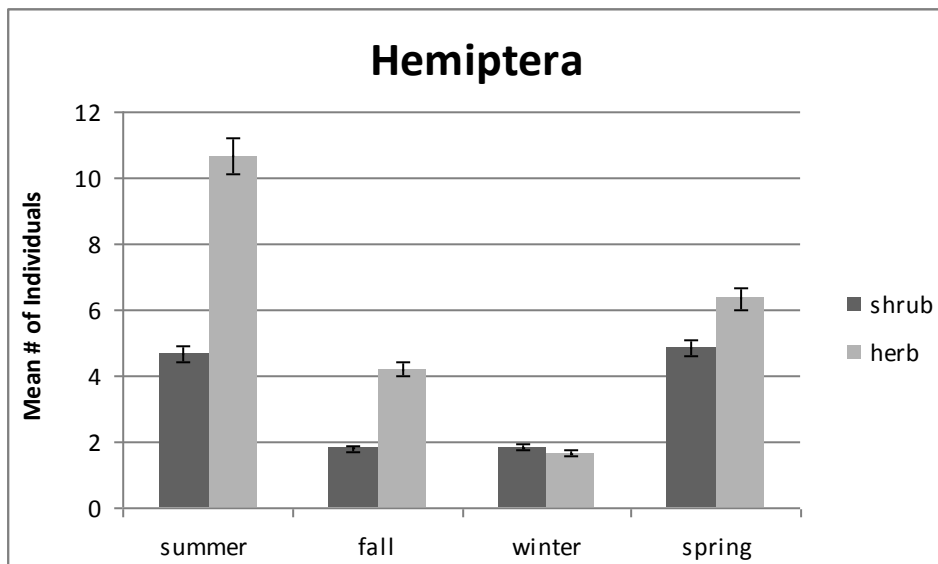


Figure 5. Mean number observations of Hemiptera per season/per vegetation type.

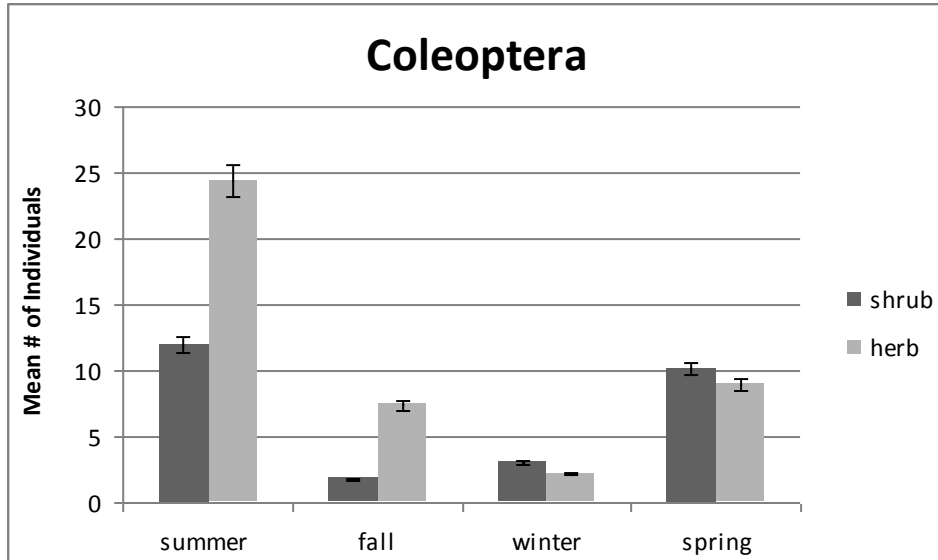


Figure 6. Mean number observations of Coleoptera per season/per vegetation type.

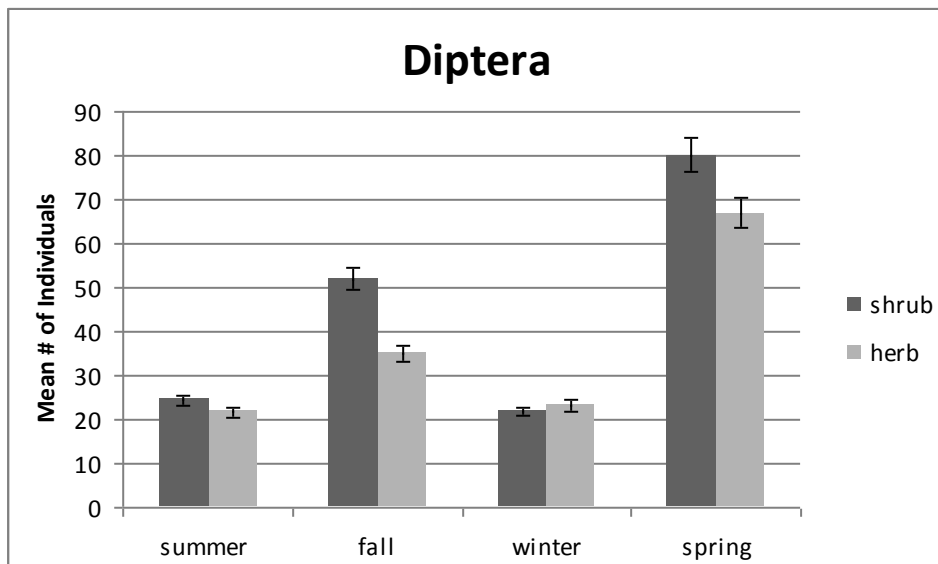


Figure 7. Mean number observations of Diptera per season/per vegetation type.

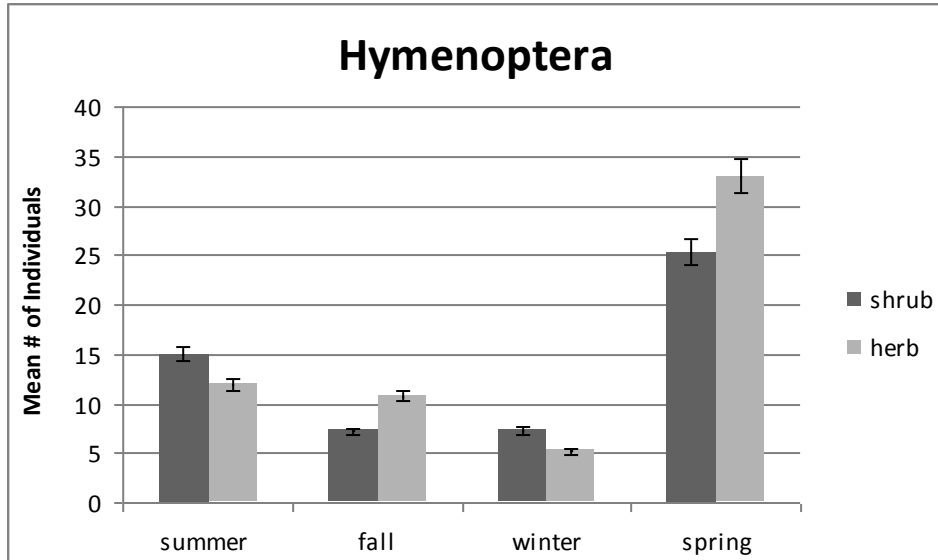


Figure 8. Mean number observations of Hymenoptera per season/per vegetation type.

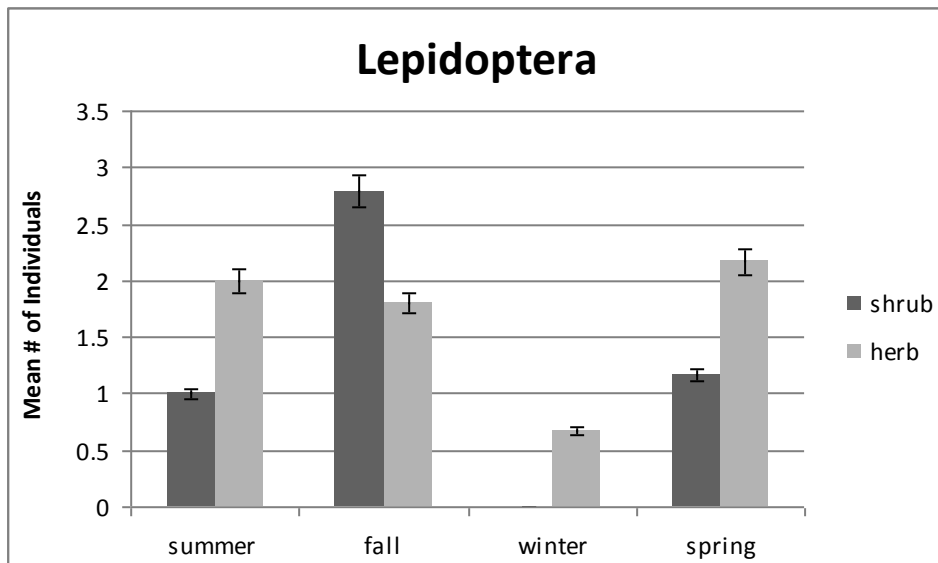


Figure 9. Mean number observations of Lepidoptera per season/per vegetation type.

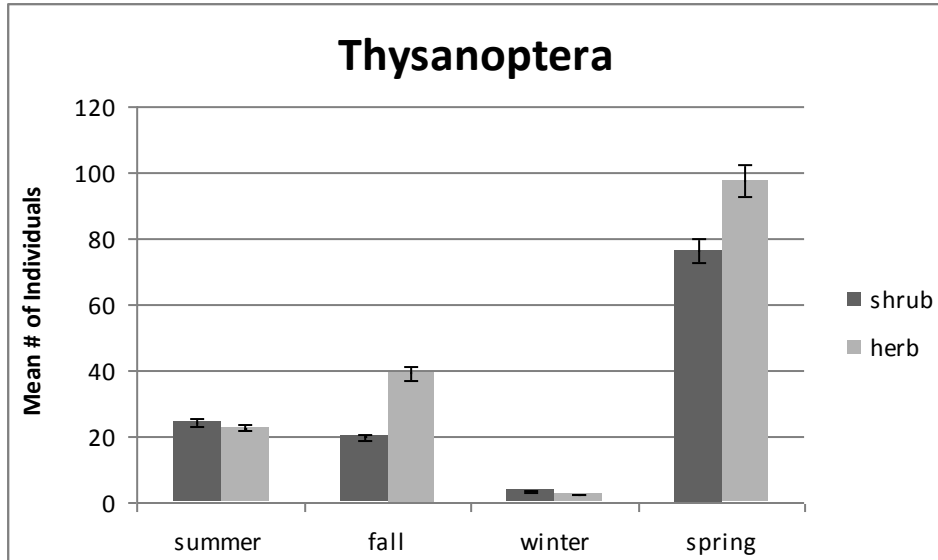


Figure 10. Mean number observations of Thysanoptera per season/per vegetation type.

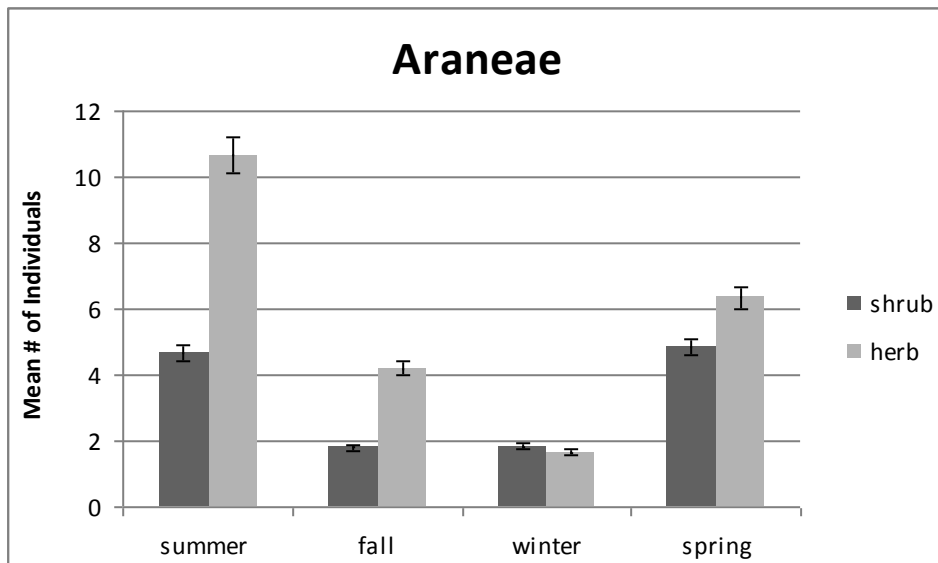


Figure 11. Mean number observations of Araneae per season/per vegetation type.

A subset of families (those families with over 25 sampled individuals), was analyzed for seasonal differences using two-way ANOVAs for season and vegetation

type. Those that showed significant differences were then subjected to Tukey HSD Post-Hoc tests. In Hemiptera, both Aphididae ($p=0.001$) and Cicadellidae ($p=0.003$) exhibited significant seasonal variation. Despite this indication by ANOVA, the pairwise Post-Hoc tests for Aphididae showed no variation between seasons. (Fig. 12) (Fig.31) I found that the interaction between vegetation and season was significant for aphids ($p=0.001$), indicating that while aphids exhibited a dramatic increase in spring for herb-dominated areas they did not experience a similar increase in shrub-dominated sites (Fig. 13). More Cicadellids were sampled in the spring than any other season (summer, $p=0.005$;fall, $p=0.009$;winter, $p=0.003$) (Fig.14) (Fig.31).

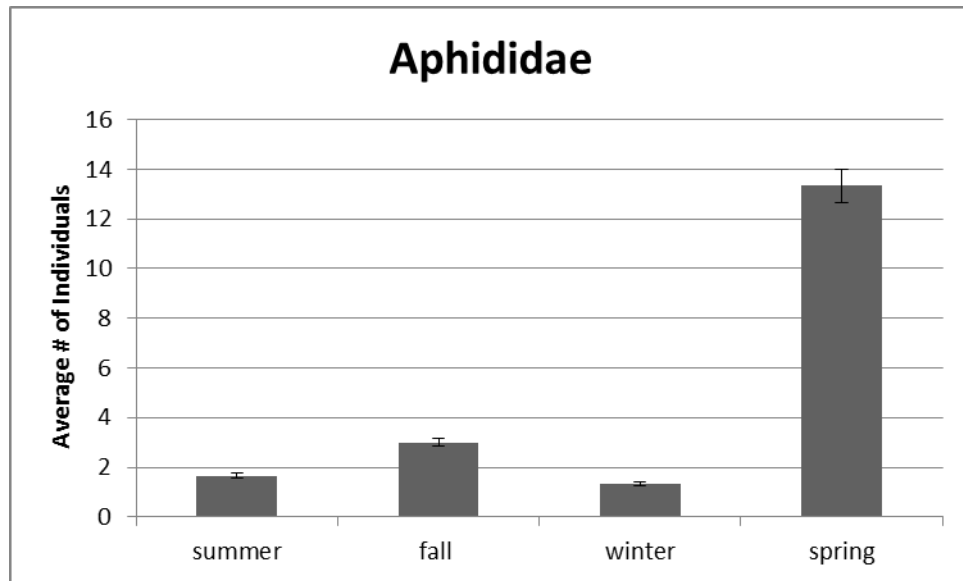


Figure 12. Mean number observations of Aphididae per season.

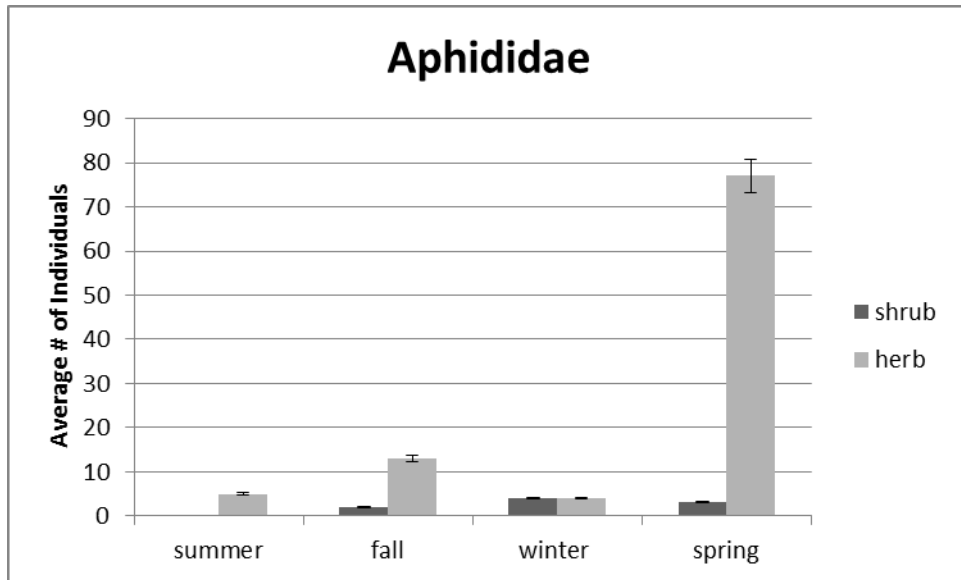


Figure 13. Mean number observations of Aphididae per season/per vegetation type.

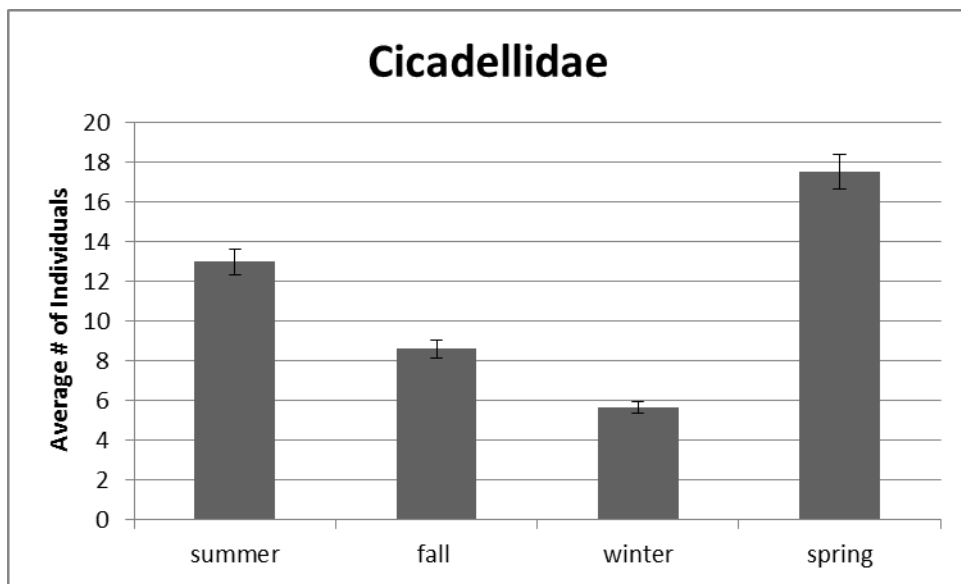


Figure 14. Mean number observations of Cicadellidae per season.

The three families of Coleoptera analyzed for seasonal differences all showed significant differences in abundance. Scolytidae showed significantly higher abundance in winter than any other season (summer, $p=0.036$; fall, $p=0.036$; spring, $p=0.036$) (Fig.

15)(Fig.33), but all of the individuals were caught on one day at the end of February.

Buprestidae was significantly more abundant in spring than any other season

(summer, $p<0.001$;fall, $p<0.001$;winter, $p<0.001$) (Fig.16) (Fig.33). Mordellidae was more

common in summer than any other season, but only significantly more abundant when

compared with winter ($p=0.011$) (Fig. 17) (Fig.30).

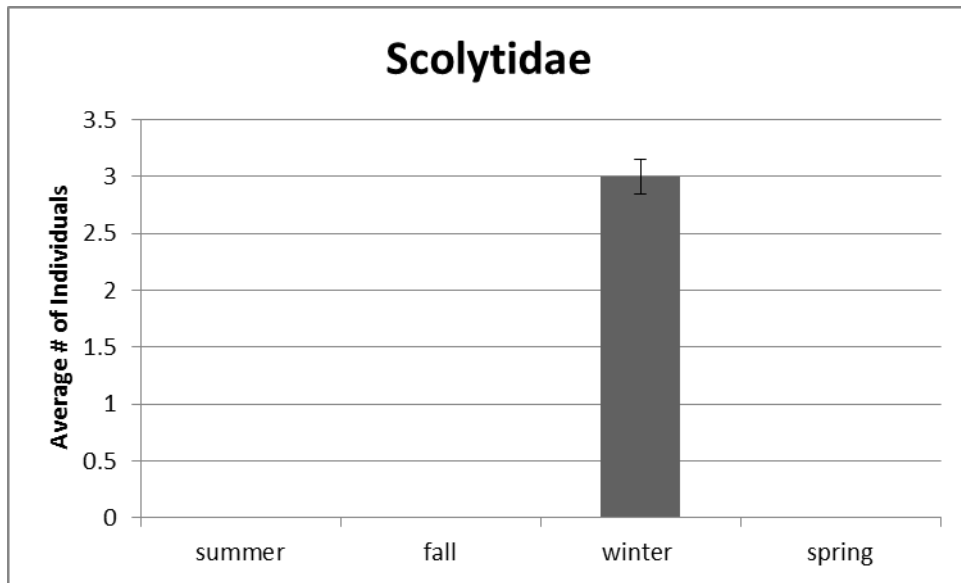


Figure 15. Mean number observations of Scolytidae per season.

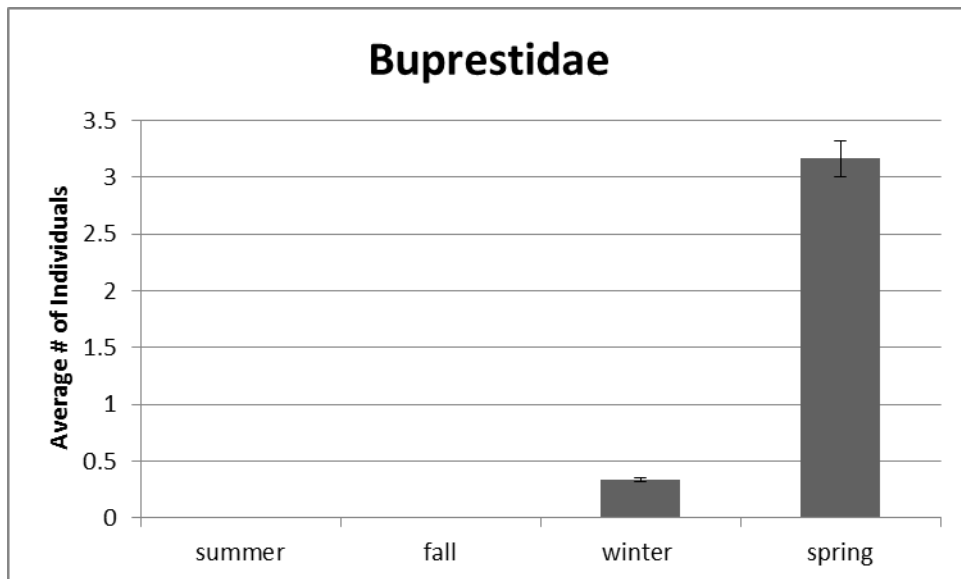


Figure 16. Mean number observations of Buprestidae per season.

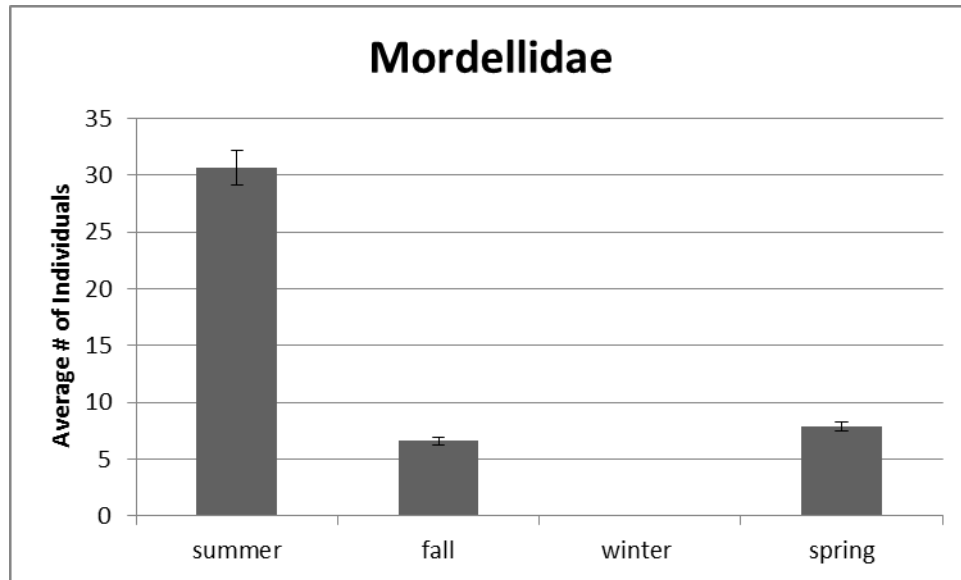


Figure 17. Mean number observations of Mordellidae per season.

Order Diptera had the highest number of families that varied significantly by season. Of the families whose larvae are dependent on plant tissues, Anthomyiids were more abundant in winter than any other season (summer, $p=0.001$; fall, $p=0.008$; spring, $p=0.002$) (Fig. 18) and Cecidomyiids were most abundant in fall (summer, $p=0.006$; winter, $p=0.010$) (Fig.19) (Fig. 31). Of the detritivores, Chironomids showed significantly higher numbers in spring than in summer or fall (summer, $p=0.001$; fall, $p=0.002$) (Fig. 20) and Muscid flies were caught significantly more frequently in winter and spring than in summer: summer:winter ($p=0.045$) and summer: spring ($p=0.015$) (Fig.21). Predatory Dolichopodids exhibited significantly higher numbers in spring than any other season ($p<0.001$ for each comparison) (Fig.22). Fungivorous Sciarids and Drosophilids also displayed seasonal variation. Sciarids were caught least frequently in winter but the only significant difference was between winter and spring (summer, $p=0.067$;

fall, $p=0.067$; spring, $p=0.007$) (Fig.23), while Drosophilids were captured significantly more often in summer than any other season (winter, $p=0.003$; fall, $p=0.006$; spring, $p=0.001$) (Fig.24). Sarcophagids, which feeding on decaying animal tissue, were most frequently trapped in the fall with significantly lower numbers caught in both summer ($p=0.006$) and winter ($p=0.008$) (Fig.25).

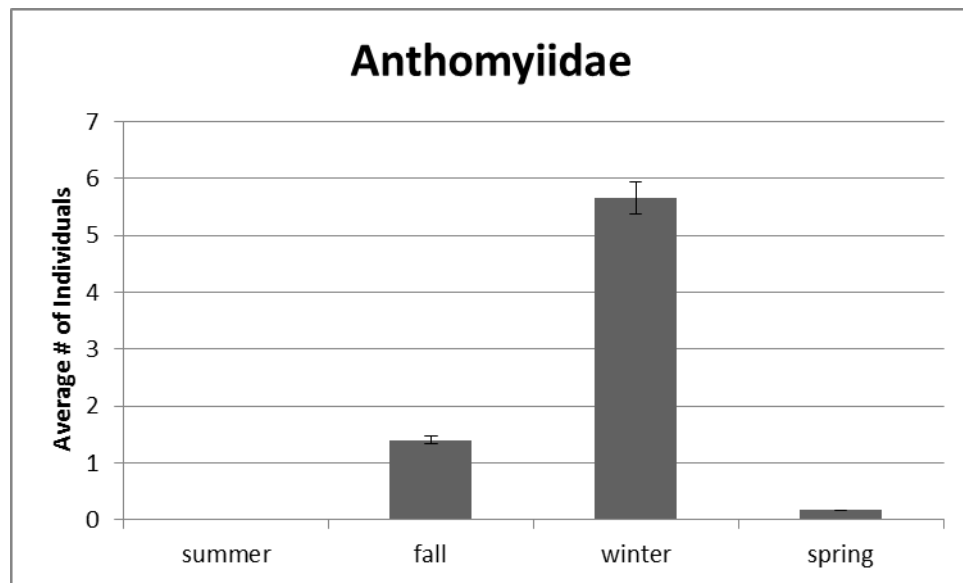


Figure 18. Mean number observations of Anthomyiidae per season.

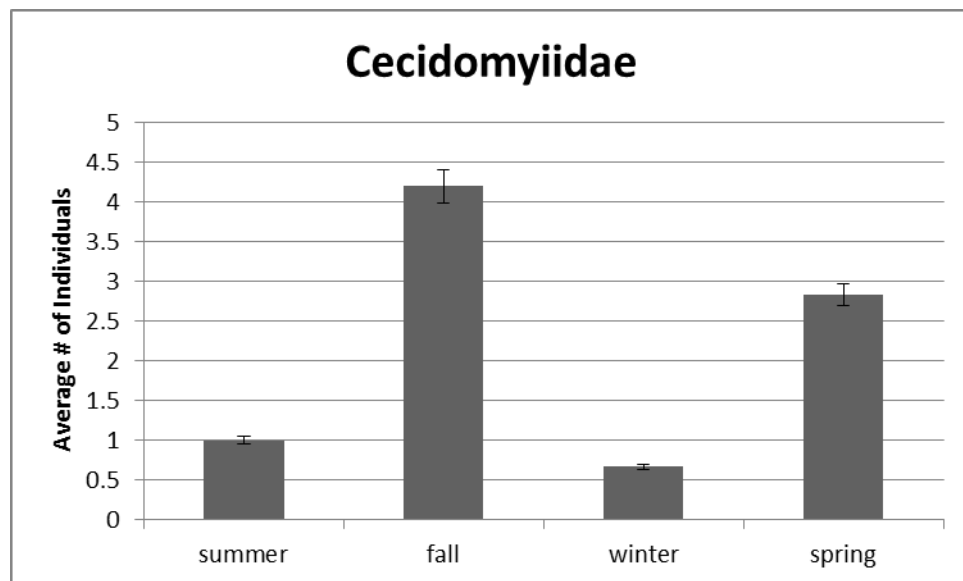


Figure 19. Mean number observations of Cecidomyiidae per season.

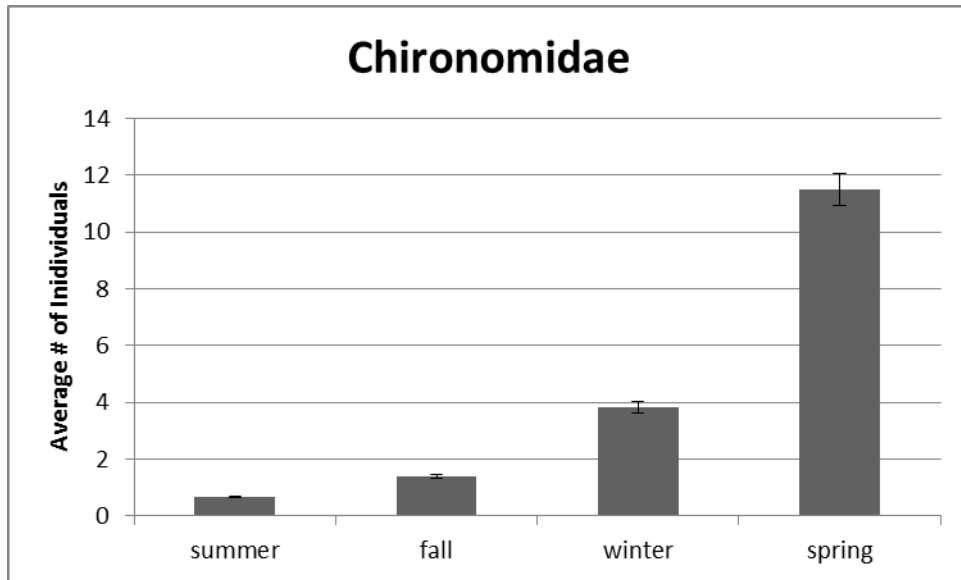


Figure 20. Mean number observations of Chironomidae per season.

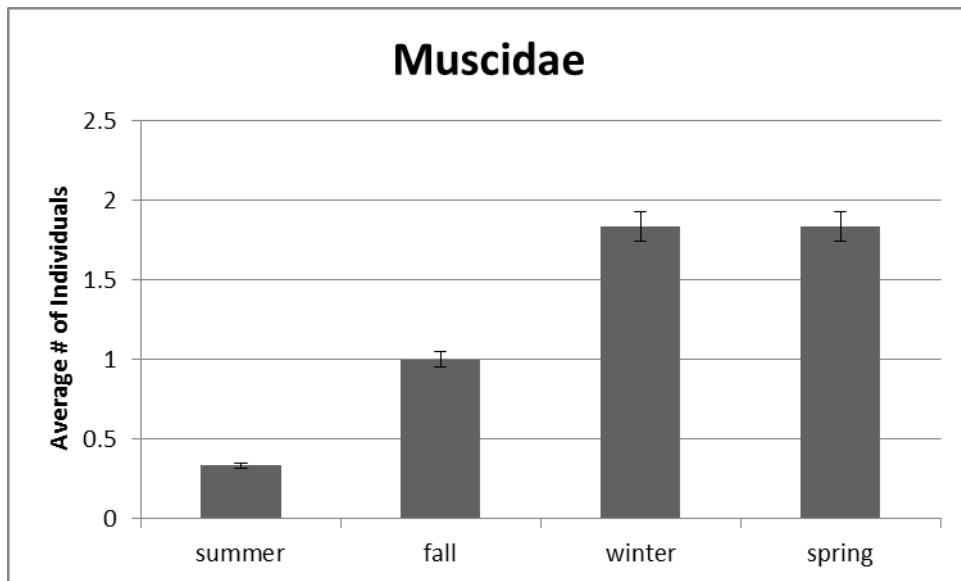


Figure 21. Mean number observations of Muscidae per season.

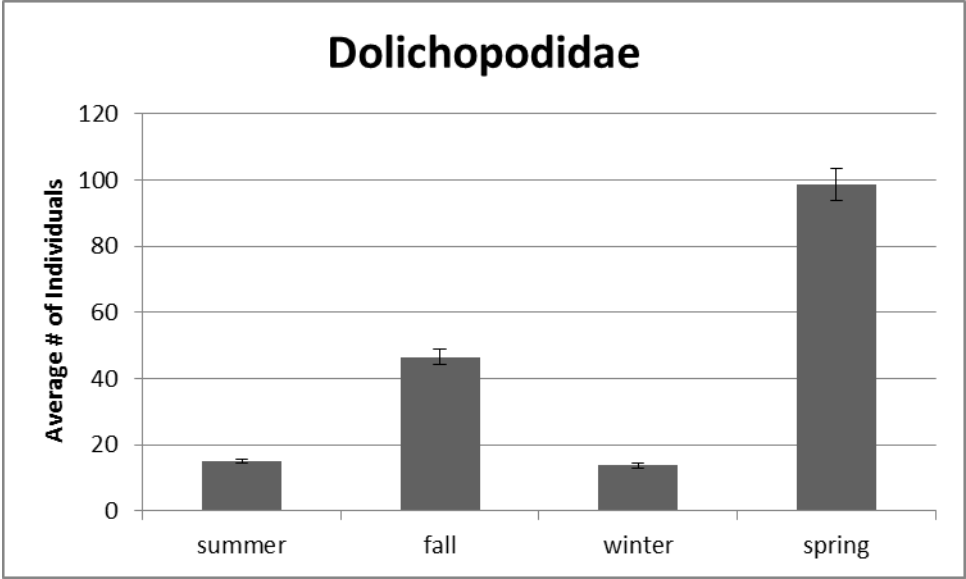


Figure 22. Mean number observations of Dolichopodidae per season.

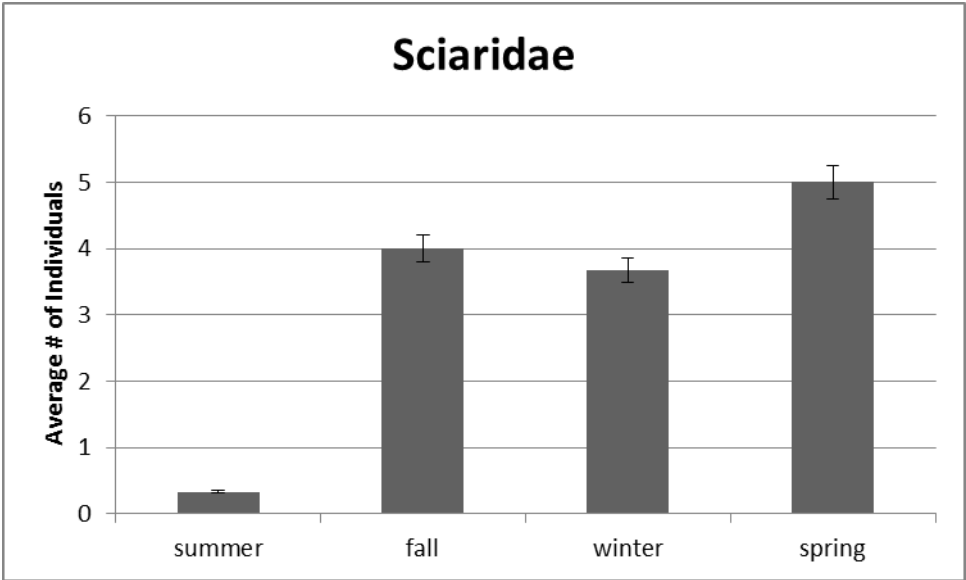


Figure 23. Mean number observations of Sciaridae per season.

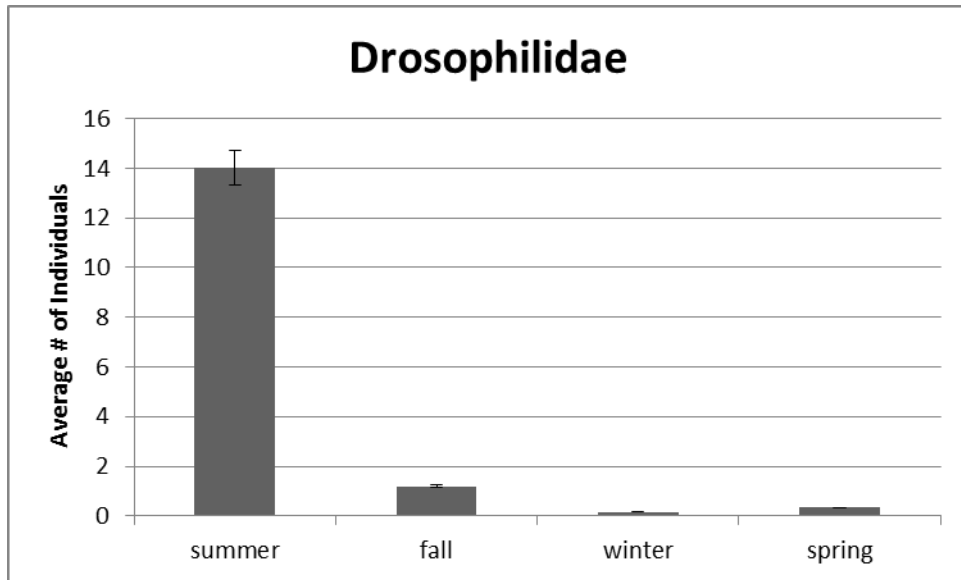


Figure 24. Mean number observations of Drosophilidae per season.

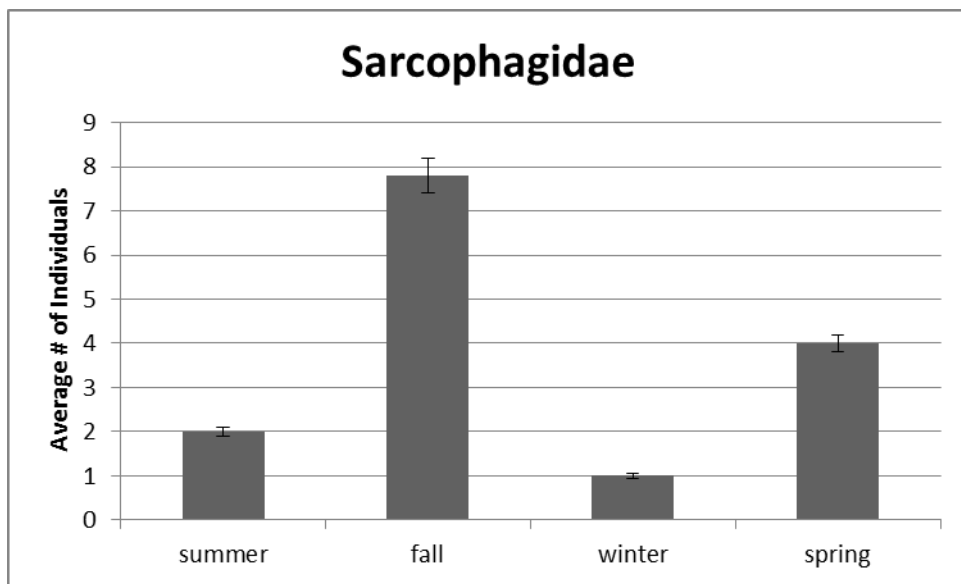


Figure 25. Mean number observations of Sarcophagidae per season.

Of the three families of Hymenoptera tested for seasonal differences, Formicidae and Myrmecidae had seasonally significant differences while Apidae did not. Formicids were most abundant in spring (Fig.26), but spring abundance differed significantly only

from fall and winter (summer, $p=0.086$;fall, $p=0.044$;winter, $p=0.037$). Myrmecids were significantly more abundant in spring than any other season (Fig.27) (summer, $p<0.001$;fall, $p=0.037$; winter, $p=0.003$)(Fig.32). Hesperids, in Order Lepidoptera, demonstrated higher catch quantities in fall and spring respectively (Fig.28)(Fig.30). Fall and spring were not significantly different from one another and neither were winter and summer, but all other seasonal comparisons were significantly different (summer:fall, $p=0.001$; summer:spring, $p=0.034$; fall:winter, $p=0.001$; winter:spring, $p=0.020$).

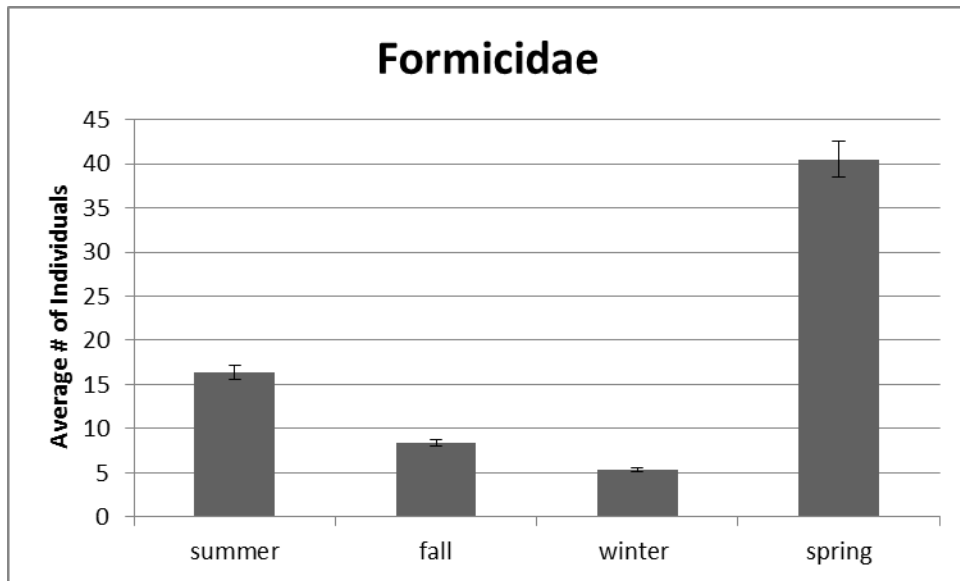


Figure 26. Mean number observations of Formicidae per season.

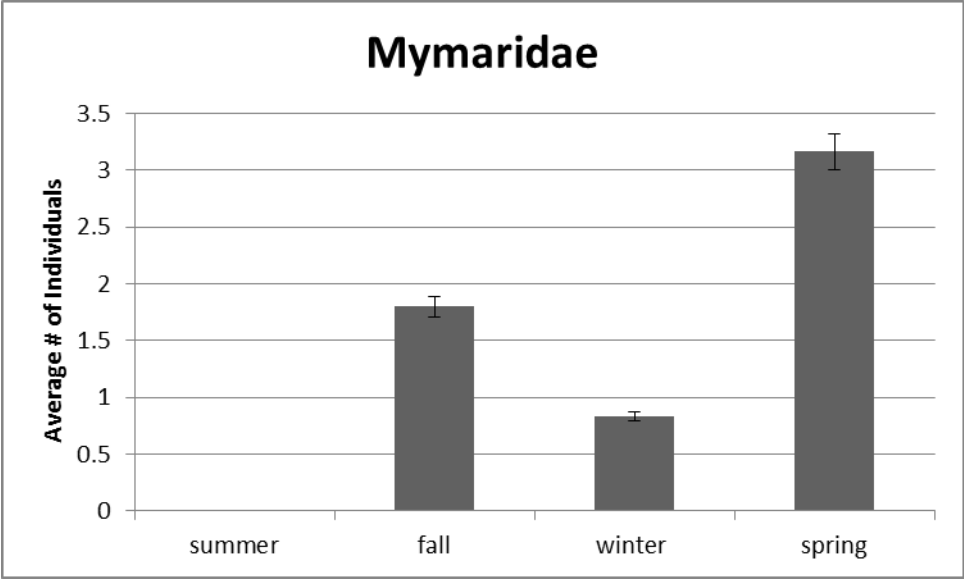


Figure 27. Mean number observations of Mymaridae per season.

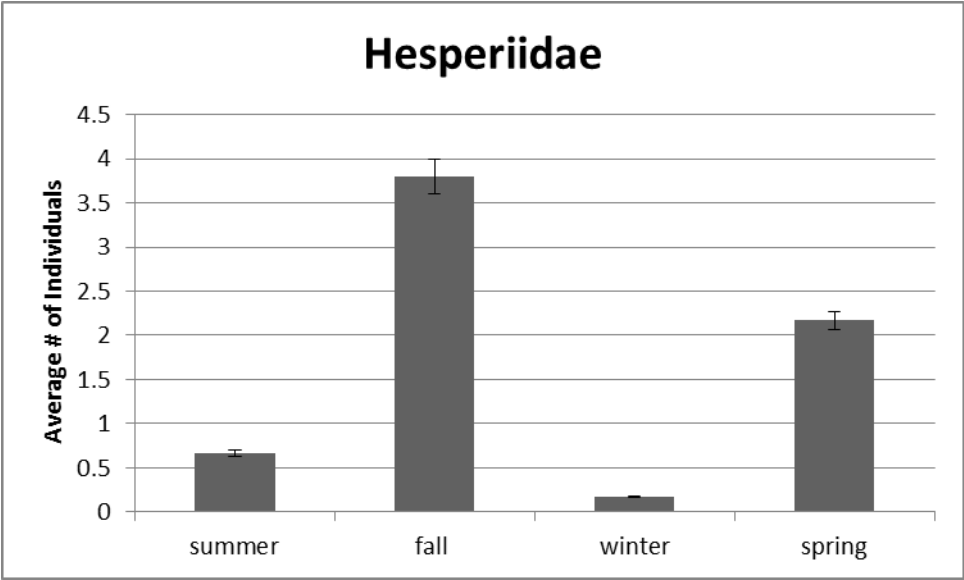


Figure 28. Mean number observations of Hesperidae per season.

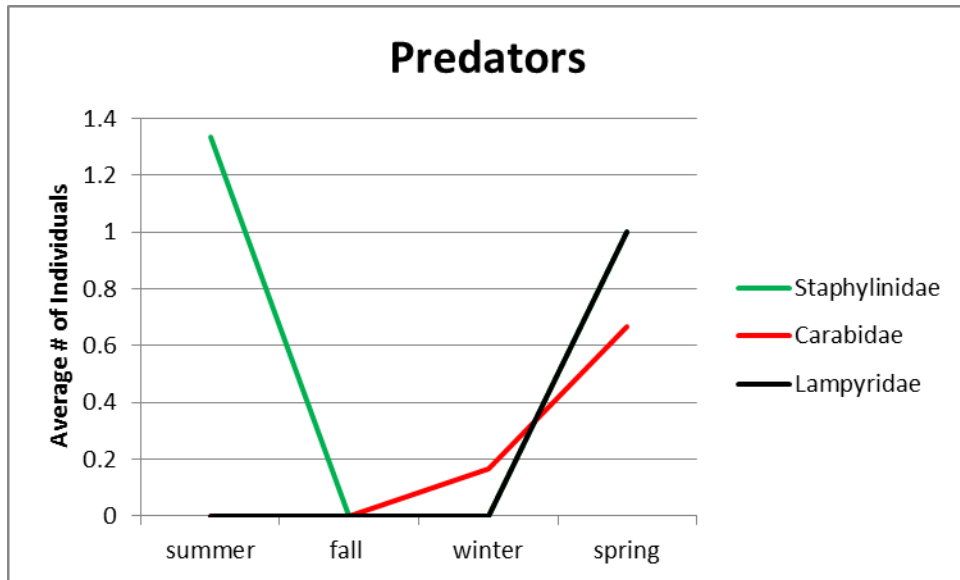


Figure 29. Mean number observations of predator families per season.

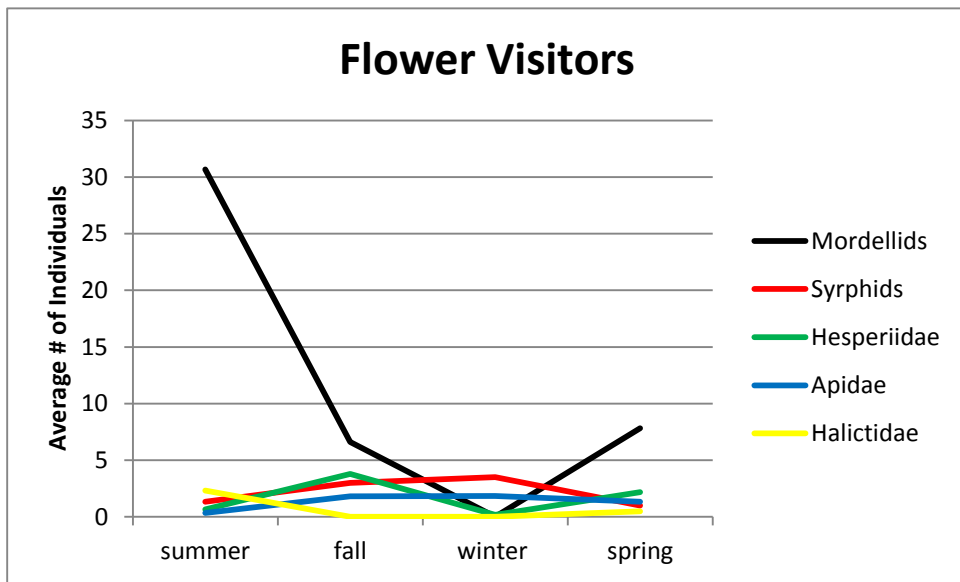


Figure 30. Mean number observations of flower visitor families per season.

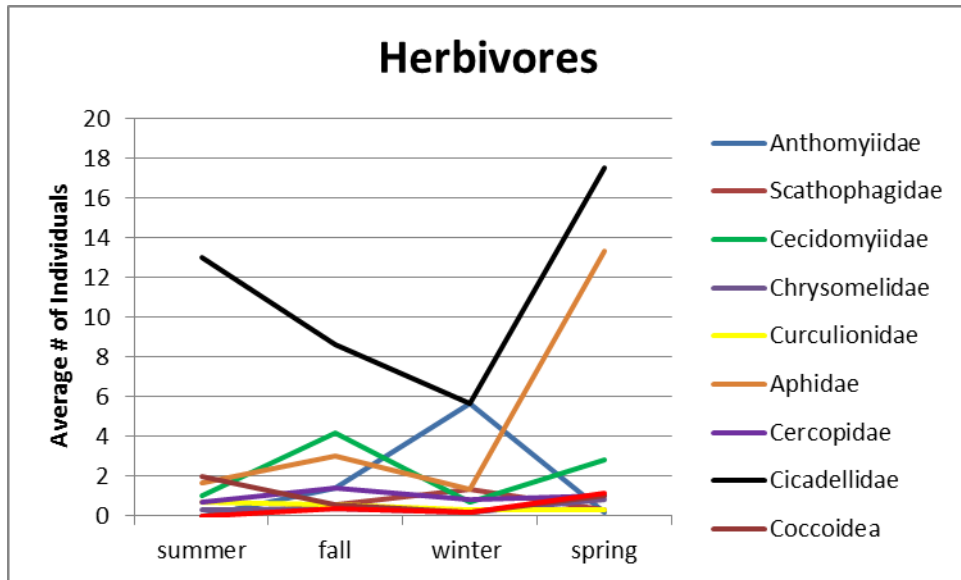


Figure 31 Mean number observations of herbivore families per season.

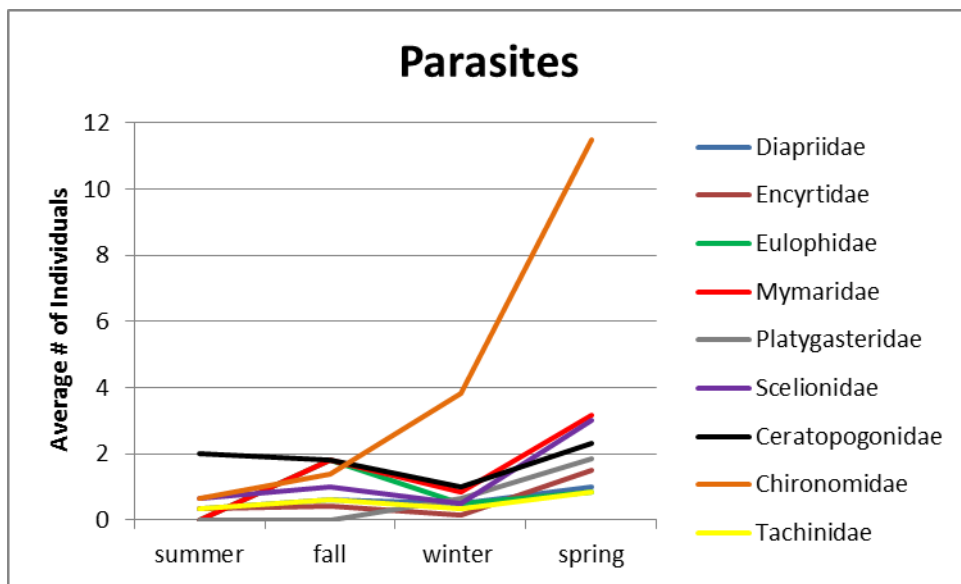


Figure 32. Mean number observations of parasitic hymenoptera families per season.

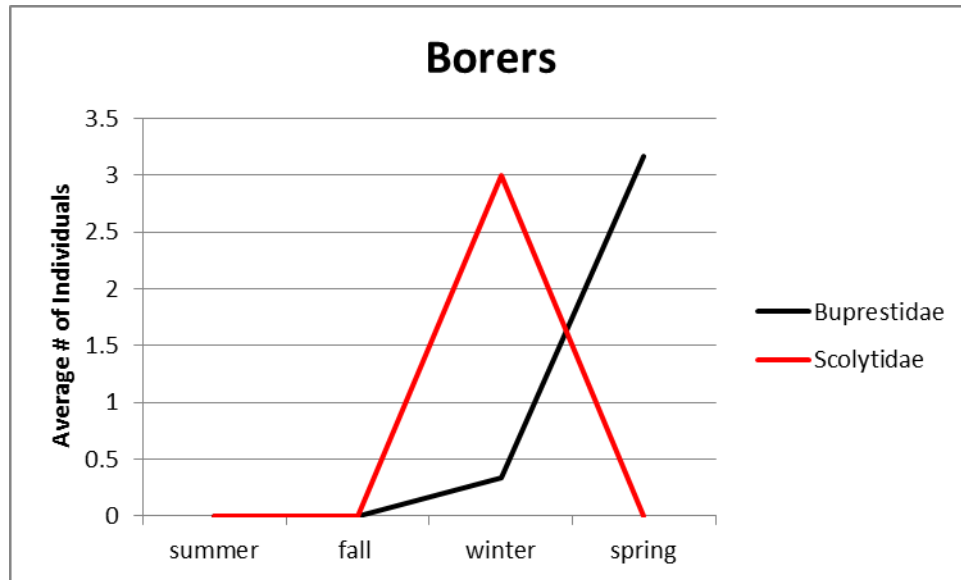


Figure 33. Mean number observations of wood-borer families per season.

Trap type catch

Arthropod bowl color catches were analyzed using a two-way ANOVA with trap color and vegetation type as factors. Total captures of all arthropods ($p=0.042$), as well as total Coleoptera ($p=0.011$), Diptera ($p<0.001$), Hemiptera ($p<0.001$), Lepidoptera ($p=0.040$), and Thysanoptera ($p=0.024$) all exhibited significant differences among trap types. Hymenoptera ($p=0.056$), Araneae ($p=0.848$), Acari ($p=0.367$), and Collembola ($p=0.460$) did not show significant differences in catch among trap types.

Two-sample t-tests were then run to determine trap efficiency among the bowl colors. Total arthropod captures were significantly greater in yellow traps than in white traps ($p=0.05$). Both Diptera and Hemiptera were captured most in yellow bowls (Diptera, $p<0.001$ for comparisons with white and blue; Hemiptera, $p=0.001$ for comparisons with white and blue). In contrast, thysanopterans were caught significantly more often in blue and white bowls than yellow bowls (blue:yellow, $p=0.001$;

white:yellow, $p=0.007$). Lepidoptera were caught significantly more frequently in blue bowls than yellow ($p=0.038$) Hymenoptera were trapped in yellow bowls significantly more than blue ($p=0.025$). Coleoptera were caught significantly more frequently in blue bowls than in white bowls ($p=0.037$).

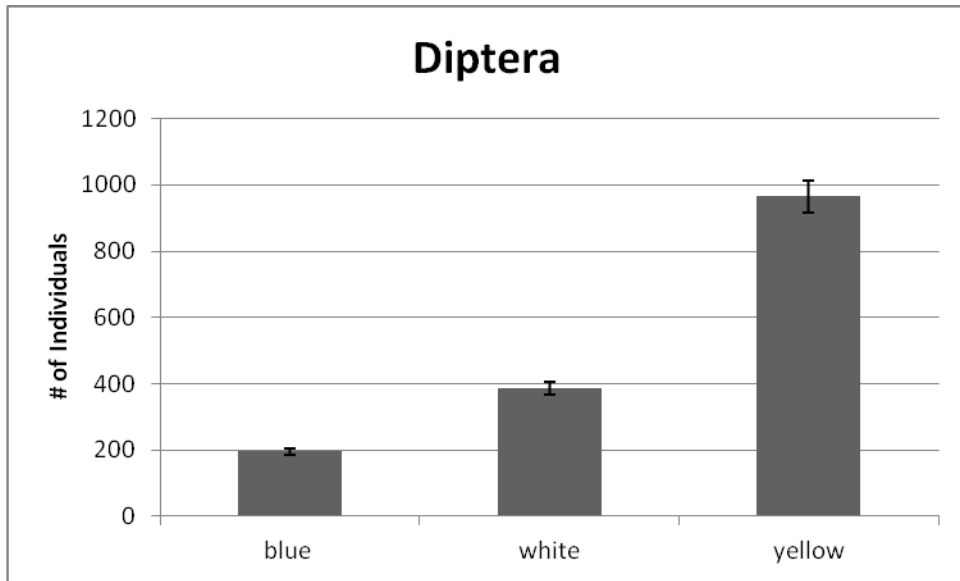


Figure 34. Number of observations of Diptera per trap color.

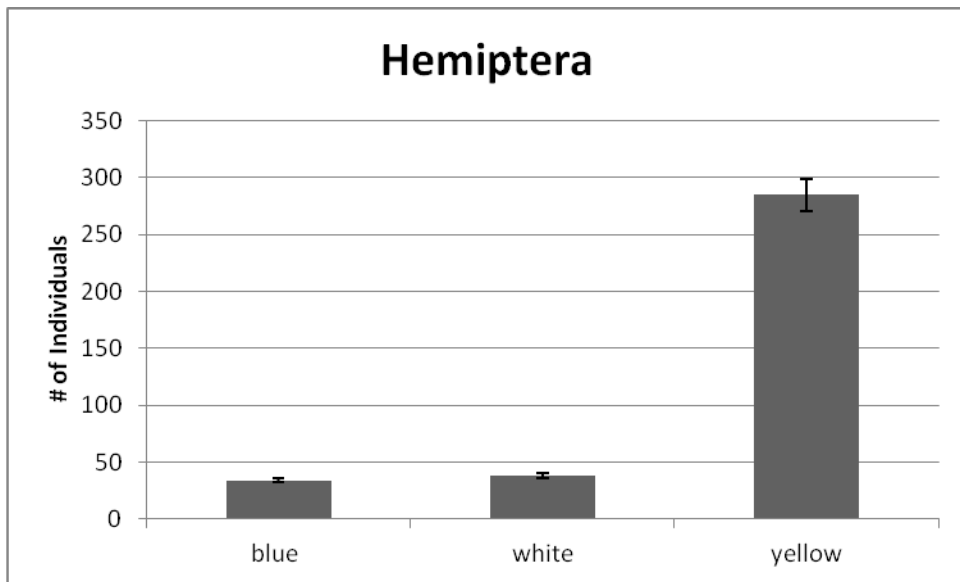


Figure 35. Number of observations of Hemiptera per trap color.

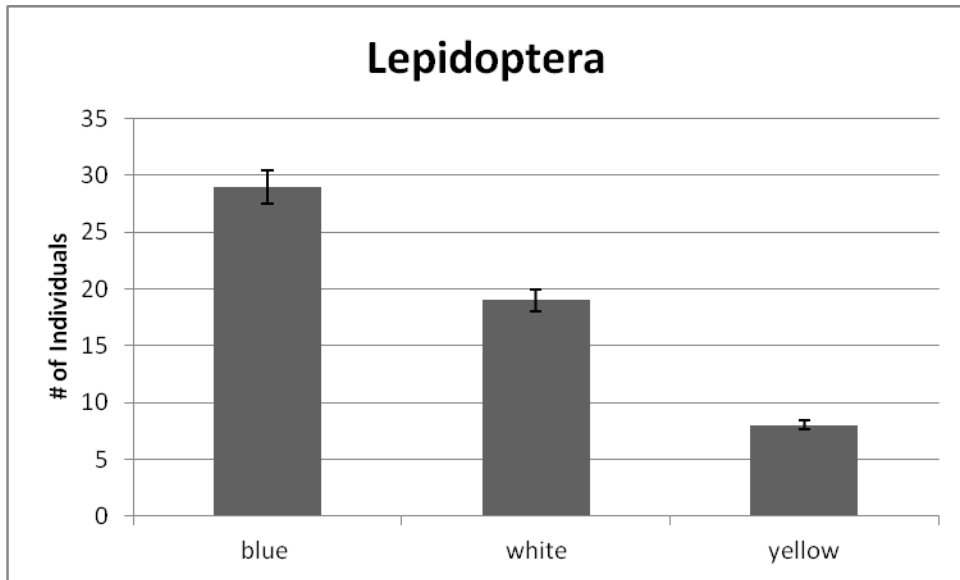


Figure 36. Number of observations of Lepidoptera per trap color.

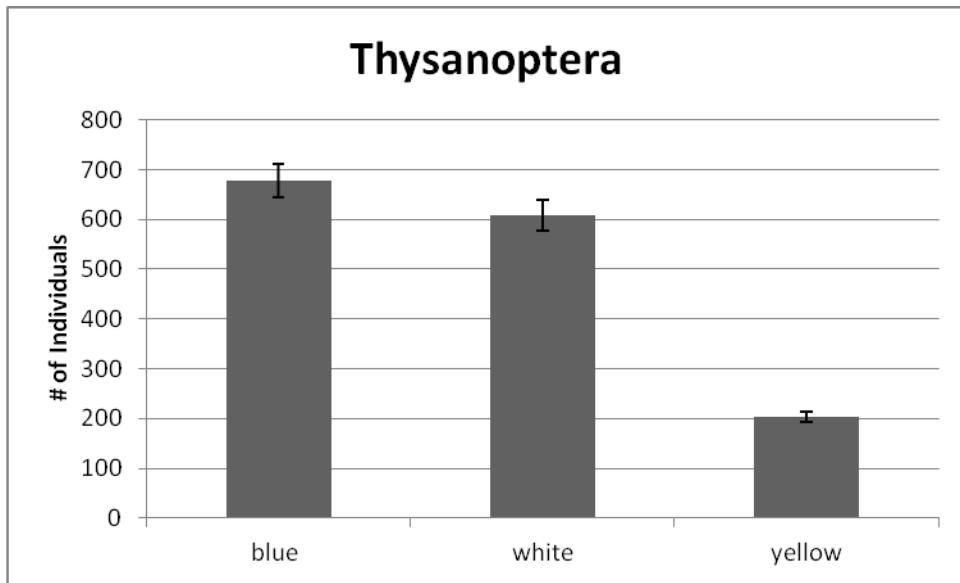


Figure 37. Number of observations of Thysanoptera per trap color.

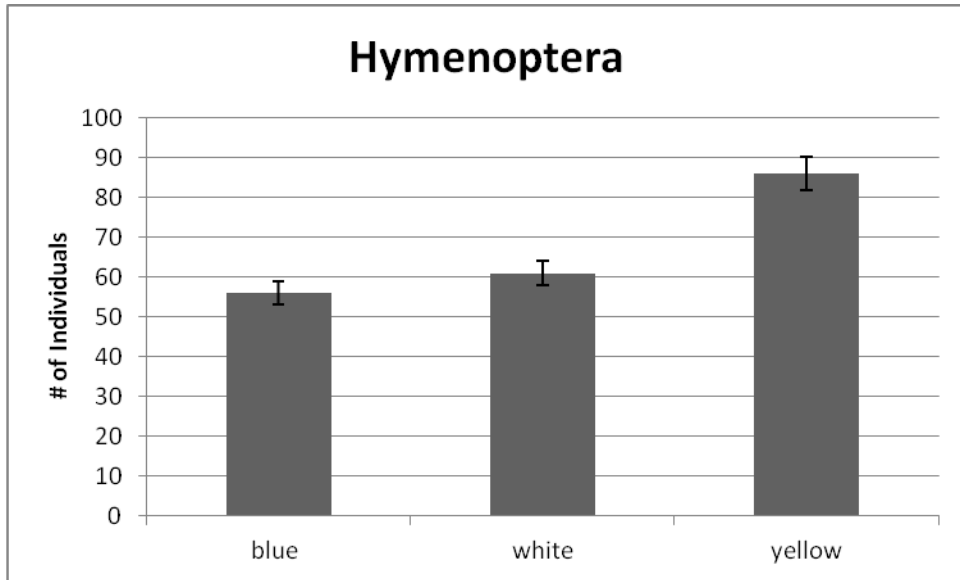


Figure 38. Number of observations of Hymenoptera per trap color.

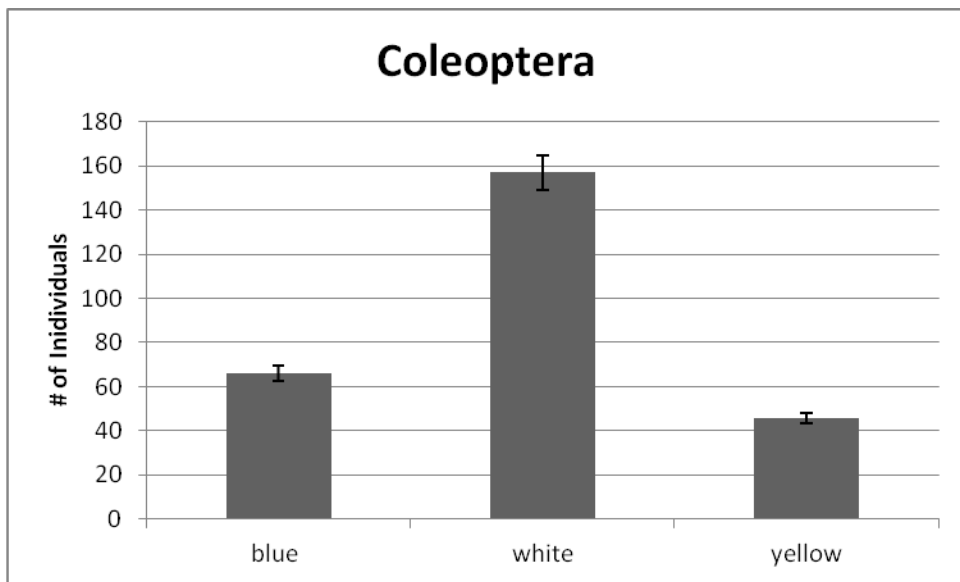


Figure 39. Number of observations of Coleoptera per trap color.

I assessed trap preference at the family level for those families represented by enough specimens to permit statistical comparisons among traps. Of the hemipterans, aphids (yellow:white, $p=0.001$; yellow:blue, $p=0.001$), cicadellids (yellow:white, $p<0.001$;

yellow:blue, $p < 0.001$), and psyllids (yellow:white, $p = 0.011$; yellow:blue, $p = 0.011$) all exhibited significantly higher numbers in yellow bowls. The lepidopteran family Hesperidae, was caught significantly more in blue bowls than yellow bowls (blue:yellow, $p = 0.004$).

In Order Hymenoptera, members of Apidae were trapped in white bowls more frequently than yellow ($p = 0.018$). Myrmecids (yellow:white, $p = 0.001$; yellow:blue, $p = 0.013$, yellow:pitfall, $p = 0.002$), and Platygasterids (yellow:white, $p = 0.013$; yellow:blue, $p = 0.001$; yellow:pitfall, $p = 0.001$), landed in yellow bowls significantly most often, Formicids and Scelionid were caught most often in the pitfall traps (Formicids- $p = 0.001$ for all comparisons against pitfall traps; Scelionids-pitfall:white, $p < 0.001$; pitfall:blue, $p = 0.001$; yellow:pitfall, $p = 0.002$), and Halictids were more frequently caught in blue bowls when compared to yellow ($p = 0.028$), but not significantly more than white.

Coleopterans showed a range of relationships to trap color. Several families exhibited non-significant trap association, but four families had a significant outcome. Mordellids were trapped most frequently in white (yellow:white, $p = 0.044$; white:blue, $p = 0.017$; white:pitfall, $p = 0.004$). Buprestids were found significantly more often in blue traps than yellow or white traps (blue:yellow, $p = 0.028$; pitfall:blue, $p = 0.028$). Lampyrids were most often taken in yellow traps (all comparisons $p < 0.001$). Carabids in pitfall traps ($p = 0.025$ compared with blue and yellow bowls) (although no significant difference existed between numbers caught in pitfall traps and white bowls).

Among Diptera, Dolichopodids and Sarcophagids were captured significantly more often in yellow traps ($p < 0.001$ all comparisons) while Drosophilids were taken most often in white ($p < 0.001$ for all comparisons) and Tabanids in blue traps (blue:white, $p = 0.003$; yellow:blue, $p = 0.001$; yellow:pitfall, $p = 0.001$). Dixids were found in yellow traps significantly more often than blue or yellow bowls ($p = 0.050$ for both comparisons).

Discussion

In this study, Shannon diversity at the family level and abundance of key functional guilds was significantly greater in herb-dominated sites than sites with extensive woody mid-story shrubs. This is despite the close physical proximity of sites with different habitat types. In some instances, these two habitats graded sharply into one another over a distance of only a few meters, and occasionally, they inter-digitated. This would be expected to promote relatively similar insect communities in samples from the two sites, but this was not the case. Despite the ability of insects to move freely among patches, functional group abundance and diversity reflected overall plant diversity; shrub-dominated patches had nearly continuous cover of *Cyrilla racemiflora* while herb-dominated sites had up to 30 species per square meter (A. Entrup, personal communication).

In contrast, no differences in total abundance, evenness, or richness of families were found between herb-dominated sites and shrub-dominated sites. This is likely due, in part, to the high numerical dominance of a few taxa, particularly Dolichopodidae

and Formicidae, and the large number of families with only a few specimens.

Combining taxa into functional groups revealed significant ecological relationships between feeding niche and vegetation structure that was obscured by the finer-scale abundance patterns of individual taxa. Phytophagous and flower visiting arthropods were more abundant in the herb-dominated sites corresponding with the increased plant diversity. Wood-boring insects and detritivores showed stronger associations with shrub-dominated sites which contain more woody stems and detritus accumulated from shrubs.

The transition from herb- to shrub-dominated sites is regulated by fire interval, and significant change in longleaf pine vegetation structure may be apparent in as little as three years (Van Lear *et al.* 2005). In this study, phytophagous insect diversity is often strongly correlated with plant diversity. Loss of a diverse herb layer to a smaller variety of shrubby species is expected to lead to lost abundance of those plant-associated insects (Armitage & Ober 2012) So, even though total abundance of arthropods is maintained in each site type, diversity is not.

Taxa Showing Habitat Association

Of the orders analyzed for differences based on vegetation structure, only Diptera showed significant differences in abundance between site types. The greater abundance of Diptera in shrub-dominated sites is largely due to the overwhelming abundance of Dolichopodids which favored those sites. Of the 6152 arthropods analyzed for associations with vegetation type, 950, or 15.4%, were Dolichopodids.

Sixty percent of these flies were sampled in the shrub-dominated zone. One factor affecting the abundance of these flies might be that they are predaceous flies feeding on a variety of small arthropods, eggs, and larvae. Previous studies have suggested that suitable prey items such as soil-dwelling arthropods increase in abundance and diversity with time after a fire, a possible reason being that larvae are often detritivorous, and shrub-dominated areas may provide more food for larvae (Hanula & Wade 2003). However, my samples did not show such a pattern; Collembola were the dominant soil-dwelling taxon, and they did not differ in abundance between sites dominated by herbs and those dominated by shrubs. My samples were based on only two pitfall traps per site, and it is possible that using additional pitfall traps to increase capture rate might have revealed small but significant differences in soil arthropod abundance or diversity. It is also possible that other invertebrate taxa not sampled by my methods are important prey of dolichopodid flies.

Eight families showed significant association with either vegetation type. In Order Coleoptera, beetles of family Lampyridae were caught significantly more often in herb-dominated sites. When signaling for mating, lampyrids often perch on vegetation (Moosman 2009). While perches would be available in both herb-dominated and shrub-dominated sites, perhaps the more open nature of the grassy sites allowed for better visibility when attempting to locate mates.

Halictid bees were found most frequently in the shrub-dominated areas. A study at Auburn University has suggested that halictids were primary pollinators of titi (*Cyrilla racemiflora*) which is the primary shrub associated with the shrub-dominated sites in

this study (Dute *et al.* 2004). This study found that specimens of *Dialictus* (Halictidae) that had visited the titi flowers carried 90% titi pollen (Dute *et al.* 2004).

The fly families Anthomyiidae and Ephydriidae were predominantly collected in the herb-dominated habitat, whereas Dolichopodidae, Calliphoridae, and Mycetophilidae were found more often in the shrub-dominated regions. Anthomyiids may have been more common in the herb-dominated areas because of the higher diversity of plant species. Known as root-maggot flies, the larvae are primarily phytophagous. Ephydriids have a variety of trophic associations, but they are primarily detritivores feeding on all manner of rotting organic material, though others include algae feeders and leaf miners (Foote 1995). Mycetophilid larvae are typically fungivores (Matile 2012) while Calliphorid larvae are heavily dependent on decaying animal matter.

Aphids were also more highly associated with herb-dominated sites than shrub-covered sites. Aphid species are selective herbivores that primarily feed on one plant species (Stern 2008). The high number of aphids in the herb-dominated sites is likely due to associations with preferred vegetation available in those sites.

Of the eight families that displayed significant preference for either vegetation type, four were more prevalent in shrub-dominated sites and four were more common in herb-dominated sites. Most of the families frequently found in herb-dominated sites were phytophagous during some part of their life cycle.

Seasonal Trends

Totals

Higher overall arthropod abundance in spring is consistent with the expectation that as temperatures warm and vegetation grows and flowers with the warming temperatures, arthropods will become more active and begin reproduction to allow larval development in the warm spring and summer months before temperatures and vegetative growth begin to dwindle later in the year (Topp 2003). These results are consistent for both the shrub- and herb-dominated areas, suggesting that the availability of young tissues promotes arthropod abundance in both habitats.

Arthropod Orders

When assessing seasonal trends by arthropod order, I found that all orders, except Collembola, varied significantly by season and that patterns of change by season were not significantly different between the site types for any order. Collembola might be less vulnerable to change by season since they are soil-litter dwellers, but other studies have suggested that they reach peak densities in winter months (Hibdon 2003). Although most orders (Hemiptera, Diptera, and Thysanoptera) followed the trend of higher abundance in spring corresponding with new plant growth, hymenopterans also had high abundances in summer likely do to the fact that formicids become more active in warmer temperatures (Ober & DeGroot 2011) when they are searching for resources.

The most abundant coleopteran, and likely the reason for the concentration of beetles in summer, are the Mordellids (flower beetles). Mordellids were 176 out of 301, or 58.5%, of beetles collected from July 2011 until May 2012 and they were heavily concentrated in the summer months. Their high densities in spring and summer are likely attributed to vegetation availability. Since they are known flower visitors that consume nectar and pollen (Rutledge & Young 2007), they may be utilizing a particular type of plant that is prevalent at that time, perhaps titi which is a summer bloomer (Fischer 1997).

Lepidopterans did not exhibit strong seasonal observations except that they were uncommon in the winter season. The only two Lepidoptera that were trapped in the winter sample came on the last sampling date at the end of February, which was a warm day that may have signified the beginning of spring and ended the overwintering period for these arthropods. Members of Araneae were significantly more common in summer than winter perhaps owing to a greater abundance of prey items in the summer months.

Families

Within Coleoptera, families Scolytidae, Buprestidae, and Mordellidae, all exhibited significant seasonal patterns. Scolytids were significantly more abundant in the winter sampling period than any other and Buprestids were significantly more abundant in the spring than any other time. One thing to note is that every Scolytid was collected at the last date of winter sampling at the end of February and that day was

warm, as noted above with the Lepidopterans. Even though, the sampling date was technically in the winter period, the increase in temperature could have signaled a change in season to the Scolytids. Scolytids are dependent on woody vegetation and are commonly associated with pine habitat. Scolytids are often associated with pine trees and typically emerge to search for a place to oviposit or a new host. It is likely that the warming temperatures serve as a signal for the advent of this stage of the normally well-hidden Scolytids' life cycle (Forcella & Harvey 1983). Of the individuals within the family Buprestidae, most were of the genus *Acmaeodera*, which are mostly flower visitors that are known to be active in spring and early summer. So this result is not surprising. None of the beetle families exhibited varying seasonal patterns between herb- and shrub- dominated sites.

Within Hymenoptera, Mymarids showed significantly higher presence in spring than all other seasons, likely corresponding with the higher abundance of organisms they parasitize (insect eggs). Formicids, which are active in warmer temperatures demonstrated higher abundance in spring and summer.

Of the analyzed Hemipteran families, Aphididae did show significant differences in seasonal patterns between site types. Closer inspection revealed that while the herb-covered sites had a highly significant increase of individuals in the spring, the shrub-dominated sites did not experience the same explosion of growth which likely prevented the pairwise comparisons from attaining seasonal significance. It appears likely that the widespread initiation of new growth in herbaceous plants in the spring provides significantly greater resources for aphids than do shrubs.

Hesperiids (Lepidoptera) were significantly more common in spring and fall than summer and winter and they exhibited different seasonal shift depending on site type. In the shrub-dominated zones there was a more substantial increase in catch during the fall than in the herb-dominated areas perhaps indicating that the shrub-dominated zones are preferred for reproduction.

I tested more Dipteran families than any other group for changes in seasonal abundance. The trends that I noticed here are that most families of flies are significantly prevalent in either summer, fall, or spring, but there is typically not much significant pairwise variation, indicating that either the fly families are making use of resource availability (vegetation or detritus) that is present over multiple seasons or that their activity is determined by temperature conditions that extend over more than one season. Each of these fly families may use particular resources that are common during one season or another, but it is difficult to pinpoint on which resources each of these families are depending since most have varying life history strategies within the families. One outlier in the fly families is Anthomyiidae. Anthomyiids were collected significantly more often in herb-dominated sites and they were also caught significantly more in winter than any other season. Since very few were caught in shrub-dominated sites at any time of year and several were trapped in herb-dominated sites, the differences in seasonal variation were significantly different as well. Since the larvae of these flies are dependent on plant tissue, it seems as if the preponderance of adults corresponds with a time of year when those larval resources are not as readily available. Cecidomyiids, which are typically gall formers, may be most abundant in fall due to emergence after

larval development takes place in young plant tissues in spring and summer.

Dolichopodids, predators, display a spike in numbers corresponding with increases in other invertebrates that are potential prey items. Chironomids and Muscids, both of which were most common in spring and winter, likely make use of detrital material that builds up over winter months. Drosophilids and Sciarids both depend on fungal material and decomposition of organic material for food resources, but Drosophilids demonstrated a peak in winter whereas Sciarids peaked in spring. The reason for this difference is likely due to Sciarid emergence concentration in spring (Nielson & Nielson 2004). Sarcophagids, which are animal tissue feeders, have shown increases in abundance with warming temperatures (Mulieri *et al.* 2008). It is unclear why they would have been more prevalent in the fall season than summer. It is possible that the incomplete summer collection has biased the collection of Sarcophagids.

Of the arthropod families analyzed for seasonal differences that did not exhibit seasonal differences, Ceratopogonids (Diptera) encompass a variety of life history patterns that may allow different species to thrive at varying times. Some are predators, some are flower visitors, while others still feed on blood (McAlpine 1981; Triplehorn & Johnson 2005). Syrphids (Diptera), surprisingly for flower visitors, had no strong seasonal patterns in this study. The apids (Hymenoptera) caught in this study were primarily *Apis mellifera* (honeybees) and they were the only apids caught in winter.

Trap Type Abundance

When discriminating between blue, yellow, and white bowls, I found that yellow bowls caught significantly more arthropods than white bowls, but no significant difference was found between yellow and blue, or blue and white. This result has been found in similar studies comparing the efficiency of colored pan traps (Hoback *et al.* 1999). It has been suggested that yellow pigments resemble pigments of foliage that insects can detect and are attracted to which is what makes yellow traps good all-purpose traps (Prokopy & Owens 1983; Leong & Thorpe 1999). When comparing relative effectiveness of bowl color by order, I found that yellow bowls were the best for trapping flies primarily due to the overwhelming abundance of Dolichopodids that landed in the yellow traps which confirms results from the Hoback *et al.* study (1999). For Lepidopterans, which were primarily Hesperiid, blue bowls were significantly better than yellow. Though associations have been found between Lepidopterans and the color yellow, in this study, as well as a study by Campbell & Hanula (2007), Lepidopterans dominated by Hesperiid have favored blue traps. This may indicate that blue is a more easily discernible color or perhaps Hesperiid are just particularly attracted to blue. Hymenopterans, as expected, landed in blue bowls significantly more often than yellow likely because shorter wavelengths of light are more visible to them including wavelengths in the UV spectrum. White and blue bowls did not exhibit significant difference and it has been shown that some bees see white as a blue-green color which may make white and blue indistinguishable (Leong & Thorp 1999). Hemipterans overwhelmingly chose yellow bowls which is consistent with other studies

(Prokopy & Owens 1983). Coleoptera significantly chose white over blue bowls while Thysanopterans chose blue bowls significantly more often than white and white bowls significantly more often than yellow. Both of these results correspond with results from Campbell & Hanula (2007).

Families

For the family-level analysis, I included the pitfall traps because several of the families were caught almost exclusively in the pitfall traps. In Hemiptera, the significantly higher numbers of Cicadellids, Aphids, and Psyllids in yellow bowls than in any other trap indicates the foliage association discussed earlier.

Members of Apidae were caught most often in white bowls, but there was no significant difference between white and blue, likely due to the visibility of blue wavelengths and the reflectance from the white bowls appearing similar to the bees. Halictids, also unsurprisingly, were caught most in blue bowls, since many bees have strong vision in the shorter wavelength range. Formicids were caught in significant quantities in pitfall traps which is not surprising since they are primarily wingless. However, the parasitic wasp group Scelionidae, were also most prevalent in the pitfall traps, which although surprising for a flying insect, is not so surprising when one considers that many are egg parasites of ground-dwellers. Mymarids and Platygasterids (both parasitic wasps) were caught primarily in yellow bowls which are known to be good for catching parasitoid wasps (Duelli *et al.* 1999).

Beetles (Order Coleoptera) were more cosmopolitan which has been found in other studies also. The significant results associating Mordellids with white bowls were contrary to the results of Campbell & Hanula (2007) where they found that Mordellids were most highly correlated with yellow pan traps. However, my findings for Buprestids with blue bowls over yellow or pitfall traps were similar to those found in the same Campbell & Hanula study . Carabids, otherwise known as ground beetles, were, not surprisingly, caught most in pitfall traps. Lampyrids prevalence in yellow bowls seems to correspond with the vegetation requirements discussed earlier in this study if the color yellow resembles foliar pigments.

Dolichopodids and Sarcophagids were primarily trapped in yellow bowls which corresponds with the pattern for many flies. The most abundant group of flies caught in this study was the Dolichopodids, and since they were most abundantly found in the yellow traps, that was part of the reason why the Dipterans were found significantly more often in yellow bowls than any other trap and why yellow bowls attracted such large numbers overall compared to the other two bowl colors. Regarding many of the other pairwise comparisons between trap types, most of the remaining significant differences fell between bowls and pitfall traps where the flies chose the bowls over the pitfalls, with one exception; members of Sphaeroceridae were caught frequently in pitfall traps.

According to my results, trap catches are very much dependent on family level attractions, so to get an adequate sampling of most orders, multiple types of traps or

colors should be employed. It is important to consider the characteristics of the group to be sampled when choosing successful traps.

Conclusions

Results from this study indicate that vegetation type does have a significant effect on several orders and families of arthropods that reside in longleaf pine savannas. Herb-dominated sites support more functional guilds as well as a higher diversity of arthropod taxa, indicating that the characteristic vegetation of restored longleaf pine savannas at the Abita Creek Flatwoods Preserve is important for arthropod community structure. Despite the matrix in which the sampled sites exist, clear differences were observed between vegetation types. These results suggest that periodic burning which maintains vegetation will help to maintain biodiversity of arthropod communities in longleaf pine savannas.

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Appendix 1

Class	Order	Family	Frequency
Insecta	Coleoptera	Brathinidae	2
Insecta	Coleoptera	Bruchidae	1
Insecta	Coleoptera	Buprestidae	19
Insecta	Coleoptera	Carabidae	7
Insecta	Coleoptera	Cerambycidae	3
Insecta	Coleoptera	Chrysomelidae	9
Insecta	Coleoptera	Ciidae	1
Insecta	Coleoptera	Cryptophagidae	1
Insecta	Coleoptera	Curculionidae	10
Insecta	Coleoptera	Derodontidae	0
Insecta	Coleoptera	Elateridae	2
Insecta	Coleoptera	Erotylidae	1
Insecta	Coleoptera	Laemophloeidae	1
Insecta	Coleoptera	Lampyridae	8
Insecta	Coleoptera	Lathridiidae	1
Insecta	Coleoptera	Limnichidae	1
Insecta	Coleoptera	Melyridae	2
Insecta	Coleoptera	Mordellidae	176
Insecta	Coleoptera	Mycetophagidae	0

Class	Order	Family	Frequency
Insecta	Coleoptera	Nititulidae	3
Insecta	Coleoptera	Phalacridae	5
Insecta	Coleoptera	Pselaphidae	1
Insecta	Coleoptera	Scarabidae	6
Insecta	Coleoptera	Scolytidae	18
Insecta	Coleoptera	Scymaenidae	5
Insecta	Coleoptera	Staphylinidae	13
Insecta	Coleoptera	Tenebrionidae	2
Insecta	Coleoptera	Trogossitidae	1
Insecta	Diptera	Agromyzidae	1
Insecta	Diptera	Anthomyiidae	33
Insecta	Diptera	Asilidae	7
Insecta	Diptera	Bibionidae	7
Insecta	Diptera	Calliphoridae	12
Insecta	Diptera	Cecidomyiidae	44
Insecta	Diptera	Ceratopogonidae	33
Insecta	Diptera	Chironomidae	99
Insecta	Diptera	Chloropidae	17
Insecta	Diptera	Chyromyidae	1
Insecta	Diptera	Conopidae	1
Insecta	Diptera	Culicidae	7

Class	Order	Family	Frequency
Insecta	Diptera	Dixidae	21
Insecta	Diptera	Dolichopodidae	950
Insecta	Diptera	Drosophilidae	51
Insecta	Diptera	Empididae	6
Insecta	Diptera	Ephydriidae	16
Insecta	Diptera	Lonchopteridae	1
Insecta	Diptera	Milichiidae	6
Insecta	Diptera	Muscidae	30
Insecta	Diptera	Mycetophilidae	20
Insecta	Diptera	Phoridae	35
Insecta	Diptera	Piophilidae	1
Insecta	Diptera	Platypezidae	2
Insecta	Diptera	Rhinophoridae	4
Insecta	Diptera	Sarcophagidae	74
Insecta	Diptera	Scathophagidae	13
Insecta	Diptera	Scatopsidae	9
Insecta	Diptera	Sciaridae	74
Insecta	Diptera	Sphaeroceridae	23
Insecta	Diptera	Stratiomyidae	1
Insecta	Diptera	Syrphidae	49
Insecta	Diptera	Tabanidae	11

Class	Order	Family	Frequency
Insecta	Diptera	Tachinidae	11
Insecta	Diptera	Tipulidae	4
Insecta	Hemiptera	Aphidae	110
Insecta	Hemiptera	Cercopidae	20
Insecta	Hemiptera	Cicadellidae	221
Insecta	Hemiptera	Coccoidea	16
Insecta	Hemiptera	Coreidae	2
Insecta	Hemiptera	Lygaeidae	2
Insecta	Hemiptera	Membracidae	8
Insecta	Hemiptera	Miridae	1
Insecta	Hemiptera	Psyllidae	11
Insecta	Hymenoptera	Andrenidae	1
Insecta	Hymenoptera	Aphelinidae	3
Insecta	Hymenoptera	Apidae	29
Insecta	Hymenoptera	Bethylidae	4
Insecta	Hymenoptera	Ceraphronidae	3
Insecta	Hymenoptera	Colletidae	1
Insecta	Hymenoptera	Cynipidae	2
Insecta	Hymenoptera	Diapriidae	19
Insecta	Hymenoptera	Dryinidae	1
Insecta	Hymenoptera	Encyrtidae	13

Class	Order	Family	Frequency
Insecta	Hymenoptera	Eulophidae	17
Insecta	Hymenoptera	Eupelmidae	3
Insecta	Hymenoptera	Eurytomidae	1
Insecta	Hymenoptera	Figitidae	1
Insecta	Hymenoptera	Formicidae	380
Insecta	Hymenoptera	Halictidae	9
Insecta	Hymenoptera	Ichneumonidae	2
Insecta	Hymenoptera	Megachilidae	3
Insecta	Hymenoptera	Megaspilidae	1
Insecta	Hymenoptera	Mymaridae	30
Insecta	Hymenoptera	Platygastridae	12
Insecta	Hymenoptera	Pompiliidae	2
Insecta	Hymenoptera	Pteromalidae	2
Insecta	Hymenoptera	Scelionidae	28
Insecta	Hymenoptera	Sphecidae	3
Insecta	Hymenoptera	Torymidae	2
Insecta	Hymenoptera	Tiphiidae	3
Insecta	Hymenoptera	Trichogrammatidae	5
Insecta	Hymenoptera	Vespidae	2
Insecta	Lepidoptera	Coleophoridae	3
Insecta	Lepidoptera	Elachistidae	3

Class	Order	Family	Frequency
Insecta	Lepidoptera	Gelechiidae	4
Insecta	Lepidoptera	Hesperiidae	36
Insecta	Lepidoptera	Lyonetiidae	2
Insecta	Lepidoptera	Nepticulidae	2
Insecta	Lepidoptera	Noctuidae	5
Insecta	Lepidoptera	Sphingidae	1
Insecta	Orthoptera	Acrididae	5
Insecta	Orthoptera	Gryllidae	9
Insecta	Orthoptera	Tettigionidae	1

Vita

Cara Beth Nighohossian was born in St. Louis, Missouri and raised in Granite City, Illinois. In the fall of 1999 she started her undergraduate career at Saint Louis University in St. Louis, MO. She double-majored in Chemistry and English and completed her B.A. in 2004. After working as a lab technician, Cara returned to school in 2008 to take biology classes at Southern Illinois University-Edwardsville. During the summer of 2009, she moved to New Orleans and enrolled in biology courses at Tulane University. In August 2008, Cara began her Master's in Biological Sciences at The University of New Orleans, which she completed in May 2014 under the advisement of Dr. Jerome Howard.