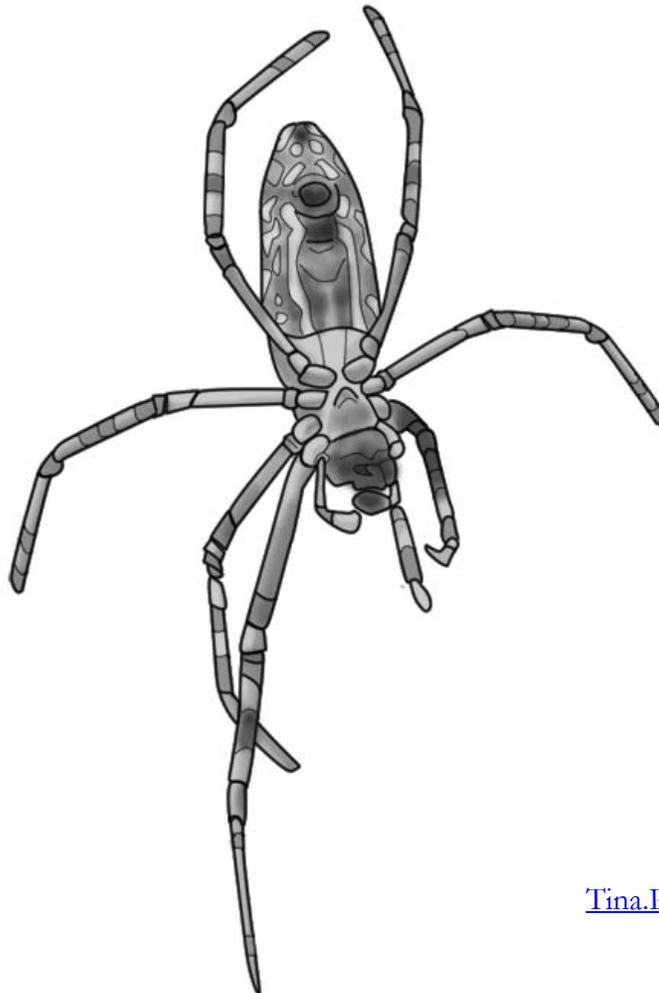


A Baseline Study of the Spider Fauna at a Costa Rican Cloud Forest Reserve

Cloudbridge Nature Reserve, Costa Rica

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ABSTRACT

Spiders play a critical but poorly understood role in the ecology of tropical forests. The aim of this study was to determine the density and diversity of spiders at a Costa Rican cloud forest reserve, and to provide a baseline by which subsequent studies on local Araneofauna may be compared. Collections were made at 6 paired study sites; 2 each for pasture, secondary forest and primary forest, with an approximate altitudinal separation of 500ft between sites. Sampling was conducted over 6 consecutive days, and consisted of hand collections, leaf-litter sorting and the use of pitfall traps. One additional collection was conducted for each low altitude site during night-time hours. The resultant data was analyzed for richness, evenness, diversity and community similarity. A unique family and morphospecies composition was found for each habitat type, with the greatest diversity found in primary forest.

Key words: *arthropod; arachnid; araneid; spider; diversity; census; Chirripo; Costa Rica*

INTRODUCTION

Spiders are abundant, diverse, and with over 34 000 recognized species, comprise amongst the largest portions of invertebrate fauna in any habitat (Coddington and Levi, 1991). They are distributed on every continent except Antarctica, and have adapted to all known ecological environments except air and open sea (Foelix, 1996; Yang, 2008). In terrestrial habitats, spiders are a dominant group of predators that, in their role as generalist feeders, often play a strong part in influencing community structure (Nentwig, 1986, Wolff, 1990). They have been reported to occur in abundances of over 1000 per meter squared (Ellenberg et al, 1986), and exhibit a variety of foraging strategies by which they exert control over invertebrate populations in varying ecological niches (Foelix, 1996). In this regard, they have also been found to serve practical roles as biological agents for the control of crop pests, in particular, harmful insects within cotton ecosystems (Breene et al., 1993; Young and Edwards, 1990). Despite this, very little is known about the abundance, distribution and natural history of many species (Yang, 2008; Wolff, 1990).

One particularly fascinating example of the potential applications of spider-derived research comes in recent studies on an African species of jumping spider, *Evarcha culicivora*, which feeds preferentially on female blood-carrying mosquitoes, and more particularly, on female mosquitoes of the genus *Anopholes*. Critically, *Anopholes* mosquitoes are the primary carrier of the human malaria parasite (Pollard and Jackson, 2007). Current studies are further investigating the behaviour and ecology of this species as a possible tool for the fight against malaria.

Recent studies have investigated the importance of spiders as ecological indicators. Terrestrial arthropods, of which spiders are amongst, have long been monitored for early warning signs of environmental change. In contrast to vertebrate indicator species, the physiology of many arthropods exhibits a greater susceptibility to environmental change, and thus greater detectability

to many monitoring methods (Kremen et al, 1993). A recent study examining the effects of anthropogenic change on spider populations found significantly greater concentrations of certain heavy metals in spider tissue when compared to other arthropods (Maelfeit, 1998). This study illustrates an important point: as predators, the concentration of any substance within a given spider will be reflective of the concentration of that substance in each organism consumed prior to that point (Clausen, 1989). It is therefore possible that trace concentrations of toxins may build to detectable levels within spider species that would otherwise go un-noticed in lower-food-chain invertebrates.

In addition, the use of spiders as an indicator species has supported research of more widespread environmental changes. A study of spider assemblages in relation to succession of heavily grazed landscapes found that certain families were characteristically represented in particular levels of succession (Gibson et al., 1992). Spiders have also been used in the study of habitat structure, where they have been found to vary with moisture levels and canopy cover (Hore and Uniyal, 2008), as well as in the study of rare habitats, such as European peat bogs, where they're densities and distributions may be communicative of the state of that community (Scott et al., 2006). They're diversity in foraging strategies and habitat preference, ease of collection as well as high relative abundance all contributes to their versatility and applicability to a range of ecological and environmental studies (Yen, 1995). While a great deal has been gleaned on invertebrate diversity in terrestrial ecosystems, significantly less is known on their role in the tropics (Russel-Smith, 2002). This present study aims to contribute to our growing knowledge on the distribution and ecology of spider communities across an altitudinal gradient and three distinct habitat types. By providing a baseline census of the araneofauna at a tropical cloud forest reserve, I hope to provide a foundation on which further studies may be built.

METHODS

Study Site

This study was conducted in the Cloudbridge Nature Reserve, a tropical cloud forest located Northeast of San Gerardo de Rivas, in San José Province, Costa Rica. The reserve is located in the valley of the Rio Chirripó, at the point of its convergence with the Rio Uran, on the Pacific slopes of the Cordillera de Talamanca. An enormous amount of diversity is contained within the reserve, owing in part to its wide altitudinal gradient of 1500 to 2620 meters above sea level, as well as its geographical location as a land bridge joining the North and South American continents. Over the years, much of the property has been modified by anthropogenic disturbance – ranging from clear cutting to cattle farming and use as plantation land. A great deal of effort has been invested in recent years to restore the flora and fauna to its original capacity, through natural re-growth as well as re-plantation, which has contributed to the varying microhabitats that are seen at present.

Data Collection

Spiders were collected from six sites comprising three distinct habitat types: pasture, secondary forest and primary forest. Two sites of matching characteristics (vegetation, canopy cover, etc) were selected for each habitat, with an approximate altitude difference of 500 feet, and a minimum of 20 feet from paths or trails (see Appendix 3 for natural history of selected sites). Spiders were sampled for six consecutive days during early August of 2009. All sampling was conducted by two observers – myself and an assistant – in order to reduce any potential observer bias as well as increase sample size. Each site was sampled for a total of 4 hours: 20 minutes per site per person, for each of the six sampling days. An additional hour (0.5 hours per person) was spent conducting night collections at each of the low altitude sites. Since each habitat site was comprised of two sites, a total of 9 observer hours were spent in total: 8 during morning hours and 1 during night time hours.

An outline of additional site details, such as geographic coordinates, elevation and vegetation are presented in Table 1, below.

Habitat		Elevation (ft)	Coordinates	Dominant Vegetation	Sampling hours	
					Day	Night
Pasture	Low	5600	N09°28.385 W83°34.349	Tropical grasses <i>Euphorbia leucocephala</i>	4	0.5
	High	6020	N09°28.293 W83°34.346	<i>Cedrela tonduzzi</i>	4	
Secondary	Low	5530	N09°28.252 W83°34.375	<i>Helicarpus americanus</i>	4	0.5
	High	6030	N09°28.122 W83°34.303	<i>Annona muricate</i> <i>Croton draco</i> <i>Quercus rapurhuensis</i> <i>Persea caerulea</i> <i>Ulmus Mexicana</i>	4	
Primary	Low	5710	N09°28.124 W83°34.301	<i>Alnus acuminata</i>	4	0.5
	High	6200	N09°28.066 W83°34.266	<i>Cedrela tonduzzi</i>	4	

Table 1. Site details: Elevation, geographic coordinates, dominant vegetation and sampling hours of each collection site.

A combination of methods was used to sample spider populations. One day prior to the commencement of sampling, each site was marked off and pitfall traps were laid. Traps were set in a 2 meter by 2 meter square, with an additional meter on each side of the traps being included in the sampling area for each site. Pitfall traps were prepared in accordance to past studies (Russel-Smith, 2002; Slowik, 1996; Wolff, 1990), with two 400ml cups set within one another and placed in a hole flush with the ground and

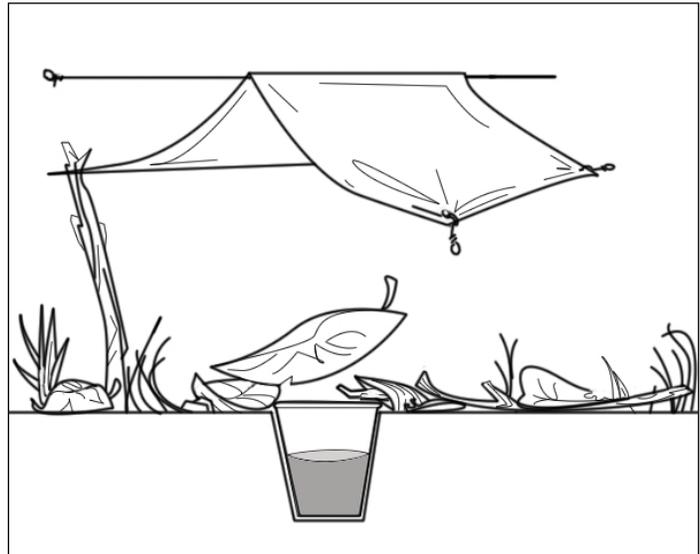


Figure 1. Schematic of pitfall trap design.

partially concealed with leaf litter. Traps were filled to a quarter of their depth with water to which trace amounts of detergent were added. Trap contents from each site were filtered through a 1 mm mesh sieve, and later pooled and preserved in 80% ethanol for subsequent sorting and identification. In addition, a 50x50”square of a transparent vinyl was suspended with rope over each trap to prevent dilution of entrapping fluid with rainfall (Figure 1).

Sampling was carried out in the morning of each day between the hours of 6-9am, and consisted of 20 minutes of spider collection and/or counts, followed by trap collection. One additional 30-minute night collection for each low-altitude habitat type was conducted without the emptying of pitfall traps. The purpose of sampling was to provide an accurate count of spider species present at a given site, so spiders that were clearly duplicates of previously caught or familiar spiders were simply recorded onto a data sheet and left unharmed. Various methods were employed to locate spiders, including ground sampling (on plant surfaces, under logs and rocks), aerial sampling (searching leaf foliage, branches and tree trunks, sweep-netting) and leaf-litter sifting (pouring leaf litter onto a white sheet and collecting/noting emerging spiders). Spiders noted by one observer but not caught were brought to the attention of the second observer in order to prevent redundant sampling.

In order to present a more comprehensive picture of spider diversity at the Cloudbridge reserve, opportunistic collections were conducted beyond the six chosen sites during the months of July and August of 2009. Spider families collected in this manner and not otherwise represented through site collections are mentioned but not included in any analyses.

Spiders were identified to family level when possible using a key by Kaston et al (1972) as well as picture guides to identification (Levi, 2002) and resources on biology and behaviour (Foelix, 1996). Because of the difficulty of identifying juveniles, only adults were identified and used in subsequent analysis. Spiders of both known and unknown species were compared with previously caught specimens and assigned a unique morphospecies (MS) identification code if considered distinct. Research suggests that morphospecies may be used in place of exact species designations in environmental monitoring (Oliver and Beattie, 1996). Following identification, specimens were

grouped according to morphospecies, preserved in 80% alcohol, and stored in the Cloudbridge laboratory for reference.

Statistical Analysis

Spider assemblages were analyzed using Excel 2007. The Shannon and Simpson diversity indices, species evenness and species richness were calculated for spider populations in each site, each habitat type and each altitudinal set of sites, i.e, data from low altitude pasture, secondary and primary forest were pooled and compared with similar data for high altitude. Additional comparisons were made within each habitat type using the proportional index of community similarity, and t-tests were run to determine whether the diversity variance between paired communities was significant ($p < 0.05$).

RESULTS

Data Collection

A total of 406 spiders representing 15 families and 73 distinct morphospecies were recorded and identified during sampling. One additional unique family (Scytodidae) and 7 additional unique morphospecies (in families Araneidae, Linyphiidae and Therididae) were identified from other areas within the reserve, or during hours outside set sampling times (see Appendix 2 for common names and habitats of observed spider families). A few families of spiders were highly abundant in each site. In low pasture, 44.7% of sampled spiders were in the family Tetragnathidae, while 35.3% were in the family Linyphiidae in high pasture. In low secondary forest, 55.2% of spiders were within the family Tetragnathidae while 52.8% were in the family Ctenidae in high secondary forest. In low primary forest, 41.9% of spiders were in the family Ctenidae, while 35.3% were in the family Linyphiidae in high primary forest (Figure 2).

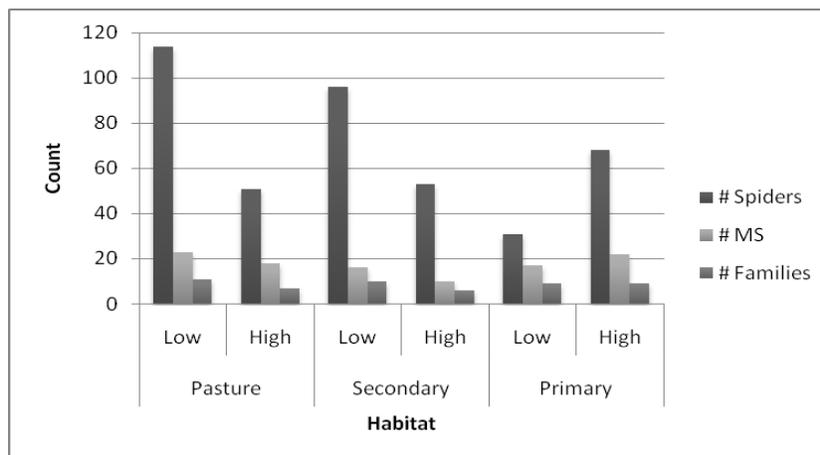


Figure 2. Spider, morphospecies (MS) and family counts for each sampling site.

When considering collective abundances across sites, Salticidae (20.7%), Tetragnathidae (18.1%) and Linyphiidae (17.2%) accounted for the largest proportion of spider species, while only Agelenidae, Ctenidae and Salticidae were represented in all of the 6 sites. Comparisons of low and high altitude sights demonstrated greater average abundances and diversity in data from pooled low altitude sights, which contained 56.7% of all spiders, 38 morphospecies and 20 unique morphospecies –while high altitude sights contained 32 morphospecies with only 13 unique species that were not additionally found in lower sights. The predominant family in low altitude sights was Tetragnathidae (25.8%) and in high altitude Salticidae (30.1%).

A complete record of spider families and abundances is outlined in Appendix 1, and summarized in Figure 3, below.

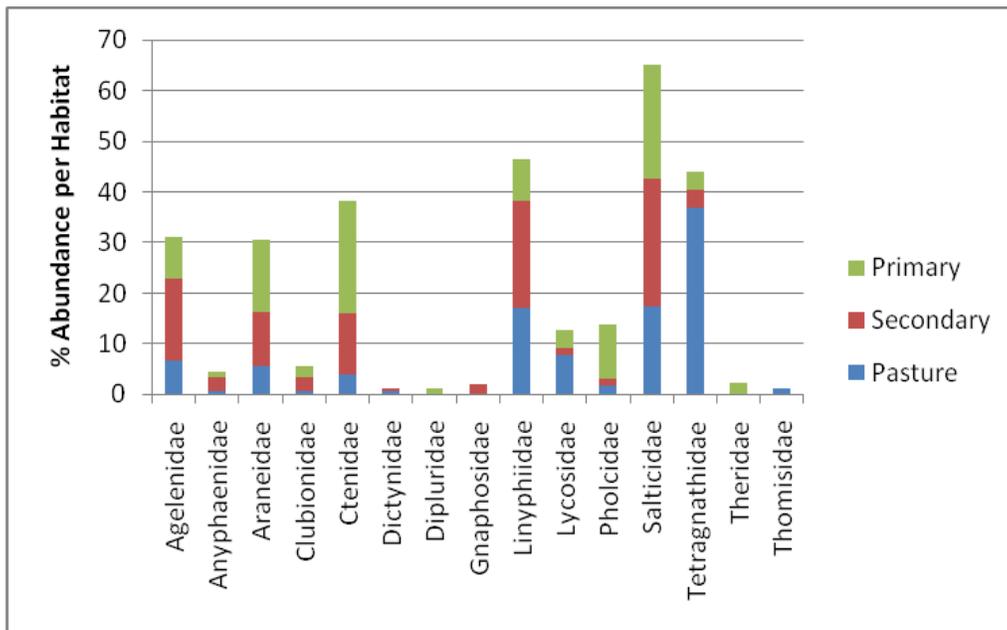


Figure 3. The percent abundance of spider families within each habitat; for example, Agelenidae comprises 6.7% of all pasture found spiders, 16.2% of all secondary forest spiders, and 8.2% of all primary forest spiders.

Of the 15 families sampled, 11 were found in various quantities in pitfall traps. Members of the family Agelenidae were collected in the greatest abundance, comprising 35% of all trap caught spiders (n=39) and existing in all three habitat types. Ctenidae, a family of wandering spider, and Salticidae, or jumping spiders, were also found in traps from all habitat types (20.5% and 15.4% respectively) (Table 3).

Families	Pasture	Secondary	Primary	Total
Agelenidae	5	6	3	14
Anyphaenidae	0	1	0	1
Clubionidae	0	1	1	2
Ctenidae	4	2	2	8
Dictynidae	1	0	0	1
Dipluridae	0	0	1	1
Gnaphosidae	0	1	0	1
Linyphiidae	1	0	0	1
Lycosidae	0	2	1	3
Pholcidae	1	0	0	1
Salticidae	4	1	1	6
	16	14	9	

Table 2. Abundances of spider families caught by pitfall traps.

Spiders caught in night collections differed in composition and type from those collected during the day (Table 4). Both Araneidae and Tetragnathidae were strongly represented (38.1% and 28.6% respectively) and were the only two families found in all 3 low altitude sites. Additionally, sampled Araneidae consisted of 10 distinct morphospecies across sites, the greatest within-family diversity observed. The greatest diversity within a habitat found in the primary forest site, which contained 16 distinct morphospecies compared to 7 in pasture and 6 in secondary. Additionally, it is worth noting that of those species recorded during night collections, 9 were unique morphospecies not recorded otherwise outside of that instant. Of these, 4 were in the family Araneidae, 2 in the family Linyphiidae, and 1 each in Thomisidae, Therididae and Pholcidae.

Family	Pasture	Secondary	Primary	Total	#MS
Agelenidae	0	0	1	1	1
Anyphaenidae	0	0	1	1	1
Araneidae	2	8	6	16	10
Clubionidae	0	0	1	1	1
Linyphiidae	1	0	2	3	3
Pholcidae	0	2	2	4	3
Salticidae	2	0	0	2	1
Tetragnathidae	8	3	1	12	2
Therididae	0	0	1	1	1
Thomisidae	1	0	0	1	1
Total	14	13	15		
#MS	7	6	16		

Table 3. Abundances of spider families surveyed during night collections.

Statistical Analysis

The species richness, species evenness, community similarity and Shannon and Simpson diversity indices were calculated for all sites as well as each habitat type and altitudinal community (Table 5). Species richness was markedly lower in combined secondary forest than either combined pasture or combined primary, with high secondary containing the fewest distinct species. Similarly, measures of species evenness were lowest for combined secondary forest ($E=0.45$), indicating that in this habitat type, a relatively small range of distinct species ($n=29$) are found in relatively uneven abundances. In contrast, species in both low and high primary forest were found to be evenly distributed in terms of abundance ($E=0.93$ and 0.88 , respectively).

	Pasture		Secondary		Primary		Low Altitude	High Altitude
	Low	High	Low	High	Low	High		
Species Richness	23.0 41	18.0	16.0 26.0	10.0	17.0 39.0	22.0	56.0	50.0
Pielou's Evenness Index (E)	0.67 0.69	0.81	0.91 0.45	0.74	0.93 0.88	0.88	0.78	0.78
Shannon Diversity Index (H)	2.1 2.6	2.3	2.5 1.5	1.7	2.6 3.3	2.7	2.8	2.7
Simpson Diversity Index (D)	0.8 0.8	0.9	0.9 0.9	0.8	0.9 1.0	0.9	0.9	0.9
Significance of Simpsons Diversity	$t=2.32$, $df=164$, $p<0.05$		$t=3.98$, $df=91$, $p<0.05$		$t=0.63$, $df=97$, $p>0.05$			
Proportional Index of Community Similarity (PS)	34.98%		25.62%		23.77%			

Table 4. Summary of statistical analysis performed on the data. Night collections were included only in combined scores for each habitat type.

Analysis of biodiversity across habitat types found primary forest to contain the greatest diversity ($D=1.0$, $H=3.3$) and secondary the least ($D=0.9$, $H=1.5$). The site with the greatest diversity according to the Shannon index (Figure 2) was high primary forest, though it is worth noting that the Simpson index (Figure 4) found much subtler differences within sites, and an equivalent diversity in high pasture, low secondary, and high and low primary forest.

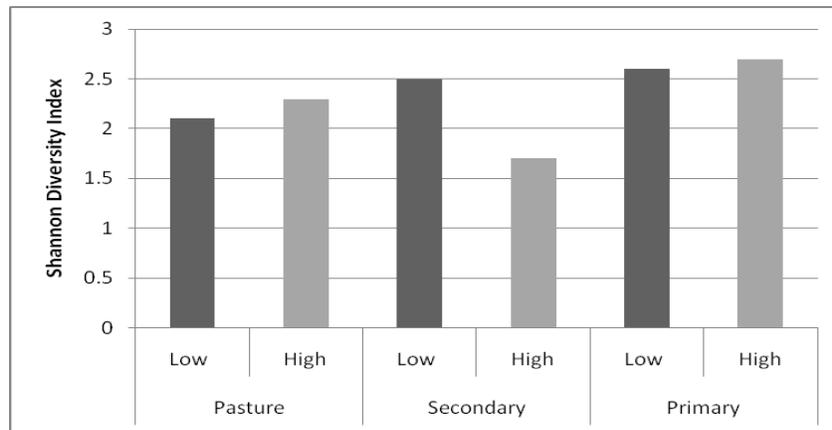


Figure 4. Average biodiversity of each low and high elevation habitat type, calculated by the Shannon Diversity Index.

Interestingly, though the Simpson index calculates near identical amounts of diversity between low and high altitude sights, an extended analysis between sights per habitat type found a statistically significant diversity difference between both pasture and secondary forest paired communities ($p < 0.05$). This difference was not found for primary forest ($p > 0.05$), indicating that the diversity between low and high altitude primary forest sights was indeed comparable, according to this measure (Figure 5).

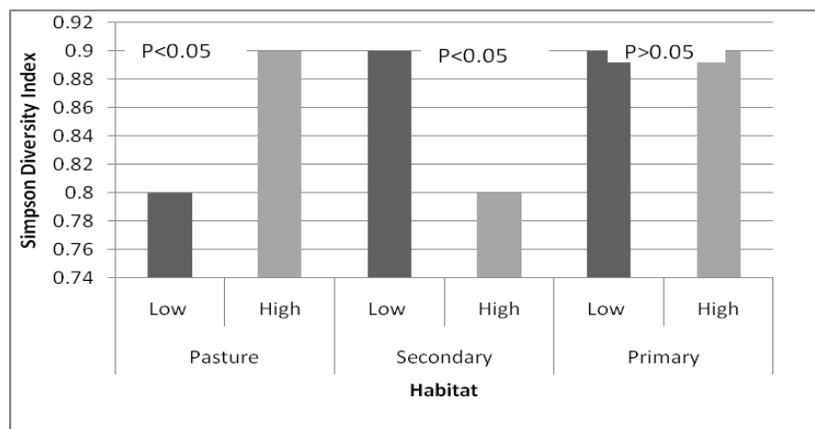


Figure 5. Average biodiversity of each low and high elevation habitat type, calculated by the Simpson Diversity Index. Habitat types with significant diversity differences between high and low altitude communities are represented when $p < 0.05$.

Another measure, an index of proportional similarity between paired communities found the greatest similarity between pasture communities (PS=34.98% similarity), while secondary (PS=25.62%) and primary (PS=23.77%) forests differed only marginally (by 1.85%). However, the previously discussed analysis of the Simpsons index found secondary, but not primary, forest communities to differ significantly. This presents a discrepancy in analysis of secondary forest sites, as they are simultaneously more distinct (Simpsons index) and more alike (proportional similarity index).

DISCUSSION

The aim of this study was to identify the spider families present at a cloud forest reserve, and determine to what degree family and morphospecies densities and composition varied with habitat type. Comparisons were made between pasture, secondary and primary forest sites, as well as between low and high altitude communities of paired sites. The results from this data demonstrate a large degree of variability, which correlates with both altitude and habitat type.

The greatest densities were observed in the low pasture site, while the greatest diversity was found in primary forest, which is intuitive when we consider that pasture, as a habitat, provides an incredibly large amount of surface area while at the same time providing little variability in microstructure. Indeed, nearly 37% of all pasture caught species were in a single family.

The composition of trap-caught collections also differed from hand-caught collections. Funnel weavers of the family Agelenidae comprised 35.9% of all trap-caught spiders, yet made up only 10.3% of spiders caught overall, while most other families were represented by only a few trap-caught individuals. For the relatively short-duration of this study, it is fortunate that other methods were adopted to supplement pitfall trap collections, as the yield was quite low (39 individuals across 144 trap collections). A study by Uetz and Unzicker (1976) determined that though pitfall trapping is amongst the most effective means of sampling wandering spiders, they should be used over an extended period of time (i.e, an entire growing season) and with analysis restricted solely to cursorial species.

It is also interesting to note that while each low altitude site varied markedly in species richness - and in some cases species diversity - from its higher altitude counterpart, when all low sights were collectively compared with all high sights, only the most minute of differences was noted. Thus, in summing the data across sights the evident altitudinal differences become blurred. This may indicate that altitude, in and of itself, was not a strong enough factor to lead to diversions in community structure, or that other factors, such as the natural history of a given site or the existence of differing microhabitats within each site, were simply stronger factors. Future studies could put in additional effort to control for these variables, by including an increased number of sites within each habitat type, spaced on a wider altitudinal gradient. Since altitude is correlated with factors such as temperature, humidity and distinctive plant growth (Koponen, 1991), it is very likely that spider communities would also be found to fluctuate as increases or decreases in these variables became more profound.

A number of measures were employed in analyzing the data from this study, and it is interesting to note that the degree of significance often corresponded to a particular measure. The Simpson index, for instance, suggests that pasture sites, when taken together, contain the smallest degree of diversity, while the Shannon index finds the same result for paired secondary forest sites. Additionally, secondary forest sites were found to contain a higher degree of similarity than primary

forest sites, according to the community similarity index, but at the same time were found to contain statistically significant differences between sites that, interestingly, were not found in primary forest comparisons. The numerical differences in these examples are small – however it is important to illustrate that the mode of analysis often colors the results. The possible inclusion of additional diversity measures in subsequent studies may yield more fitting or consistent results, as no single index can perfectly reflect the diversity of a given species (Routledge, 1979).

Recent studies have also discussed the possibility that applying diversity indices to invertebrate studies may possess intrinsic shortcomings, since the rate of capture is linked with individual activity and detectability (Scott, 2006). The low-altitude night collections in this study clearly demonstrate this point: both species abundances and diversity varied with time of collection, with a total of 9 unique morphospecies found during night searches that were otherwise unrecorded during daytime hours. In future studies, a collection schedule that included a range of day and night-time hours, as well seasons and even microhabitats, would contribute to a more accurate picture of spider community structure.

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APPENDICES

Families	Pasture		Secondary		Primary		#MS	%
	Low	High	Low	High	Low	High		
Agelenidae	9	12	2	16	3	6	2	10.3
Anyphaenidae	1	0	3	1	0	0	1	1.5
Araneidae	2	2	2	0	1	12	16	9.1
Clubionidae	1	0	0	2		1	3	1.7
Ctenidae	4	3	12	28	13	5	8	10.5
Dictynidae	2	0	0	0	0	0	2	0.5
Dipluridae	0	0	0	0	1	0	1	0.2
Gnaphosidae	0	0	1	0	0	0	1	0.7
Linyphiidae	11	18	11	0	8	24	13	17.2
Lycosidae	13	0	0	2	0	3	3	4.7
Pholcidae	2	1	2	0	1	1	5	3.4
Salticidae	18	12	9	4	2	14	4	20.7
Tetragnathidae	51	3	53	0	1	2	3	18.1
Theridae	0	0	0	0	1	0	2	0.5
Thomisidae	0	0	1	0	0	0	2	0.5
Total	114	51	96	53	31	68	66	
#Families	11	7	10	6	9	9		
#MS	23	18	16	10	17	22		

Appendix 1. Spider families sampled at low and high altitude pasture, secondary and primary sites. Number of distinct morphospecies (MS) per site as well as within a given family are outlined, in addition to percent abundances of each family across all sites. Night collections omitted.

Family	Common name	Location
Agelenidae	Funnel weavers	Funnel web
Anyphaenidae	Ghost spider	Leaf litter, low bushes
Araneidae	Orb weavers	Vertical orb web
Clubionidae	Sac spiders	In leaf litter, under stones or logs
Ctenidae	Wandering spiders	In leaf litter
Dictynidae	Mesh weaver	Irregular web low to ground
Dipluridae	Funnel web tarantula	In leaf litter, under stones
Gnaphosidae	Ground spiders	In leaf litter
Linyphiidae	Sheet web weavers	Sheet web in bushes, tall grasses
Lycosidae	Wolf spiders	In leaf litter, tall grasses, low vegetation
Pholcidae	Daddy long-leg spiders	Irregular web under rocks or logs
Salticidae	Jumping spiders	In leaf litter, tall grasses, low vegetation
Tetragnathidae	Long-jawed orb weavers	Slightly angled orb web
Therididae	Combfooted spiders	Irregular cobweb
Thomisidae	Crab spider	On low trees, bushes

Appendix 2. Common name and habitat type of spider families found on the reserve.

Habitat	Altitude	Natural History
Pasture	Low	Pasture and cropland for 20yrs; natural regrowth permitted 3yrs ago; never replanted
	High	Pasture and cropland for 20yrs; natural regrowth permitted 3yrs ago; never replanted
Secondary	Low	Pasture and plantation for 10yrs; replanted with native tree species 3yrs ago; young secondary forest
	High	Pasture and plantation for 10yrs; natural regrowth permitted 10yrs ago; older secondary forest
Primary	Low	Old, undisturbed forest; never replanted or disturbed
	High	Old, undisturbed forest; never replanted or disturbed

Appendix 3. Natural history of study sites.

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