December 2016

Archinsects and arachnitects: The leaf structures that arthropods construct in the protected areas of Monteverde

Holly Eichrodt

Archinsects and Arachnitects: The leaf structures that arthropods construct in the protected areas of Monteverde

Holly Eichrodt
Department of Environmental Studies, and Art
University of California, Santa Cruz
EAP Tropical Biology and Conservation Program, Fall 2016
16 December 2016

ABSTRACT

This study aimed to understand which insect and arachnid families manipulate leaves to make shelters and for what purposes they make them. I investigated the types of structures they create and how this may benefit their survivorship within three diverse protected areas of Monteverde-Estación Biológica Monteverde, Bajo del Tigre and Rachel Dwight Crandell Reserve.
I collected a total of 56 individuals in the orders Lepidoptera, Araneae, and Orthoptera. I quantified the different types of leaf modifications made as well as the plant family in which they were made. I wanted to determine if there was specificity within the different families. The most abundant family I found was Anyphaenidae—a family of arachnid, and this was the only family collected at all three of my sites. I also found that there were different uses for the leaves, which I classified as shelter, feed, molt, pupate, and eggs—and I described the refuge that each individual created (by structure and plant family) and compared them. An interesting result is this area houses a unique cricket, which is the one of two families in Orthoptera that spins silk. Furthermore, I did not find species specificity in the family of arthropod's plant choice—this could be due to insufficient data collected from each family of arthropod especially in the order Lepidoptera.

Insectos y arañas arquitectos: Las estructuras de hojas construídas por artrópodos en las zonas protegidas en Monteverde

RESUMEN

El presente estudio tuvo como objetivo comprender qué familias de insectos y arácnidos manipulan las hojas para hacer refugios, y los diferentes tipos de usos que les dan. Investigué los tipos de estructuras que crean y cómo esto puede beneficiar su supervivencia dentro de tres áreas protegidas diversas de Monteverde - Estación Biológica Monteverde, Bajo del Tigre y Reserva Rachel Dwight Crandell.
Coleccioné un total de 56 individuos en los órdenes Lepidoptera, Araneae, y Orthoptera. Cuantifiqué los diferentes tipos de modificaciones de hojas hechas así como la familia de plantas en las que fueron hechas. También tuve como objetivo determinar si había especificidad dentro de las diferentes familias. La familia más abundante que encontré fue Anyphaenidae, una familia de arácnidos, y ésta fue la única familia encontré en los tres sitios. También encontré que había

diferentes usos para las hojas y las clasifiqué como refugio, alimentación, muda, pupa y huevos, y describí y comparé el refugio que cada individuo creó (por estructura y familia de plantas) Un resultado interesante es que esta área alberga un grillo único, que es el único Orthoptera que produce seda. Además, no encontré especificidad de especie en la familia de la elección de las plantas de los artrópodos-esto podría ser debido al tamaño de la muestra tomada de cada familia de artrópodos, especialmente en el orden Lepidoptera.

Insects are some of the most creative architects, utilizing whatever is at their disposal for protection from predators and weather to increase their chances for survival (Fukui, 2001). Many create refuges through manipulation of leaves with silk—using the silk to create an enclosure. It is understood that some larvae of Lepidoptera as well as Arachnids use leaf architecture as a means of growth, feeding, or for laying eggs, securing maximum protection (Hanson and Nishida, 2016; Suter et al, 2011). They will modify the foliage to form a shelter—two examples being caterpillar species that roll or fold a leaf in on itself to create a protective feeding tunnel, or weevils that construct complex leaf structures to hide their eggs (Entomology, 2004). Many species of caterpillar are specialized to feed on certain plants since they have evolved the ability to withstand the various chemical defenses. Species that do not carry these chemically defensive traits must avoid predators by making themselves harder to find. (Hanson and Nishida, 2016). It might be expected to find Lepidoptera species that cannot manage these specialized chemical defenses, rely on their larvae to make themselves more discrete through leaf manipulations, and only on certain plant types without chemical defenses (Hanson and Nishida, 2016). Some spider species will use silk to construct bends in a leaf to create optimal protection for behaviors such as laying eggs (Suter et al., 2011). For example, the *Clubonia riparia*, or the leaf-curling sac spider, create three sided capsules out of a blade of grass or leaf to enclose themselves in this structure to lay eggs. (Suter et al, 2011). This takes a fair amount of energy from the spider, but it seems to increase security and survival. The goal of this study was to investigate the various strategies employed by certain insects and arachnids that create these refuges, and get a better understanding of the benefits and costs of using this energy to construct them. Since these structure-building behaviors are presumably coded into their DNA, I wondered if there was species specificity within family. Do certain arthropods follow the same or similar architectural patterns within the same family of plants? Essentially, I wanted to understand what families are the architects of the arthropod world, and what structures they create and why. And furthermore, at the different protected areas of Monteverde, in varying life zones, will there be different species?

MATERIALS AND METHODS

Study Sites

I included three sites around Monteverde : the trails surrounding the Estación Biológica, the Rachel and Dwight Crandell Memorial Reserve trails behind the Monteverde Institute, and the Bajo del Tigre reserve trails. All three of these areas are protected and belong in a different life zone. The Estación Biológica is located in the lower montane wet forest, the Rachel Dwight Crandell Memorial Reserve trails are in premontane wet forest, and Bajo del Tigre is classified as premontane moist forest.

Data Collection

I surveyed each of the three sites for six hours. I chose a different trail each time I went in to collect data in order to cover a large area. I walked the length of the trail slowly surveying from left to right and when there was a break in the trail creating an entrance to the woods, I searched in the deeper forested area for ten minutes. I did not spend as much time in the woods as the trails—I found that leaf structures were more heavily concentrated on the edges, and more scattered in denser foliage. On the trails, when there were more crowded patches of plants, I would stop and examine. Otherwise, when spread out, the manipulated leaves were fairly noticeable when moving. Once I finished a trail, I would walk back the way I came, continuing to examine, but at a faster pace, just to make sure that I had not missed anything, and then I would choose a new trail. When I found a leaf that had been modified, I removed it from the plant, taking enough of the plant to be able to identify it to family level, and then placed it in a plastic bag. Once brought back to the lab, I double-checked whether there was an arthropod present using the leaf refuge, took pictures, and then described the manipulations to the leaf and the exhibited behavior. I classified the shape of the structure by naming it something that described the form. I then identified the plant to family level with the help of Eladio Cruz, and arthropod to family with help from Emilia Triana for families in the order Araneae, and Kenji Nishida for families in order Lepidoptera and Orthoptera. In my data I also included notes about the plant, how many individuals were using the plant (in other homes), and anything else notable about place or behavior.

In order to understand the diversity between the three sites, I did a Shannon Wiener Diversity Index test.

RESULTS

The most abundant family of arthropod architects for all areas is the family Anyphaenidae (21 individuals) followed by Theridiidae (6), and the family Pyralidae (6), and then Salticidae (4) (Figure 1). The least abundant families were Bombycidae (1), Mimallonidae (1), Decophoridae (1) and Scytodidae (1) (Figure 1). The richest order was Lepidoptera (8, not including "Micro Lepidoptera"), then Araneae (4), and lastly, Orthoptera (1) (Figure 1).

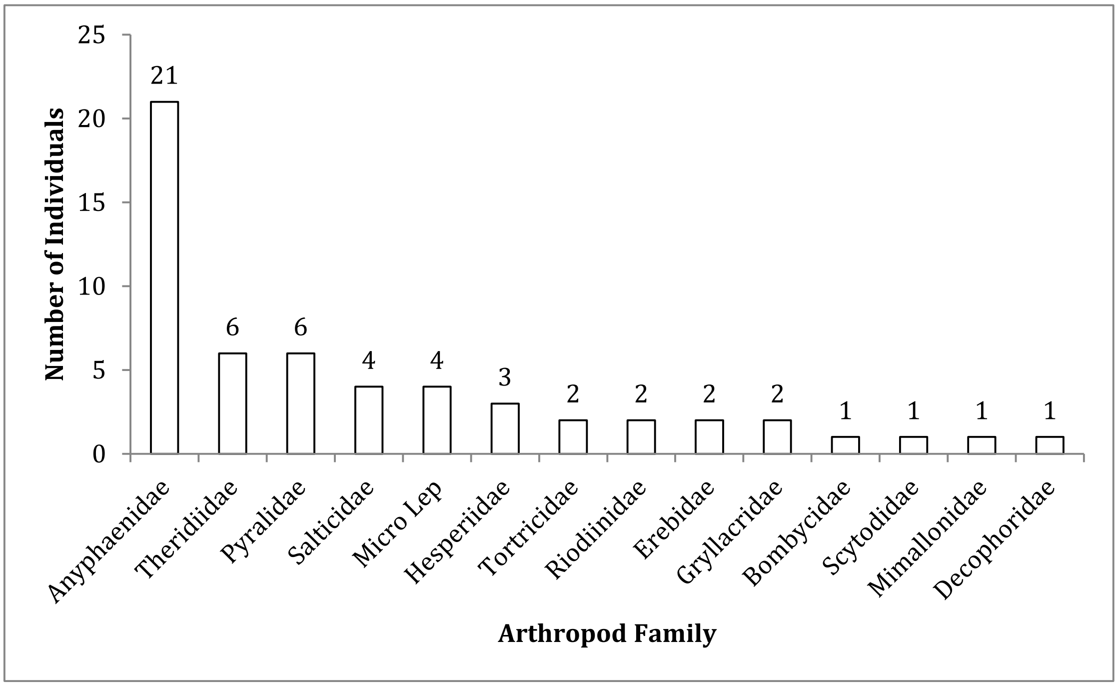

Figure 1. Number of individuals in each family found at all three sites: Estación Biológica, Rachel Dwight Crandell Reserve trails, and Bajo del Tigre.

I found more individuals in Bajo del Tigre (22), followed by Rachel and Dwight (21), and the least were caught in the Estación Biológica trails (13). At Bajo del Tigre and Rachel and Dwight, 8 different families were collected, and I collected 6 different families at the Estación Biológica (Figure 2).

The most abundant family, and found in all three sites, was the Anyphaenidae, and the largest amount of Anyphaenidae were collected in Bajo Del Tigre (9), followed by the Rachel and Dwight (8), and last the Estación Biológica trails (4). Theridiidae, the second most common family found, was only collected at Rachel and Dwight (5), and at the Estación Biológica (2). Pyralidae, the third most common and a family of the order Lepidoptera, was only collected in Bajo Del Tigre (4), and the Estación Biológica (2) (Figure 2).

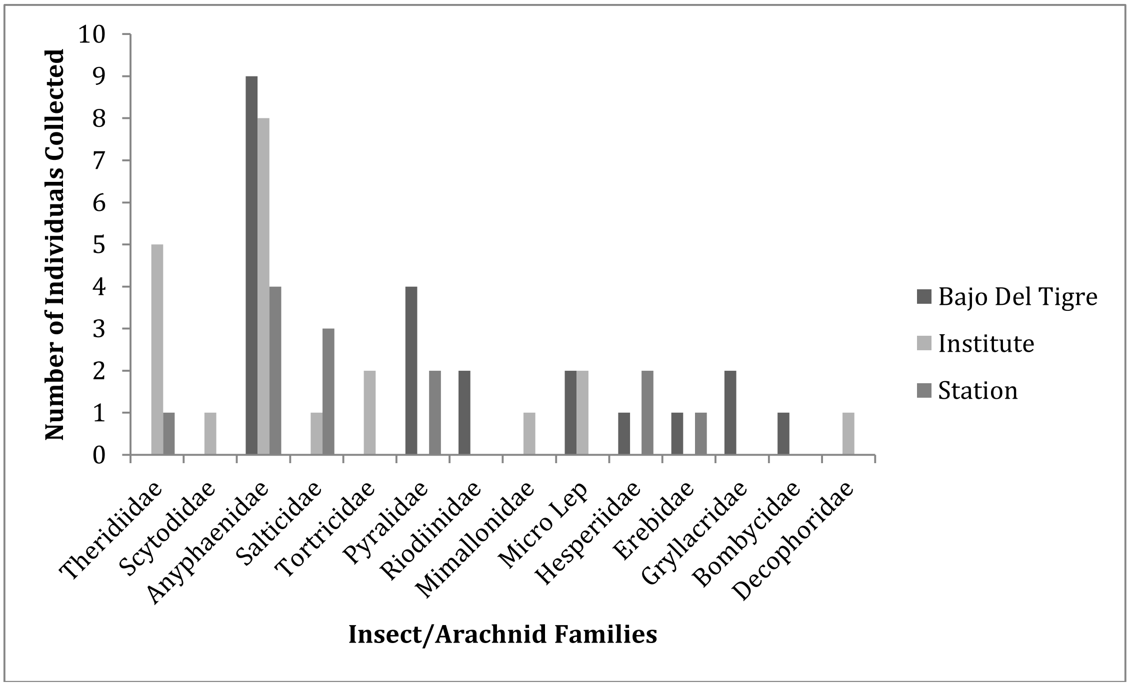

Figure 2. The families of insects and arachnids collected at all three sites: Estación Biológica (Station), Rachel and Dwight Crandell Reserve (Institute), and Bajo Del Tigre.

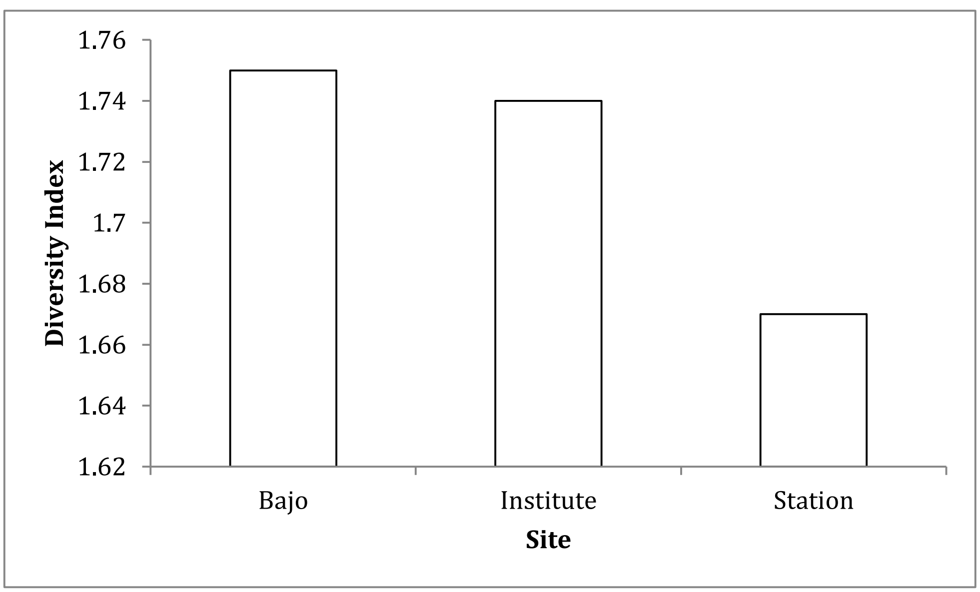

Figure 3. Shannon Weiner Diversity Index for the three sites of Bajo Del Tigre, Rachel and Dwight (Institute), and the Estación Biológica.

The diversity between sites was not statistically different. The diversity index for Bajo Del Tigre is 1.75, for Rachel and Dwight is 1.74, and for the Estación Biológica is 1.67 (Figure 3).
The family Anyphaenidae had 13 individuals who were observed laying eggs, which was the most abundant category. The arachnid families were more commonly found exhibiting behaviors of shelter—Theridiidae (6), Anyphaenidae (6), Salticidae (2), molting—Anyphaenidae (2), Salticidae (1), or laying eggs—Anyphaenidae (13), Theridiidae (1), Scytodidae (1), and Salticidae (1). For the Lepidopteras, the behaviors exhibited were feeding and pupate. The most common family feeding was Pyralidae (6), where all specimens found were displaying this behavior, and the groups that exhibited the majority of pupation were Riodiinidae (2), Hesperiidae (2), and the micro-Lepidopteras (2) (Figure 4).

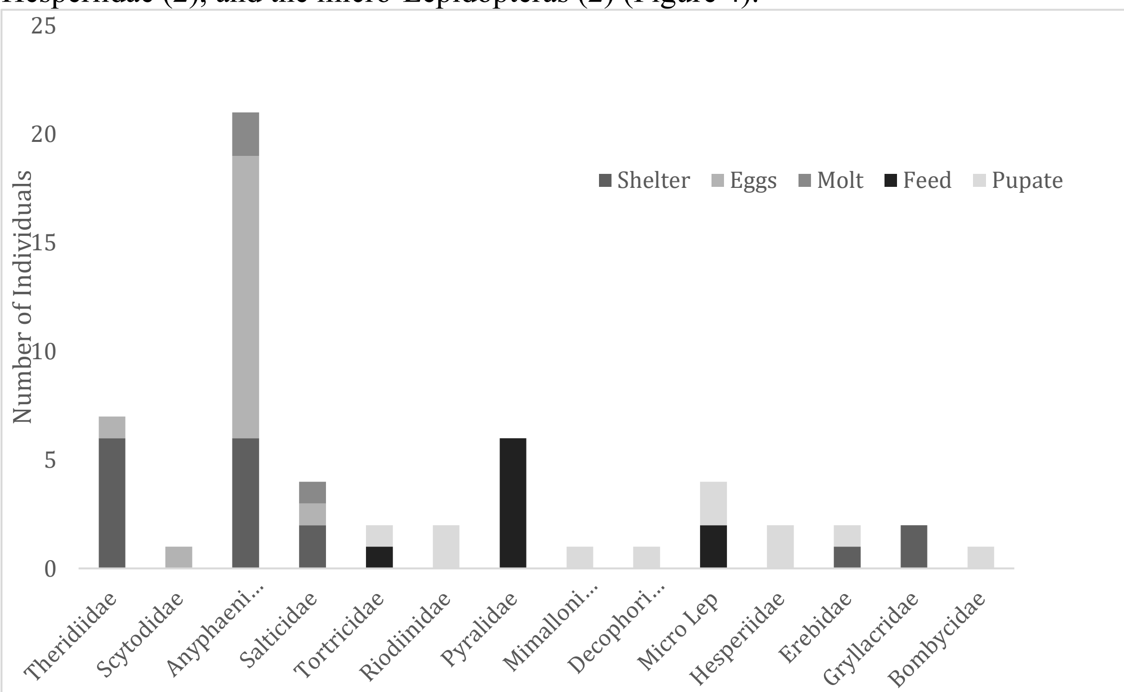

Figure 4. Families of the insect or arachnid and the behavior that they exhibited in the leaf structure.

Displayed below is where the families overlap in terms of leaf structure, and the behavior within the refuge (Table 1). The highest instance of overlap is within the Anyphaenidae family with the exhibited behavior being laying eggs, and the structure being "pyramid" (11). The next highest overlap is in the family Theridiidae with "tsunami" as a structure for shelter (3). All of the rest of the families either only have one or at most, two overlaps with behavior and leaf structure.

Table 1. The family, the leaf structure, the behavior, and how many there were in each category.

Insect/Arachnid Family	Leaf Structure	Shelter	Molt	Eggs	Feed	Pupate
Anyphaenidae	Gyro	2				
Anyphaenidae	Gyro		2			
Anyphaenidae	Elf Shoe			2		
Anyphaenidae	1-Roll	1				
Anyphaenidae	Elf Shoe	1				
Anyphaenidae	Pyramid			11		
Anyphaenidae	Empanada	2				
Bombycidae	Teepee					1
Decophoridae	Small Taco					1
Erebidae	Torta	1				
Erebidae	Loose Tip curl					1
Gryllacrididae	One-fold	1				
Gryllacrididae	One-fold	1				
Hesperiidae	Burrito					1
Hesperiidae	Teepee					1
Hesperiidae	Leaf cap					1
Micro Lep	Churro				1	
Micro Lep	Quesadilla					1
Micro Lep	Tiny tip fold					1
Micro Lep	Wish bone				1	
Mimallonidae	Dead leaf shelter					1
Pyralidae	Churro				2	
Pyralidae	Taquito				2	
Pyralidae	Side Roll (Curl)				2	
Riodiinidae	Quesadilla					1
Riodiinidae	Open Box					1
Salticidae	Nachos			1		
Salticidae	Nachos	1				
Salticidae	Pocket Fold		1			
Salticidae	Fern Tunnel	1				
Scytodidae	Boat fold			1		
Theridiidae	Which hat	1				
Theridiidae	Tsunami	3				
Theridiidae	1-Roll			1		
Theridiidae	Fern Tunnel	1				
Tortricidae	Taquito				1	
Tortricidae	Quesadilla					1

There are a few instances where there are overlaps between insect/arachnid family, plant family, and site (Table 2). Anyphaenidae on Fabaceae occurred at Bajo del Tigre and the Institute, Anyphaenidae on Rubiaceae occurred both in Bajo del Tigre and the Estación Biológica, Anyphaenidae on Solanaceae at Bajo del Tigre and the Institute, and same for Anyphaenidae on Lauraceae. The only overlaps among place and plant family occurred for the family Anyphaenidae. The overlap for arthropod family and plant family was slim as well. Individuals from the family Anyphaenidae were recorded using the plants from the family Solanaceae (4), and Rubiaceae (3). In the order Lepidoptera, the only overlap occurred with individuals utilizing Rubiaceae (2).

Table 2. Overlap of the individuals' family, the plant family in which they created the leaf structure, and site.

Insect/Arachnid Family	Plant Family	Bajo del Tigre	Rachel and Dwight	Estación Biológica
Anyphaenidae	Myrsinaceae		X	
Anyphaenidae	Asclepiadaceae		X	
Anyphaenidae	Acantaceae			X
Anyphaenidae	Asteraceae			X
Anyphaenidae	Fabaceae	X	X	
Anyphaenidae	Rubiaceae	X		X
Anyphaenidae	Salicaceae			X
Anyphaenidae	Piperaceae		X	
Anyphaenidae	Solanaceae	X	X	
Anyphaenidae	Timeliaceae		X	
Anyphaenidae	Capriforliaceae	X		
Anyphaenidae	Lauraceae	X	X	
Anyphaenidae	Sapotaceae	X		
Bombycidae	Rubiaceae	X		
Decophoridae	Lauraceae		X	
Erebidae	Araceae			X
Erebidae	Solanaceae	X		
Gryllacrididae	Piperaceae	X		
Gryllacrididae	Rubiaceae	X		
Hesperiidae	Malvaceae			X
Hesperiidae	Rutaceae			X
Hesperiidae	Araliaceae	X		
Micro Lep	Myrsinaceae		X	
Micro Lep	Araliaceae		X	
Micro Lep	Rubiaceae	X		
Mimallonidae	Piperaceae		X	
Pyralidae	Asteraceae			X
Pyralidae	Acantaceae			X
Pyralidae	Rubiaceae	X		
Pyralidae	Unknown	X		

Pyralidae	Asteraceae	X		
Riodiinidae	Myrsinaceae	X		
Riodiinidae	Meliaceae	X		
Salticidae	Piperaceae		X	
Salticidae	Rutaceae			X
Salticidae	Fern			X
Scytodidae	Piperaceae		X	
Theridiidae	Araceae		X	
Theridiidae	Piperaceae		X	
Theridiidae	Fern			X
Theridiidae	Lauraceae		X	
Theridiidae	Rubiaceae		X	
Tortricidae	Proteaceae		X	
Tortricidae	Araceae		X	

DISCUSSION

This study concluded that although there may not be a species specificity of architecture by family, or plant family used, there were clear trends in what kinds of species were crafting their own homes from leaves. Within family, especially displayed among the arachnid families, for the different functions they would exhibit, there was a different structure they would use to accommodate each function. The Anyphaenidae family for example constructed many different types of refuges, but all of them were used differently—the "pyramid", a cone-like structure folded tree times, was most likely the species *Clubonia riparia* (Suter et al, 2011) was always and exclusively utilized for laying eggs. A shelter, classified as the "gyro", an upturned structure with webbing pulling the center together was most often used for molting. Most arachnids post molting are less mobile for a couple days—once they shed their exoskeleton, the skeleton underneath is soft and pliable until it hardens (Overton, 2007). Creating a shelter in order to molt with protection is a good use of energy to ensure survivorship. The more closed structures, such as "elf shoe" were structures that were discrete as they wrapped the leaf into a small horizontal cone shape. This was more often used as a shelter. These differences in refuge type could also be determined by the different species that were present within family—if I had identified to species level, this could have been understood better. Another family of arachnids, the Theridiidaes, also had interesting things regarding leaf structure. The differences in shape were not drastic, but they appeared different, most likely because of the leaf they utilized. For example, a "witch hat" on an Araceae plant verses a "tsunami" on a Lauraceae. The Araceae provides a much wider and stouter leaf, while the Lauraceae is longer and leaner—the way the fold was created was very similar, but gave a different appearance with a different plant family.

For Lepidoptera, there were fewer consistencies with shape—this could be due to my small sample size from each family. However, I did notice that for different behaviors- pupate and feed, there were similar shapes. For feed, larvae almost always demonstrated a roll structure, while for pupation; they constructed more flat structures with multiple leaves.

Another thing to note is that the Theridiidae family was collected most abundantly in the Rachel and Dwight (Institute) trails, less so at the Estación, and then not at all in Bajo del Tigre. I found them at every site, but their webs varied. The individuals collected at the institute (5) had their webs solely contained within one leaf while the webs of the individuals found at the station (1) and Bajo Del Tigre (0) expanded to other leaves. They still utilized a leaf curl for protection, but they had a web that extended down to other leaves or other parts of the plant—demonstrating a classic Theridiid web structure—meaning a more or less irregular web with strands attached to a substrate below a protective cover of a leaf, rock, or branch (Shapiro, 2014). This kind of structure, that I did not collect or include in my data set, I also observed in other individuals especially within Bajo del Tigre. There was a type of small orb weaver that utilized a manipulated a leaf or a couple of manipulated leaves for protection. They would build their webs underneath or between the leaves and have the leaves off to the side as a base to take refuge in if there was danger or something startled it. This type of behavior however, I did not observe behind the Institute, and seldom in the Estación trails.

My results showed that the richness of arachnid families is lower, but the abundance is fairly high, and the richness of Lepidoptera families is higher, but has a lower abundance. Also for spiders, there are not necessarily family specificities to leaf type used—this may be more prevalent in the Lepidoptera families even though my data does not show this. For example, one of the individuals in the Hesperiidae family is of the species *Astrapes augeas*, and they are only found on plants in the Malvaceae family (Carmona, 2016). Additionally, they are almost always found in a little home that they made for themselves in the leaf for protection while they feed (Carmona, 2016). This is one species that was included in my data, and it was found on a Malvaceae.

There are many plants that employ chemical compounds for defense against herbivores (War et al., 2012). So although there was not an explicit trend with insects and their choice of leaves, it is plausible that they chose specific families of leaves for different reasons. If the individual is able to cope with the chemical defense of a plant, then they may not make these structures for they would not need to expend the energy for protection from parasites or other predators. Instead their own chemical compounds would be their defense. (Gentry and Dyer, 2002). Without a chemical resistance, the larvae chose plants that were less harmful, and they spent the extra energy for protection. According to a study done by Robert Marquis and John Lill, there are likely other structural features of host plants that attribute to an individuals choice of construction site. This had to do with weight of the larva, and differences in nitrogen, nitrogen availability, and protein-binding capacity of leaf extracts (Marquis and Lill, 2010). This however, really only pertains to when larvae exhibited the behavior of feeding rather than pupating.

Also explained by my results, there was not necessarily a trend or overlap between family of individual and the family of plant that they used for the structure within the three sites. This lack of overlap could be attributed to the fact that there was not a significant amount of individuals collected from all families other than Anyphaenidae. The only overlap that did not occur within the family Anyphaenidae was in Pyralidae with Rubiaceae.

Another finding, was that in some cases there were other individuals using structures that they did not create. They would take over refuges that the individual who created it, abandoned. I found species partaking in this behavior such as weevils and other Coleoptera. Another type of individual that I suspect could be deemed a "squatter", or individual that overtakes an old refuge is from the Salticidae family. The two structures that I classified as "nacho", I believe created their own structure, since one individual recreated it within the plastic bag, but the ones found in "fern tunnel" and "pocket fold", I expect the individuals were taking over an old refuge for protection as well as means of energy preservation. I did not include those two structures within the data set however, because I have no data to support that claim.

Another insect, that at first, I assumed to be a squatter was a cricket from the Gryllacridae family. However, I learned that they do in fact spin silk to build shelters and are one of two families in this order that are able to do this (Walker et al., 2012). This type of cricket is known as the Raspy cricket and during the day they retreat to the leaf shelter they created—this has been presumed to be a defense against predation, but it has also been suggested to be a protection from desiccation in dryer areas (Walker et al., 2012).

It is important to understand how different arthropod use their environment and understanding how they protect themselves. When we understand our environment better, we can connect to it more—as well as seek to better conserve it. During this study, there were many things that occurred that I found interesting and surprising—but since it is a little understudied, I was not able to explain these occurrences. With more interest in this topic, we will be able to understand the behaviors of the many arthropods among us.

Future Studies

In all three sites, I encountered a high quantity of vacant caterpillar refuges. These more often had been used for feeding. However, it made me consider at what point do Lepidoptera deem a leaf unsalvageable—when do they move on to another food source? Some it seemed, ate away a good amount of the leaf, while others only depleted a small portion of it. Perhaps this is something that varies with family or species, size, or how close the individual is to pupating. In the future, I would like to study this in greater depth.

Another consideration I would like to look more into is whether the individual, when put under stress, exhibits the behavior it created the shelter for faster—for example laying eggs or pupating, or if the disturbance changes the behavior they would have exhibited, as this is something that could have skewed my data as well.

Another aspect that would have been beneficial to focus on was at which height the specimen was collected from—although I could not see easily or reach individuals higher up it would be an interesting thing to note. Observationally, I found that arachnid individuals were more often higher up and Lepidoptera were closer to the forest floor. With more time and resources it would also be interesting to see what architect species are found higher up in the canopy.

ACKNOWLEDGEMENTS

I would like to thank my advisor Sofia Arce Flores for all her help throughout the entire process, for taking an interest in my project and essentially making it a reality—by providing me with all the necessary resources to keep me moving forward. I would also like to thank her baby Abi for always brightening my day with her presence. I would like to thank Emilia Triana for helping me identify my arachnid families and for diminishing my fear of spiders. A special thanks to Kenji Nishida for allotting me some of his time to identify my insect species and for continuing to keep in touch on the specific species of larvae once reared. I would also like to thank Eladio Cruz for identifying my plant families, as this was very helpful. And a final shout out goes to all of the

EAP staff and family for keeping me engaged and in good spirits—and to Frank Joyce for making this program and experience possible!

LITERATURE CITED

Bartlett T, Hyche L. 2003. Leaf Curl/Roll.

Carmona M. 2016. Astraptes augeas (Hesperiidae). *Area de Conservacion Guanacaste Costa Rica*.

Fukui A. 2001. Indirect interactions mediated by leaf shelters in animal-plant communities. *Population Ecology*. 43(1). 31-40.

Gentry G, Dyer L. 2002. On the conditional nature of neotropical caterpillar defenses against their natural enemies.

Hanson P E, Nishida K. 2016. Insects and Arthropods of Tropical America. Cornell University Press, Ithaca, NY.

Marquis J, Lill J. 2010. Impact of plant architecture versus leaf quality on attack by leaf-tying caterpillars on five oak species. *Oecologia*. 163 (1).

Overton M. 2007. How Do Spiders Grow: (Moulting and Regeneration). *The Tarantula's Burrow.*

Shapiro, L. 2014. Brief Summary. *Encyclopedia of Life*.

Suter B, Miller P, Stratton G. 2011. Egg capsule architecture and siting in a leaf-curling sac spider, Clubonia riparia (Araneae: Clubionidae). *Journal of Aracnology*. BioOne.

Walker AA, Weisman S, Church JS, Merritt DJ, Mudie ST, Sutherland TD. 2012. Silk from Crickets: A New Twist on Spinning. PLoS ONE 7(2): e30408.

War A, Paulrai M, Ahmad T, Buhroo A, Hussain B, Ignacimuthu S, Sharma H. 2012. Mechanisms of Plant Defense Against Herbivores. Plant Signaling and Behavior. NCBI.