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Understory Epiphyte Hydrology: Analyzing water storage capacity of epiphytes along an elevational gradient in western Ecuadorian cloud forest

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Analyzing water storage capacity of epiphytes along an elevational gradient in western Ecuadorian cloud forest

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ABSTRACT
Epiphytes are defined as plants that grow on a host, often another plant, and acquire their nutrients and water from the atmosphere. As such is true, epiphyte composition is largely dependent upon atmospheric and thus climactic conditions. Due to high levels of atmospheric water availability that results from the frequent presence of mist, clouds, and high humidity, epiphytic plants grow and thus store water within the above ground region of the Andean cloud forest at levels higher than in any other ecosystem found in Ecuador. This study was done in hopes of revealing any trends of epiphytic water storage capacity along an elevational gradient within the western Ecuadorian cloud forest of the Santa Lucia Reserve. Individual trees were analyzed at 5 different elevations along an altitudinal gradient that spanned 1650 to 2270 meters. Within each analyzed tree, data was collected between approximately 5 and 7 meters above the ground. Vascular individuals were recorded to the family level, and moss coverage and moss thickness were estimated. Epiphytic growth was sampled from a standard 2500 cm^2 region of each tree, and from this sample, water capacity (g/m^2) was extrapolated. It was found that water capacity of mosses and other non-bromeliad epiphytes increased with elevation. Moss cover was also seen to increase with elevation, and moss thickness was seen to peak at roughly 2040 meters. An increase in water storage capacity was correlated with both an increase in moss cover as well as number of vascular epiphytes present within sampled trees. Changes in moss composition appeared to influence both vascular epiphytes and vascular individuals more generally. An increase in moss cover was correlated with an increase in number of vascular epiphytes, and an increase in moss thickness was correlated with an increase in number of vascular individuals, including climbers and epiphytes. It was speculated that as the level of water associated with moss is dependent upon how much is available in the surrounding environment, the change in moss composition that is correlated with a change in water capacity is due to climactic conditions that vary with elevation.

RESUMEN
Epífitas son plantas que crecen en un anfitrión, a menudo otra planta, y adquieren sus nutrientes y agua de la atmosfera. Como resultado, la composición de epífitas en el bosque depende mucho de las condiciones atmosféricas y climáticas. Niveles altos del agua atmosférica existe en el bosque nublado andina como resultado de la presencia frecuente de nubes, neblina, y humedad alta. Por esto, epífitas crecen a niveles más altos aquí que en cualquier otro ecosistema del Ecuador. El objetivo de este estudio fue demostrar cómo la capacidad de las epífitas para almacenar agua puede cambiar con la elevación en el bosque nublado ecuatoriano de la Reserva Santa Lucia. Árboles fueron analizados en 5 altitudes distintas entre las elevaciones 1650 y 2270 metros. Por cada árbol, datos fueron recolectados entre 5 y 7 metros sobre el suelo. Fueron identificadas las familias de las plantas vasculares, y también la cobertura y grosor del musgo. Epífitas fueron recolectados de un área estándar de 2500 cm^2 de cada árbol. De esto, la capacidad del agua (g/m^2) fue determinada. Se descubrió que un aumento de la capacidad del agua del musgo y otras epífitas (no bromelias) está relacionado con un aumento de la elevación. El cubierto de musgo también aumenta con la elevación, y el grosor del musgo alcanza su punto máximo a 2040 metros. Un aumento de la capacidad del agua también está relacionado con un aumento en cuberito del musgo y numero de individuales epífitas. Los cambios en la composición del musgo parecían influir ambos las epífitas vasculares y, más generalmente, las plantas vasculares. Un aumento del cubierto del musgo está relacionado con un aumento del número de epífitas vasculares, y un aumento del grosor del musgo está relacionado con un

aumento del numero de plantas vasculares (epífitas y plantas trepadoras). La cantidad de agua que esta asociado con el musgo depende de la cantidad de agua disponible en el ambiente cercano. Por lo tanto, se especula que el cambio en la composición del musgo que está relacionado al cambio en capacidad del agua se debe a condiciones climáticos que cambian como cambia la elevación.

ACKNOWLEDGEMENTS

INTRODUCTION

Tropical montane forest, often referred to as *cloud forest*, is a type of tropical forest found at high elevations, ranging anywhere from below 1000 meters to over 3000 meters (Bubb et al., 2004). It's characterized by a nearly constant presence of mist and clouds, dense vegetation, and high levels of biodiversity. Rainfall can range anywhere from 500 to 6000 mm (Bubb et al., 2004). Throughout South America, including Ecuador, large swaths of cloud forest can be found along both the eastern and western sides of the Andes. Due to the steep nature of the terrain of cloud forests, fast moving but stable streams are common, regulated by the presence of forest. Furthermore, cloud forests provide an ecosystem service of promoting water infiltration into the soil (Gotsch, 2017) as well as storing water within the canopy, largely via epiphytes.

Within cloud forests, trees act as hosts for an abundance of epiphytes, hemi-epiphytes, and other single stemmed woody species. *Epiphytes* can be defined as plants that grow on a host (other plants or objects) but derive their nutrients and water from the surrounding environment (*Epiphytes*, 2012). *Hemi-epiphytes* can be defined as plants that spend part of their life cycle as an epiphyte. A hemi-epiphyte may germinate within a tree and later make contact with the ground via its aerial roots. Conversely, a hemi-epiphyte can also start growing within the soil, climb up a tree, and eventually sever its connection with the ground, living the later portion of its life cycle in an epiphytic manner (Zotz, 2013). Finally, while they are not epiphytes, many woody, single stemmed plants, such as lianas, that keep roots in the soil their whole life cycle, interact with epiphytes within host trees. They can compete with epiphytes for space or act as hosts for epiphytic plants to grow on.

Epiphytes play a very important role in the plant composition and biodiversity of cloud forests. They comprise a significant amount of the forest's biomass, providing up to 50% of the leaf area of the canopy (Gotsch, 2017). Epiphytes are not directly parasitic and can take a variety of forms. There are a variety of both vascular and nonvascular epiphytic plants in the Ecuadorian cloud forest. Nonvascular mosses and other bryophytic epiphytes are abundant in the Andean

cloud forest, coating nearly all available surfaces. Considering vascular epiphytes, orchids, ferns, bromeliads, and aroids are all important components of epiphytic vegetation in this region (Krömer et al., 2005). As a result of the nearly constant water source from clouds and mist frequently passing through, epiphytic plants can grow in any part at any level of the cloud forest. Ferns, mosses, bromeliads, and other epiphytes can be found growing on rocks, tree trunks, and on branches high up within the canopy of the cloud forest. The cloud forest's unique set of environmental conditions make it one of the best ecosystems for epiphyte growth, and thus, an ideal location for their study.

Figure 1.1: The figure above reflects the diversity of epiphytes that can be found within the Santa Lucia Cloud Forest Reserve within the western Ecuadorian cloud forest. From left to right are individuals of the families Orchidaceae, Bromeliaceae, Clusiaceae, and Aspleniaceae. All these plants are currently in an epiphytic form. Clusiaceae, however, can be thought of as a hemi-epiphyte as it begins its life as an epiphyte but eventually its aerial roots can make their way to the ground.

Figure 1.2: The figure above reflects some of the climbers that can be found growing within the understory of the trees in the Santa Lucia Cloud Forest Reserve, located in the western Ecuadorian cloud forest. From left to right are individuals of the families Campanulaceae, Gesneraceae, Begoniaceae, and Marcgraviaceae.

The hydrological cycle in cloud forests is complex and a key part of what makes the ecosystem unique. As one moves up the mountains from lowland rainforest to lower montane cloud forest to upper montane cloud forest, overall precipitation is seen to increase, via crown drip, and evapotranspiration, defined as water moving between the soil/plants/earth and atmosphere, is seen to decrease (Bruijnzeel, 2011). Temperature also decreases with an increase in altitude (Ding, 2016). As epiphytes depend on the surrounding atmosphere to acquire water, these changes in climate would support changing epiphyte adaptations, compositions, and niches. Positive correlations have been found between rainfall and epiphyte richness (Bruijnzeel, 2011). In his book about tropical montane cloud forests, Bruijnzeel notes that information about the

geographic distribution of cloud forest epiphytes is lacking. Filling in this lack of information would be helpful in a conservation context, considering that epiphytes such as orchids can have high levels of endemism.

As cloud forest, and thus the ideal conditions for epiphyte growth are altitude dependent, epiphyte diversity and abundance changes along an altitudinal gradient. One study done specifically on variation of epiphytic fern diversity in southern Mexico along an elevational gradient of 100 to 2200 m, split into 4 bands, found fern diversity to be highest in the highest band, between 1900 and 2200 meters (Jiménez-López, 2020). Another study done in the Bolivian Andes, between 350 to 4000 meters, found that species richness of epiphytes peaked at about 1300 meters. In consideration of what was the cause for this, air humidity was considered important but could not be treated as the sole determinant for this pattern as humidity was recorded as higher at elevations above 1300 meters where epiphytic species richness began to decline. Temperature, rainfall, and tree composition were also all considered as possible factors, but a solid conclusion was not drawn as to what appeared to be the factor(s) that were correlated with this pattern of epiphytic species diversity (Krömer et al., 2005). Another study, done on Hainan Island, south China, that considered both what biotic and abiotic factors along an elevational gradient might affect vascular epiphyte distribution, found that the indirect effects of elevation change influenced epiphyte species richness more than epiphyte abundance. Relative humidity, tree community characteristics, basal area of host trees, mean annual temperature, and soil fertility all seemed to play a significant role in epiphyte richness and abundance. Air humidity and tree basal area had the strongest direct effects along the elevational gradient (Ding, 2016). A fourth study done in the tropical montane cloud forests of Costa Rica found the factors that most strongly correlated with the epiphytic diversity change along an elevational gradient to be vapor pressure deficit (VPD) and leaf wetness. Correlating most strongly, an increase in VPD was associated with a decrease in epiphytic abundance. Defined as the difference between the current vapor pressure and the saturation vapor pressure, VPD takes into account both relative humidity and temperature which are both known to vary with change in elevation (Gotsch, 2017).

Epiphytes in trees act as huge water sponges in the cloud forest, sequestering large amounts of the water that is available in the atmosphere. A study in Serra do Mar State Park in Brazil found that the water storage capacity of non-vascular epiphytes in old growth montane forests was between 913.4 and 13370 L of water per hectare (Berro, 2022). As environmental factors that change with elevation appear to have an effect on epiphytes, it seems that perhaps elevation change could also be correlated with differences in epiphytes' ability to store water. A study done in Southern Thailand along an elevational gradient of 25 m to 1500 m, from lowland to montane forest, found that water storage capacity of epiphytic bryophytes increased with elevation. Water storage in lowland forest ranged from 4 to 10 l/ha whereas in montane forest, water storage ranged from 200 to 1500 l/ha (Chantanaorrapint, 2017).

Site location:

This study was completed in primary forest within the cloud forest ecosystem in the Santa Lucia Cloud Forest Reserve in Pichincha, Ecuador (see figures 1.3 and 1.4). Epiphytes have been studied previously within the Santa Lucia Reserve. In the fall of 2022, a study of epiphyte distribution along an elevational gradient was completed. It was found that average moss coverage, fern count, and bromeliad count per tree increased with elevation, though not by a statistically significant amount (Melnick, 2022). Another past study done in Santa Lucia found arthropod communities to be more diverse in nonvascular epiphyte mats than in bromeliads (Jones, 2022). It should be noted that both studies were done between November and December whereas this study was completed between April and May. Both study periods fall within Ecuador's wetter and rainier season, but Nov/Dec is at the beginning of this period whereas Apr/May falls closer to the end of this season. In dryer conditions, sap flow and sap velocity have been seen to decrease for cloud forest woody epiphyte species. Osmotic adjustment has also been seen to occur within epiphytes during these dry periods (Gotsch, 2017). This demonstrates that dryer periods can have an impact on epiphytes and potentially their composition.
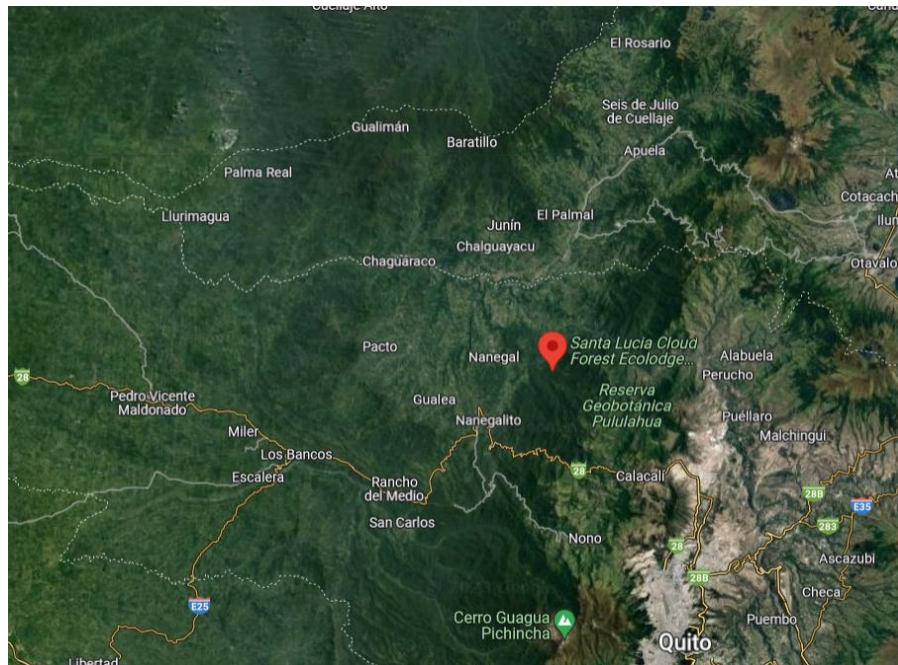

Figure 1.3: Above is a map derived from Google Maps that depicts the location of the Santa Lucia Cloud Forest Reserve relative to other parts of Ecuador. Santa Lucia is located in the western Andes, northwest of Quito, Ecuador.
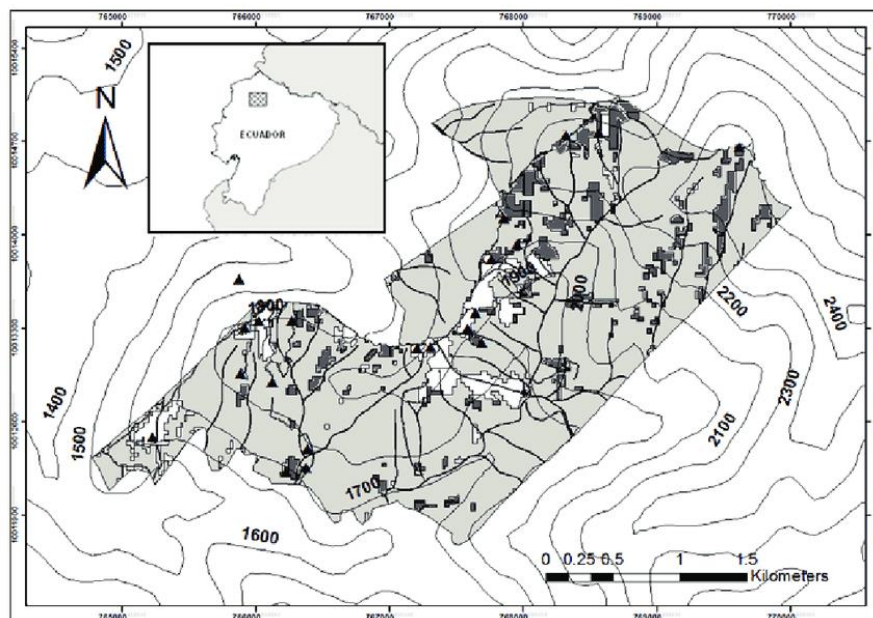
Figure 1.4: The map above is of the Santa Lucia Cloud Forest Reserve (SLCR). Contour lines are reflective of elevation in 100-meter intervals. Light-gray shading indicates primary forest; dark-gray shading indicates secondary forest, white shading indicates silvopasture, solid black lines indicate watercourse, and dotted line indicates trails.

The following scientific question guided this research: How does the water storage capacity of epiphytes in the Santa Lucia Cloud Forest reserve vary by elevation? The principal objective of this study was to identify how the water storing capacity of epiphytes within the Andean cloud forest at the Santa Lucia Reserve might vary along an elevational gradient. Due to the humid and cloudy nature of western tropical montane cloud forests, large quantities of both vascular and nonvascular epiphytes are able to grow and thus store water within the above ground region of the forest. As such is true, both vascular and nonvascular epiphytes were considered in terms of determining water storage capacity. More specific objectives of this study were to **1.** Extrapolate the water storage capacity of epiphytes between approximately 5 and 7 meters above the forest floor. **2.** Determine to the taxonomic family level the composition of vascular epiphytes and climbers growing within the understory between approximately 5 and 7 meters above the forest floor. **3.** Determine if there is correlation between altitude and epiphyte water storage capacity. **4.** Determine if there is a correlation between vascular epiphyte composition and water storage capacity.

METHODS & MATERIALS

Materials:

The materials for this project included a 6.3-meter extension ladder, 3 5-meter ropes, and a climbing harness used to ascend sampled trees. 10 meters of twine, a 150-cm measuring tape, and a 3-meter measuring tape were used to demarcate the sampled area within the tree as well as measure various factors. A notebook, camera, and various cloud forest plant guides were used to identify epiphytic, hemi-epiphytic, and climbing plant growth within the understory. 5 breathable bags were used for transporting plant samples from sample sites to the laboratory. A 3 kg scale (with marked 20 g intervals), 2 t-shirts, and 2 plastic bins were used to determine the water storage capacity of sampled epiphytes.

Site descriptions:

All sites where trees were sampled were within the primary forest of the Santa Lucia Cloud Forest Reserve. Sites were selected to meet the criteria of being within primary forest as well as separated by approximately 150-meter elevation intervals. In total, sites covered a 620-meter elevation gradient with elevations ranging from 1650 to 2270 meters. The lowest site sampled was located at approximately 1650 meters along the waterfall trail. The second lowest site, at approximately 1815 meters, was along the self-guided and waterfall trails. The middle elevation site, at approximately 1960 meters, was along the principal trail. Further down this trail was the next highest site, at approximately 2110 meters, and even further, the highest site at 2270 meters.

Within each sampling site, 9 trees were sampled. To standardize the trees being sampled, to eliminate 3rd variable issues, and to allow for safe data collection sampled trees had several criteria that must be met. The first condition was that trees must have a diameter at breast height (DBH) between 15 and 70 cm. This specification was made to ensure trees were large enough to support the ladder. It was also made to ensure that trees were not so big that the rope could not be manually wrapped around the trunk to secure the ladder. A second condition was that only trees that could safely be accessed with a ladder were analyzed. A related third condition was that no dead trees were sampled as they could be unsafe. Additionally, the lack of shade from a living canopy could provide different conditions which would therefore support different epiphytic and hemi-epiphytic flora. A fourth condition was that trees with anti-epiphytic adaptations, such as peeling bark, were avoided as the point of this study was to analyze epiphytic flora. Finally, trees tilted past 30° were not included as their angle "might support a different flora caused by increased deposition of falling debris" (Catling et al., 1989). To prevent bias, once the site was reached, all the nearest trees that fit these requirements were sampled.

Once a tree was deemed to fit the requirements above, the ladder was secured to the tree near both the bottom and the top to prevent the ladder from falling. An additional rope was secured to the tree that could be attached to a climbing harness to further prevent falls. The ladder was extended to reach as high as possible (given safety and structure of the tree). Twine was used to demarcate a sampling site a meter above, below, and out to each side of the top of the ladder. Within this sampling site, 4 variables were measured. The diameter of all the observed trunks within the sampling site was taken to extrapolate the total surface area being observed. Moss coverage was estimated in 10% intervals. Moss thickness was measured in 5-6 different spots evenly spaced apart within the 2500 cm^2 area that would later be used to estimate water capacity. These 5-6 measurements were averaged to acquire the measurement that would

later be used for data analysis. Finally, vascular individuals with a diameter/length larger than 10 cm were counted and identified to the family level. Once this data had been collected, plant and soil matter that was present on the tree was sampled from a 2500 cm^2 area. To standardize this area and prevent bias from affecting what part was sampled, the 2500 cm^2 area immediately above the top of the ladder was used.

Figure 2.1: The photos above both were taken at ~1815 meters. The top of the ladder is approximately 6.3 meters above the ground. The area in which epiphytes were analyzed within each tree is from 1 m above the ladder to 1 m below the top of the ladder.

Water capacity:

Each set of epiphytes collected from a 2500 cm^2 area was stored separately and brought back to the laboratory. Here, these epiphytes were further separated. Bromeliads were separated from moss and other epiphytes. As bromeliads can grow to be quite large and hold vast amounts of water superficially, they were considered separately. The methods used to analyze the water capacity of the bromeliads versus other epiphytes differed slightly. For each group of epiphytes, two weights were taken, a dry weight (DW) and a wet weight (WW). From these weights, two statistics were calculated. Water storage per unit area could be determined (WW-DW) as well as how many times their dry weight in water epiphytes were able to store (WW/DW).

Bromeliads: To determine the dry weight of bromeliads, all water within was removed. To determine the wet weight, bromeliads were held upright (in the position they were originally found in on the tree) and submerged in water. From this position, all excess water was allowed to run off, and from here the WW was recorded. It should be noted that this process measured the water that bromeliads are able to store superficially. It did not measure the water they stored vascularly.

Moss and other epiphytes: To determine the dry weight of this group of epiphytes, as shown in fig. 2.2 below, the plants were wrapped in an old t-shirt and as much water as possible was squeezed from the epiphytes by twisting the cloth. While it was not possible to remove all water from these plants, the straining process was done as consistently as possible for each epiphyte group to acquire results about water capacity that were consistent, though perhaps a bit smaller than reality. To determine the wet weight, the epiphytes were submerged in water, removed, and after all excess water had run off, the WW was recorded.

Figure 2.2: The photos above depict the process used to obtain the dry and wet weights for the sampled moss + other epiphytes. The top left image depicts the freshly sampled epiphytes. Bromeliads were separated to be analyzed separately. The top right image depicts the cloth method used to strain the water from the epiphytes. The bottom images, from left to right, depict the dry epiphytes (dry weight), submerged epiphytes, and drained epiphytes (wet weight).

Data was analyzed using Microsoft Excel and R Studio. Excel was used to create datasets which were transformed into .csv files which were then imported into R Studio and analyzed. Different variables were analyzed with both linear and polynomial models to see if any correlations were present. Multiple R-squared values as well as p-values were utilized to see the strength and statistical significance of correlations. R Studio was also used to calculate Shannon, Exponential Shannon, Simpson, and Inverse Simpson diversity indices at each elevation. Additionally, it was used to calculate Jaccard and Sorenson similarity and dissimilarity indices as well as the Morisita-Horn similarity indices between the different elevations.

The variables *elevation*, *water capacity (g/m^2) of mosses + other non-bromeliad epiphytes, wet weight to dry weight ratio, moss % coverage, and moss thickness (cm)* were all

considered when analyzing water capacity along an elevational gradient. The vascular plants that were counted within the 2-meter tall plots were also analyzed against these variables: most specifically on the family level, most broadly as vascular individuals, and finally as epiphytes or climbers. The family level classifications were used to classify individuals more broadly as epiphytes, climbers, or hemi-epiphytes. Since there were only a few families of hemi-epiphytes, such as Araceae, Clusiaceae, and Moraceae, and because these families were most often observed in their epiphytic form, they were treated as epiphytes for statistical analysis. Piperaceae plants were sorted individually as epiphytes or climbers. Piperaceae in the *Peperomia* genus were classified as epiphytes whereas individuals of the *Piper* genus were classified as climbers (see figure 2.3 below).

Figure 2.3: Pictured above are three individuals of the Piperaceae family. From left to right, they are of the genus' *Peperomia*, *Peperomia*, and *Piper*, and thus classified as epiphyte, epiphyte, and climber.

ETHICS

Only plants that were going to be analyzed as samples for each of the 9 trees at each elevation site were purposefully removed from trees. Any property of Santa Lucia that was utilized for the project was not misused. The community of Santa Lucia and surrounding areas was respected.

RESULTS

Vascular epiphyte composition along an elevation gradient:

In total, between the 5 elevations and 45 trees from which data were collected, a total of 947 vascular epiphytes were identified, belonging to 28 different families. The overall most prevalent families for vascular epiphytes were Bromeliaceae (18.7% relative abundance), Polypodiaceae (16.1%), Orchidaceae (13.1%), Dryopteridaceae (11.4%), Araceae (9.6%), Hymenophyllaceae (6.1%), and Piperaceae (4.3%).
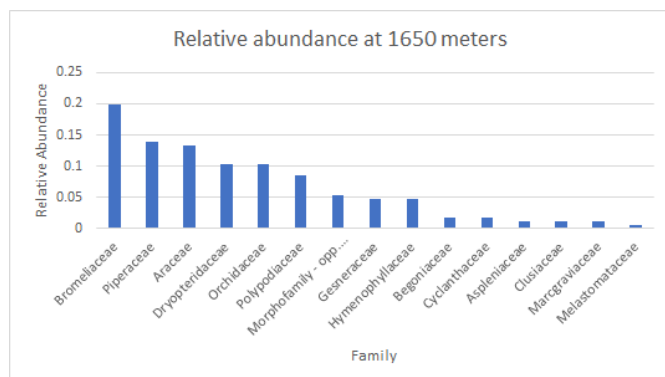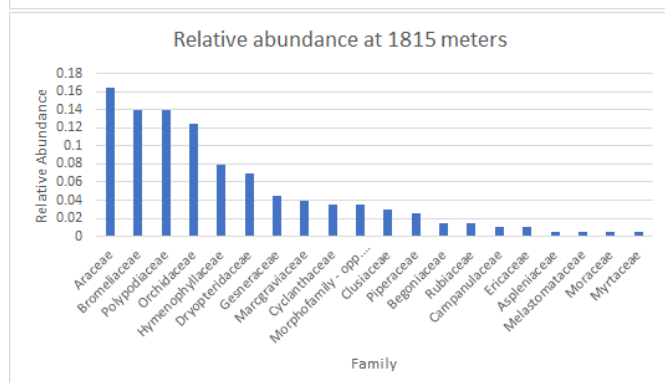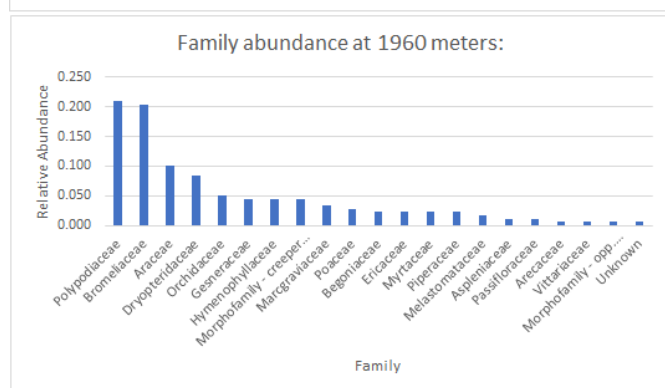
Figure 3.1: To the left is depicted the relative abundance of each family identified at each altitude.

At 1650 meters, Bromeliaceae was the most abundant family at 19.9% relative abundance, followed by Piperaceae (13.9%) and Araceae (13.3%).

At 1815 meters, Araceae was the most abundant family at 16.4% relative abundance, followed by Bromeliaceae (13.9%) and Polypodiaceae (13.9%).

At 1960 meters, Polypodiaceae was the most abundant family at 20.9% relative abundance, followed by Bromeliaceae (20.3%) and Araceae (10.2%).
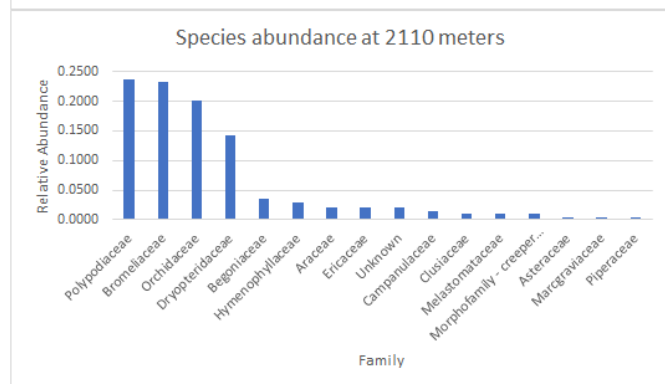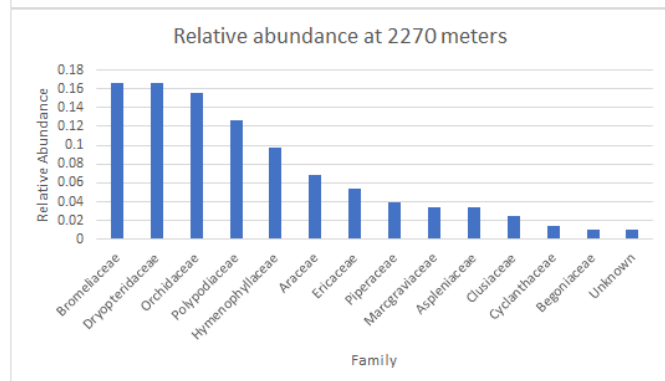
At 2110 meters, Polypodiaceae was the most abundant family at 23.7% relative abundance, followed by Bromeliaceae (23.2%) and Orchidaceae (20.2%).

At 2270 meters, Bromeliaceae and Dryopteridaceae were the most abundant families at 16.6% relative abundance, followed by Orchidaceae (15.6%) and Polypodiaceae (12.7%).

Biodiversity and comparison indices:

Both the Shannon and Simpson biodiversity indices calculated 1815 meters to be the most biodiverse elevation. 1960 meters was calculated to be the next most biodiverse, followed by 1650, 2270, and finally 2110 meters. As indicated with colors (see table 3.1 below), according to the Shannon index, 1815 and 1960 meters are nearly identical, considering biodiversity values. Simpson, on the other hand, calculated very similar values for biodiversity between 1650, 1960, and 2270 meters. For both the Shannon and Simpson indices, the biodiversity at 2110 meters is significantly lower than at the rest of the sites, relatively speaking.

Table 3.1: Below are the Shannon, exponential Shannon, Simpson, and inverse Simpson diversity indices that were calculated using the family level identifications of vascular epiphytes at each elevation.

	1650 m	1815 m	1960 m	2110 m	2270 m
Shannon	1.88	1.96	1.95	1.71	1.85
ExpShannon	2.71	2.83	2.81	2.46	2.67
Simpson	0.722	0.725	0.721	0.706	0.721
InvSimpson	3.59	3.63	3.58	3.40	3.58

The Jaccard and Sorenson dissimilarity indices that were calculated between each site are reflective that from site to site, in all cases but one, family composition of the vascular individuals recorded between sites was more similar than dissimilar. The case that proved to be an exception was between 1960 and 2110 meters, with a total dissimilarity value of 0.54.

Table 3.2: Below are the calculated Jaccard and Sorenson dissimilarity values between each change in elevation of ~150 meters. A dissimilarity value that is *higher* than 0.5 is indicative that the two sites are more dissimilar than similar. A value of 0 signifies complete similarity, and a value of 1 signifies complete dissimilarity. Turnover dissimilarity signifies the replacement of old families by new families, and nestedness occurs when the families of one site with less families than another site are all a subset of that other site. The beta diversity/total dissimilarity value is calculated by adding together the turnover and nestedness dissimilarities.

	1650 – 1815 m	1815 – 1960 m	1960 – 2110 m	2110 – 2270 m
Jaccard Turnover Dissimilarity	0.00	0.40	0.42	0.27
Jaccard Nestedness Dissimilarity	0.24	0.02	0.12	0.09
Jaccard Beta Diversity/Total Dissimilarity	**0.24**	**0.42**	**0.54**	**0.35**
Sorenson Turnover Dissimilarity	0.00	0.25	0.27	0.15

Sorenson Nestedness Dissimilarity	0.14	0.02	0.10	0.06
Jaccard Beta Diversity/Total Dissimilarity	**0.14**	**0.27**	**0.37**	**0.21**

The Morisita-Horn similarity index indicates that between elevational sites, on the family level, there were high levels of similarity.

Table 3.3: The Morisita-Horn Similarity index is used below to calculate the similarity between each pair of ascending elevational sites. A value of 0 represents two completely dissimilar sites whereas a value of 1 represents completely similar sites. The values below were calculated using the sums of the number of vascular plant individuals at the family level that were recorded at each site.

	1650 – 1815 m	**1815 – 1960 m**	**1960 – 2110 m**	**2110 – 2270 m**
Morisita-Horn Similarity Index	0.955	0.942	0.950	0.961

Family richness & biodiversity interactions with elevation change & water capacity:
Family richness interactions: No statistically significant correlations were found between family richness within individual trees and elevation or between family richness within individual trees and water capacity. Likewise, no statistically significant correlations were found between site wide family richness and elevation or between site wide family richness and water capacity.
**Biodiversity interactions**: No statistically significant correlations were found between site wide water capacity and site wide biodiversity values calculated with the Shannon or Simpson indices.

Water storage capacity along an elevational gradient:
In consideration of water storage capacity of epiphytes, between the 5 elevations and 45 trees from which data was collected, mosses (primarily) + other non-bromeliad epiphytes were able to store between 180 g and 11400 g (average 1734 g, median 1200 g) of water per square meter. Additionally, it was found that the same group of plants was able to hold between 1.8 and 6.0 (average 3.2, median 3) times their dry weight of water. Considering bromeliads, water storage capacity ranged from 20 g to 8440 g (average 675 g, median 160 g) of water per square meter. Superficially, bromeliads were able to hold between 1.3 and 4 (average 2.2, median 2) times their weight in water.
**Water storage vs. elevation:** Considering the relationship between water storage (g/m^2) and elevation (m), see figures 3.4 and 3.5, a positive and statistically significant linear correlation appears to exist. In figure 3.4, two exceptionally high values exist at 2270 meters. These two values were removed, and the linear model statistics were recalculated to see if a statistically significant relationship still existed. The p-value of 0.031 is larger than the p-value calculated when the outliers were present (0.0084), but it still falls below the threshold of 0.05, suggesting a

statistically significant positive correlation does exist between elevation and water storage per square meter.
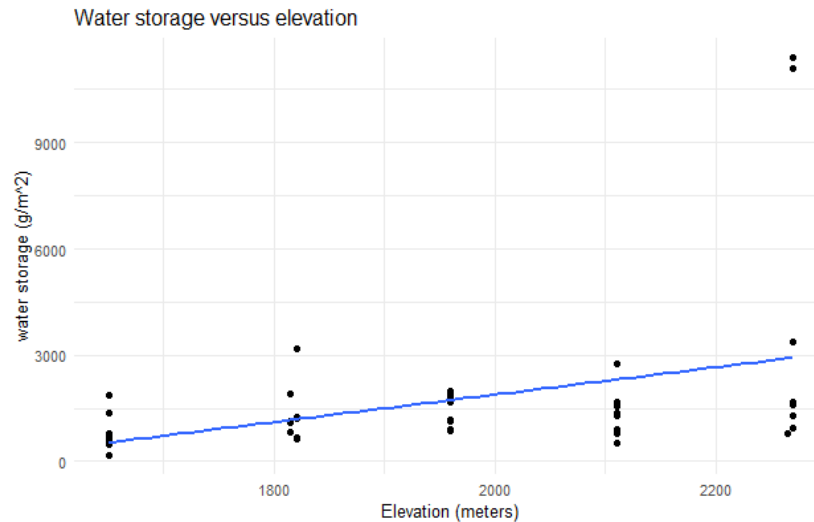
p-value: **0.00836**; multiple R^2: **0.151**; slope = **3.87 g/m^3**

Figure 3.4: The figure above depicts the extrapolated water storage for moss and other non-bromeliad epiphytes in grams per square meter versus elevation, **including 2 outliers**. Each data point represents the extrapolated water capacity for a single tree.
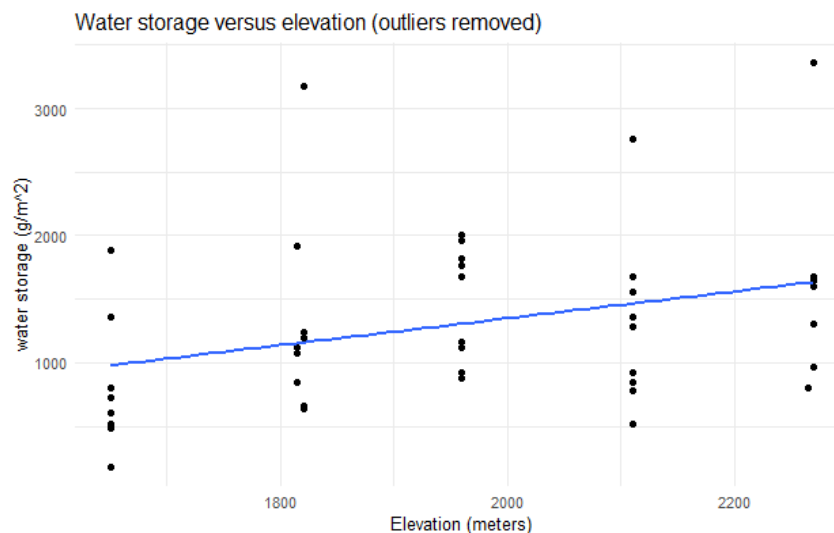
p-value: **0.031**; multiple R^2: **0.12**; slope = **1.06 g/m^3**

Figure 3.5: Like figure 3.4, the figure above depicts the extrapolated water storage for moss and other non-bromeliad epiphytes in grams per square meter versus elevation, **excluding 2 outliers**. Each data point represents one tree. In this figure, the two exceptionally high values at 2270 meters have been removed.

WW:DW ratio vs. elevation: Considering the relationship between the WW:DW ratio of mosses and other non-bromeliad epiphytes and elevation, a statistically significant correlation does not appear to exist (see figure 3.6). The p-value is above the acceptance threshold and the multiple-R^2 relatively small.
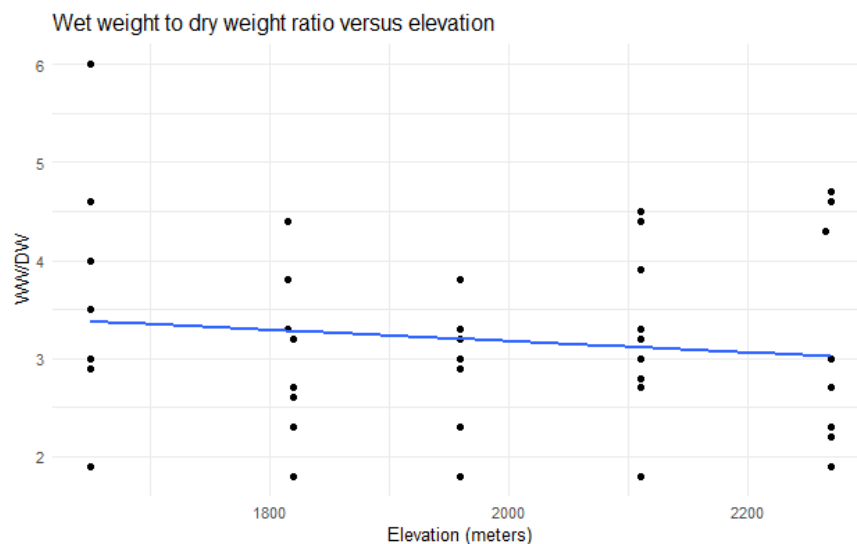
p-value: **0.373**; multiple R^2: **0.0185**; slope = **-0.000577 m^{-1}**

Figure 3.6: The figure above plots the WW:DW ratio determined for moss and other non-bromeliad epiphytes that were sampled from analyzed trees versus elevation.

Moss cover vs. elevation: Statistically significant relationships were found for both the linear and polynomial models that compared elevation to moss cover (see figure 3.7 below). The linear model predicted a positive relationship between the two variables whereas the polynomial model predicted a peak in moss cover around approximately 2110 meters. The p-value for the linear model is slightly smaller than that of the polynomial model, but the multiple R^2 value is larger for the polynomial fit than it is for the linear fit.
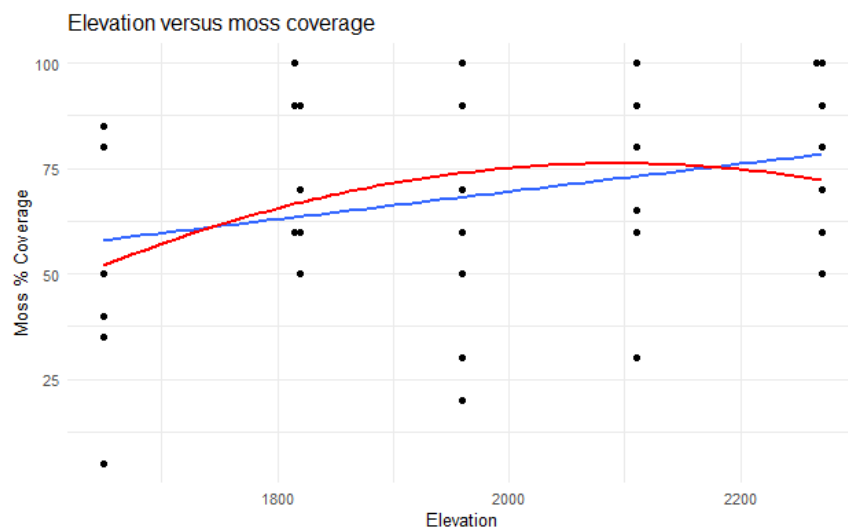


Linear model: p-value = **0.0460**, multiple R^2 = **0.0934**, slope = **0.0328 % / m**
Polynomial model: p-value = **0.0493**, multiple R^2 = **0.134**, peak ≈ **2110 m**

Figure 3.7: The figure above depicts moss percent coverage within sampled trees versus their respective elevations. A linear fit is represented by the blue line, and a polynomial fit is represented by the red line.

Moss cover vs. water storage capacity: As significant correlations were found between elevation vs. water storage capacity (of moss and other non-bromeliad epiphytes) as well as elevation vs. moss cover, a statistically significant relationship was also seen to exist between water storage capacity (of moss and other non-bromeliad epiphytes) and moss cover (see figure 3.8 below). The positive linear relationship found to exist between the two variables predicts that for every increase in moss cover by 1%, water storage capacity increases on average by 9.6 g/m^2.
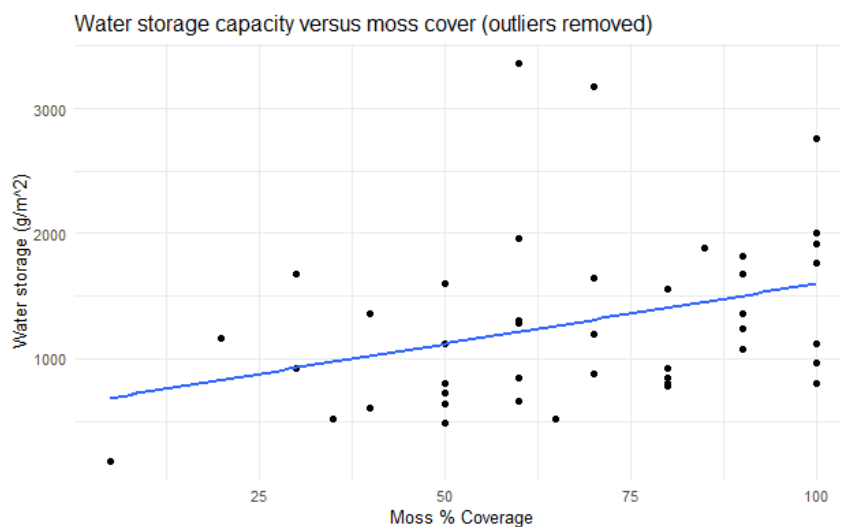
p-value = **0.0239**, multiple R^2 = **0.118**, slope = **9.618**

Figure 3.8: Above compares the water storage capacity (g/m^2) extrapolated from mosses and other non-bromeliad epiphyte growth versus moss % coverage.

Moss thickness vs. elevation: In consideration of elevation versus moss thickness, a statistically significant relationship was found between these variables when fitted to a polynomial model (see figure 3.9 below). A peak in average moss thickness on trees is modeled to be between 2000 and 2100 meters.
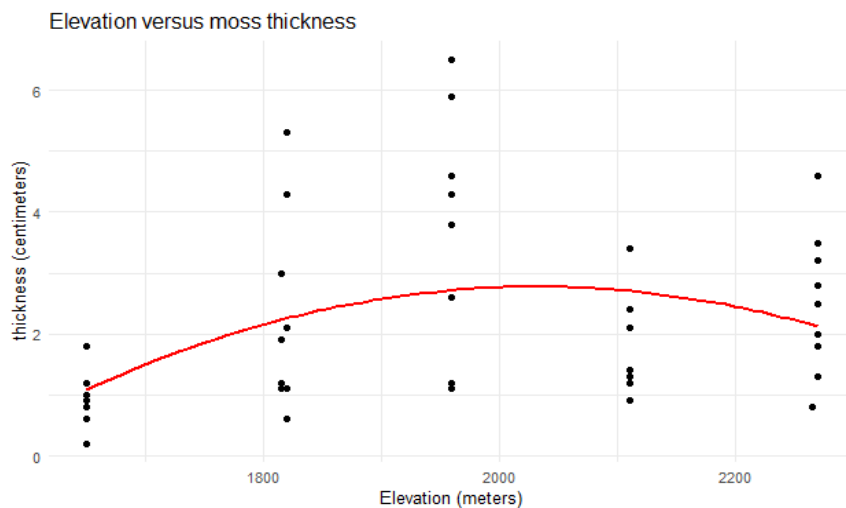

p-value: **0.0311** multiple R^2: **0.152**; peak ≈ **2040 m**

Figure 3.9: Average thickness of moss/soil mats growing on trees along an elevational gradient. The red line is a unimodal fit, fitting the data to a polynomial model.

Primarily nonvascular epiphytic water storage capacity considered in relation to vascular epiphytes:

Water capacity vs. epiphytic individuals: It was found that an increase in the number of vascular epiphytic individuals that were documented on a tree positively correlated with an increase in the extrapolated water storage capacity (g/m^2) of mosses and other non-bromeliad epiphytes of that tree (see figure 3.10 below). The linear model predicts that for an increase in water capacity of 1000 g/m, on average, the number of epiphytic individuals within a 2-meter stretch of a tree would increase by approximately 3 individuals.
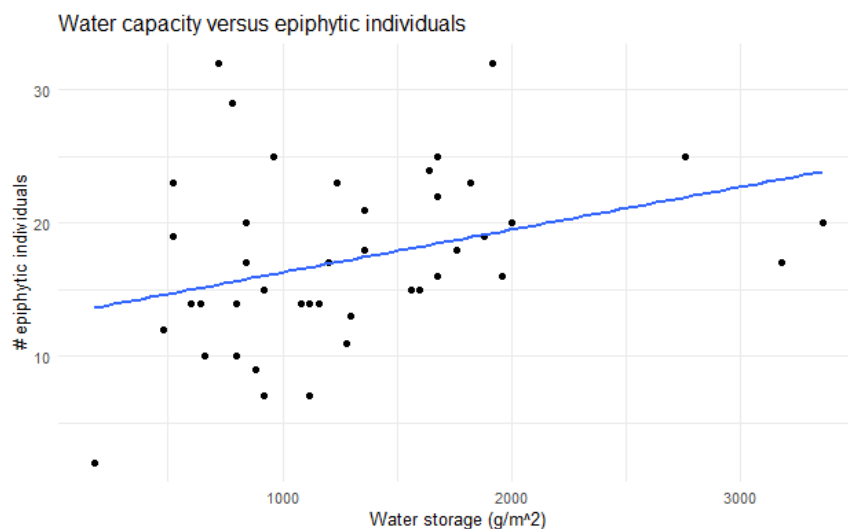
Linear model: p-value: **0.0276**; multiple R^2: **0.113**; slope = **0.00321 individuals/gm^{-2}**

Figure 3.10: The figure above compares the extrapolated water storage capacity of mosses and other non-bromeliad epiphytes (g/m^2) versus the number of epiphytic individuals that were counted within the tree from which that water storage capacity was extrapolated.

Water capacity vs. climbing individuals: No statistically significant relationship was found between water storage capacity and number of individuals of plants that were classified as climbers.

Moss cover vs. epiphytic individuals: When considering moss coverage on a tree versus the number of epiphytic individuals present on that tree, a statistically significant correlation exists for a linear model (see figure 3.11 below). The positive relationship predicts that for each 1% increase of moss cover, the number of epiphytic individuals should increase by 0.11.

Epiphyte individuals versus moss cover
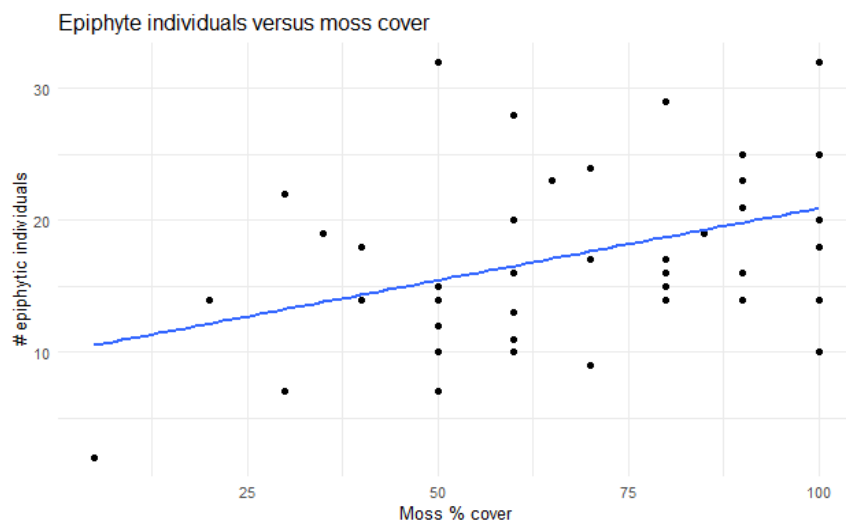
p-value: **0.00653**; multiple R^2 = **0.160**; slope = **0.110 individuals / %**

Figure 3.11: The figure above shows the relationship between the number of epiphytic individuals and moss % coverage within a 2500 cm² area of tree surface. A linear model with a positive and statistically significant slope has been fitted to the data.

Moss thickness vs. all vascular individuals: A statistically significant relationship was found to exist between moss thickness and number of vascular individuals present (see figure 3.12 below). A positive, linear relationship was found, so that for every increase of moss thickness by 1 cm, within a 2-meter stretch (top to bottom) of a tree trunk, the number of vascular individuals on average increased by 1.65. This relationship was also analyzed for moss thickness vs. number of epiphytic individuals as well as for moss thickness vs. number of climbing individuals. It was found, however, that the strongest relationship existed between total number of individuals and moss thickness.

Moss thickness versus vascular individuals present
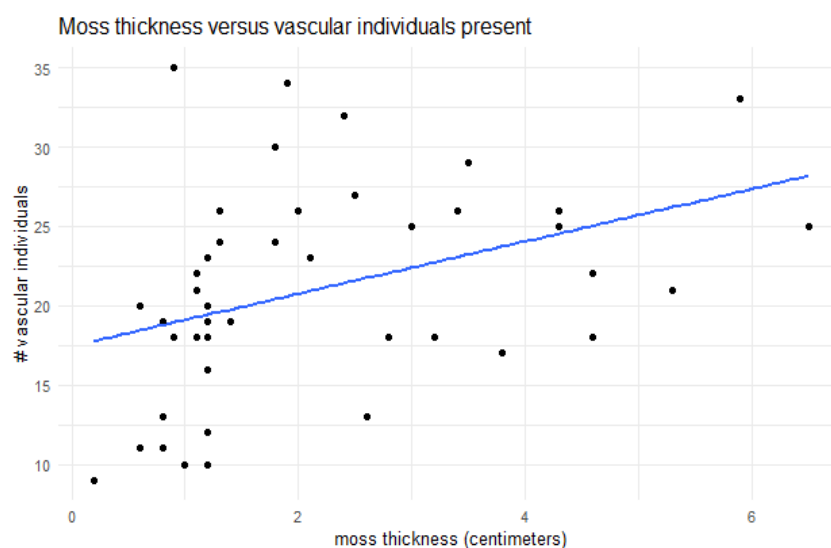
p-value: **0.00884**; multiple R^2 = **0.150**; slope = **1.65 individuals/cm**

Figure 3.12: Depicted above is the relationship between the number of vascular individuals and the thickness (in cm) of moss/soil mats within a 2-meter (top to bottom) plot on a tree. The blue line depicts the linear model fitted to the data.

Epiphytic vs. climbing individuals: While the observed correlation between them was negative, a statistically significant correlation did not exist between the number of epiphytic individuals and the number of climbing individuals present on a single tree.

External variables:

No statistically significant relationships were found between canopy/forest height and the following variables: elevation, water capacity (g/meter) of mosses and other non-bromeliad epiphytes, wet weight to dry weight ratio, moss % coverage, moss thickness, number of vascular individuals, number of epiphytic individuals, or number of climbing individuals. Each of these variables was considered as a site/elevational average. Additionally, when comparing the slope at each site to the site/elevational average for each of these variables, no statistically significant correlations were found. For canopy cover, however, some statistically significant correlations were found to exist.

Moss cover vs. canopy cover: When comparing the values of moss % coverage and canopy % coverage at each elevation, a statistically significant relationship was found (see figure 3.13). The two variables are seen to have a negative linear relationship where for each increase in canopy coverage by 1%, moss coverage decreases on average by nearly 2%.

p-value = **0.00428**, multiple R^2 = **0.954**, slope = **-1.885**
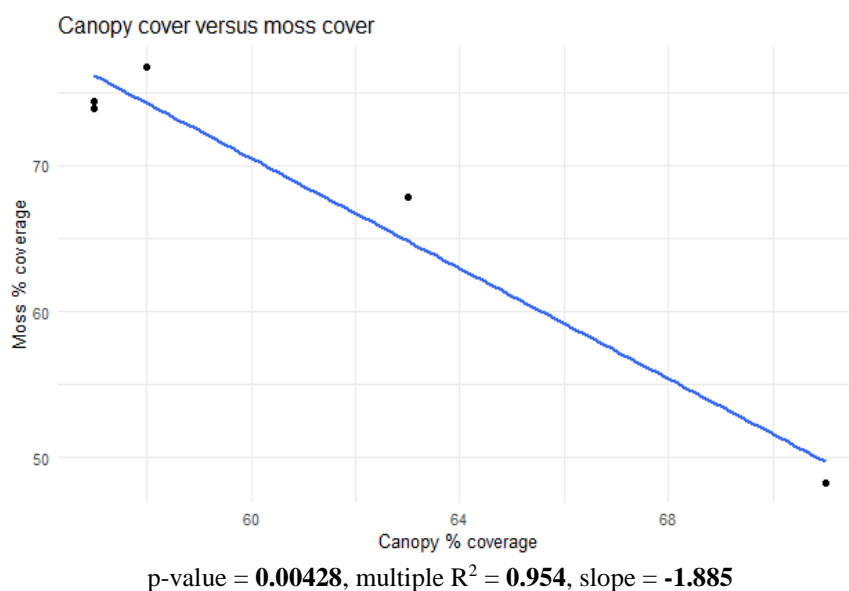
Figure 3.13: Above the average canopy coverage between elevations is compared to the average moss coverage at each elevation.

Vascular individuals vs. canopy cover: A statistically significant, negative, linear correlation exists between canopy coverage and the number of vascular individuals (see figure 3.14 below). The linear model predicts that for each 1% increase in canopy coverage within an elevational site (this includes 9 sampled trees), the number of vascular individuals will decrease by nearly 3.

Vascular individuals versus canopy cover

p-value = **0.0112**, multiple R^2 = **0.913**, slope = **-2.70**

Figure 3.14: The scatterplot above compares canopy coverage to the number of vascular individuals. Each data point made between these variables uses elevational averages. The variable 'vascular individuals' includes all plant individuals which were identified to the family level in each tree.

ANALYSIS & DISCUSSION
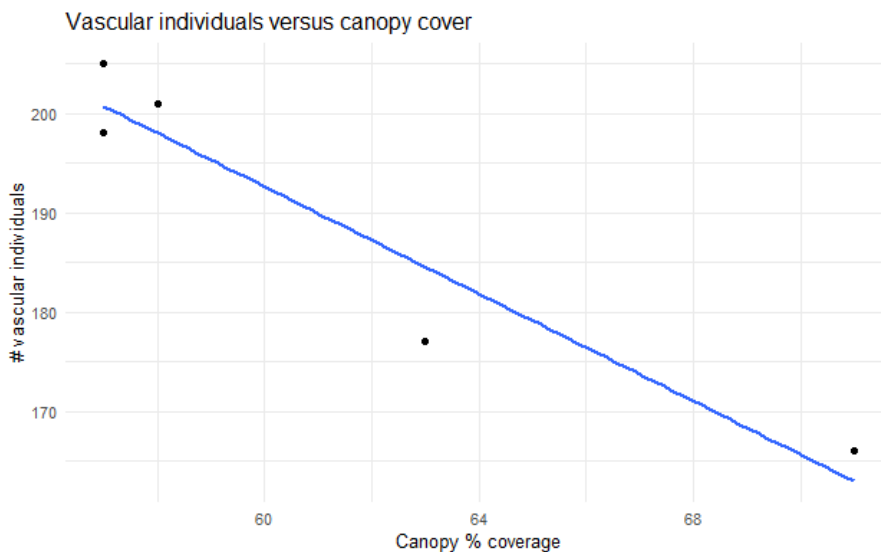
Nonvascular epiphytic water storage capacity along an elevation gradient:

When considering water storage capacity of mosses and other non-bromeliad epiphytes along an elevational gradient, a positive linear correlation was found to exist between water storage capacity and elevation (see figures 3.4 and 3.5). The substrate used to determine water capacity for mosses and other non-bromeliad (NB) epiphytes was largely and sometimes entirely composed of mosses. Soil, ferns, and occasionally other vascular epiphytes were also common within this substrate, but all these significantly less so than bryophytes. This is important to keep in mind when interpreting these results.

Along this elevational gradient, moss cover as well as moss thickness were also found to have statistically significant correlations to elevation (see figures 3.7 and 3.9). For moss coverage, both linear and polynomial models were found to be statistically significant. The linear model for moss cover vs. elevation would be logical if considering the likewise positive and linear correlation that exists between water storage capacity of mosses and other NB epiphytes with elevation. The increase of moss coverage (seen with this elevational increase) could increase the water storage capacity (g/m^2) by increasing the amount of substrate in which water can be stored on the surface of a tree. It should be mentioned that the relationship between moss coverage and water storage capacity, when considered without the two outliers, was also found to be statistically significant and positively and linearly correlated (see figure 3.8). This relationship supports the given theory. An increase in moss thickness, which is seen up to 2110 meters, could also help to explain the observed increase in water storage capacity with elevation. Thicker moss mats would result in an increased water storage capacity within a specified area. An increase in moss thickness cannot be treated as the sole determinant of water storage capacity

increase, however, as the unimodal model predicts a peak between 2000 to 2100 meters after which thickness is modeled to decrease.

Since it is known that mosses are poikilohydric, meaning the amount of water associated with them is directly associated with the availability of this water in the surrounding environment (León, 2006), these found statistics could reflect that along the elevational gradient, conditions that affect water availability are changing in some way. An increase of water storage capacity, primarily by mosses, resulting from increased moss coverage and thickness would be consistent with findings of past studies, such as the study done between 25 to 1500 meters in southern Thailand (Chantanaorrapint, 2017) which found water storage capacity (l/ha) of bryophytes to increase with elevation. However, the elevational ranges of these two studies are different, so by referencing the work of Chantanaorrapint, it cannot be known if water storage capacity of bryophytes should continue to increase past 1500 meters. As was found by Oishi in 2018, in a study of the water storage capacity of mosses, between 1800 and 2800 meters in temperate forests and alpine zones in Japan, along the eastern trail, a unimodal relationship was seen between elevation and water storage capacity of mosses, increasing until approximately 2400 meters, and then decreasing again. This finding is somewhat comparable to the findings here, considering the linear increase in water storage capacity falls within the range of the increase seen with Oishi's results. It should be noted, however, that this study took place within different forest types and considered all mosses, rather than just mosses present on trees.

Nonvascular water storage capacity considered in relation to vascular epiphytes:
Looking beyond the relationships between water storage capacity and mostly nonvascular epiphytic growth, this water storage capacity was also statistically significantly correlated with the number of epiphytic individuals (see figure 3.10). This suggests that an increase in water availability can support a higher number of epiphytes growing within a set area. The variable 'number of epiphytic individuals', however, cannot indicate if the epiphytic biomass is also increasing as it was observed that epiphyte individuals can vastly range in size and weight. If it were possible to measure the dry weight of vascular epiphytes, this might provide more valuable insights about the relationship that might exist between vascular epiphyte growth and nonvascular epiphyte water storage. The number of epiphytic individuals was also seen to be positively and linearly correlated with moss cover (see figure 3.11). As moss cover was also seen to be positively correlated with water storage capacity (see figure 3.8), this could explain the positive correlation between epiphytic individuals and water storage capacity. For epiphytes to germinate within a tree, substrate is necessary. Higher moss coverage could increase the germination potential of epiphytes within a tree as it increases the surface area within a given tree that is hospitable to the germination of, for example, an angiosperm from a seed or a pteridophyte from a spore. Literature has noted that the abundance of accidental epiphytes (normally terrestrial plants) is higher in European arboreal forests when moss cover is higher (Hoeber, 2022). This is consistent with what was found in this study, though key differences are that all epiphytes were considered rather than only accidental epiphytes and forest location and type were also different.

Moss thickness was also found to be statistically significant and positively correlated with the number of *vascular* individuals present within the 2-meter stretch of the tree that was observed (see figure 3.12). Vascular individuals refer to both the epiphytes and climbers that were identified within the tree. This increase in moss thickness provides more substrate and thus more space for the roots vascular individuals to grow. A past study on ferns found that the

occurrence of larger, vascular, spore producing fern individuals (sporophytes) increases with an increase in moss height. (Harrington, 2021). Though it only considers ferns, this past result is consistent with the results found within the current study. It should be noted that positive correlations also existed between climbing individuals and epiphytic individuals and moss thickness. However, the correlation including epiphytic individuals was not quite statistically significant, and the correlation including climbing individuals, though statistically significant, was weaker than the correlation between total vascular individuals and moss thickness. When considering why moss thickness might not be *as* important for the number of epiphyte individuals present, as compared to moss coverage, this could have something to do with moss thickness not playing as much of a role in providing a place for epiphytes to germinate. As seedlings/young ferns are quite small, any thickness of moss might be sufficient to provide a starting place for growth. It would be interesting, however, in future studies, to see if moss thickness has any correlation to biomass of epiphytes present. Perhaps germination potential depends more on a point, but when considering growth potential of individuals, more/deeper substrate is necessary. When considering the statistically significant and positive correlation between climbing individuals and moss thickness, it can be speculated that thicker moss might provide better growing substrate for climbing plants, providing better grip than a bare tree trunk or bark only covered by a very thin layer of moss. When collecting data, multiple instances were observed where climbers were growing up thick masses of dangling moss, no woody support present within.

Biodiversity trends:

Between both the Shannon and Simpson indices, 1815 meters was calculated to be the most biodiverse elevational site. For the Shannon index, the site at 1960 meters was nearly identical, considering biodiversity score. For Simpson, 1960 meters was a bit lower in biodiversity than 1815 meters, but nearly identical to 1650 and 2270 meters for biodiversity score. Of each of the elevational sites, the most common families had the lowest family abundances at 1815 meters, signifying higher levels of evenness. While 2270 meters was comparable to 1815 meters given low family abundance percentages for the top families, there were significantly fewer total families counted at 2270 meters as compared to 1815 meters.

One study reports that throughout the Andes, epiphyte diversity typically peaks between 1000 and 2000 meters (Gentry & Dodson, 1987). A study done in the Bolivian Andes, between 350 to 4000 meters found epiphyte species richness to be highest at 1300 meters (Krömer et al., 2005). Another study that looked at large scale diversity patterns of vascular epiphytes in the montane forest of Ecuador reported peak epiphyte diversity, given the number of species, to be between 1000 to 1500 meters (Küper, 2004). The findings of this current study do align with the more general trend of Gentry and Dodson's report. The trends reported by the two newer studies are lower than was seen within this study. However, this study did not collect data at these lower altitudes. Additionally, diversity was only analyzed to the family level, whereas the study in the Bolivian Andes looked to the species level. To see a biodiversity peak more clearly within this study, continuation of data collection at both higher and lower elevations would help. Additionally, identification more specific than the family level might have provided different insights. For example, the Orchidaceae family, with between 28,000-32,000 species (Anghelescu, 2020), is significantly larger than the Bromeliaceae family with over 3200 species (Zizka, 2019), but both were treated equally when calculating biodiversity. A final thought to consider is that elevational diversity/richness peaks of all epiphytes can differ significantly from

diversity peaks of a specific family or order of epiphytes. For example, a study done specifically epiphytic fern diversity in S. Mexico along an elevational gradient of 100 to 2200 m found fern diversity to be highest between 1900 and 2200 meters (Jiménez-López, 2020). This is significantly higher than the previously mentioned elevational peaks for epiphyte richness. Likewise, another study mentions that while they found overall epiphytic richness to be greatest around 1000 m, orchid species richness peaked at 1600 and 2000 m (Cardelús, 2006).

Figure 4. The orchids depicted above reflect a mere fraction of the vast orchid diversity that is present within the western Ecuadorian cloud forest. All four photos were taken within sampled trees in the Santa Lucia Cloud Forest Reserve.

Analysis of richness and species diversity/richness peaks of individual families at different elevations would be interesting but cannot be done in detail in this study as most individuals were not classified beyond family level. Additionally, the focus of this study was water capacity, and as mentioned in the results, these richness and biodiversity trends do not appear to have any significant correlation with water capacity.

The Jaccard, Sorenson, and Morisita-Horn similarity/dissimilarity indices all showed trends of higher levels of similarity than dissimilarity between elevational sites. The Marisita-Horn index calculated values that indicate very high levels of similarity. This index does tend to be overly reactive to abundant individuals. The fact that the most abundant families were typically the same between sites may contribute to the very high score. For example, Bromeliaceae and Orchidaceae were within the top 5 most abundant families at every elevation (see figure 3.1). Additionally, between each increasing elevational site, when considering the top three families present, either 2 or 3 out of 3 families are the same between each site (see figure 3.1). The oversensitivity of the Morisita-Horn similarity index in addition to the previously stated reasons could result in this index giving a slightly higher than truly representative value.

External variables:
Slope, canopy cover, and forest canopy height were considered and analyzed as other possible explanatory variables besides elevation. No statistically significant relationships were found between the analyzed variables and slope or forest canopy height. Between canopy cover and the analyzed variables, however, some statistically significant correlations were found.

Canopy cover was found to have a negative, linear correlation with moss cover. This result was surprising as past studies have found positive correlations between canopy cover and moss cover (Sales, 2016; Haro-Carrión, 2009). The locations of these other studies, however, differ when considering climatic conditions such as elevation and humidity. Sales attributed the positive correlation seen between moss cover and canopy cover to an increase in relative humidity. Since humidity within the Santa Lucia western Ecuadorian cloud forest is generally

higher, changes in relative humidity due to changes in canopy cover may not be as pivotal in determining moss cover. Availability of light because of canopy cover could instead play a greater role in determining moss cover for this ecosystem. Increased canopy cover would result in reduced levels of sunlight reaching the trunks of trees where epiphytes can be found growing. As moss is a photosynthesizing organism, it depends on sunlight for energy. Less sunlight would result in less light energy available to be converted into chemical energy via photosynthesis, lower levels of growth, and, perhaps, lower levels of coverage on tree trunks. Canopy cover was not found to correlate significantly with elevation, so it cannot be pinned as the sole or principal variable that changed along the elevational gradient that resulted in changes of water capacity, moss coverage, and moss average thickness.

Like with moss cover, canopy cover was also found to have a statistically significant, negative, linear correlation with the number of vascular individuals (see figure 3.14). A past study done within cacao plantations in the Chocó region of Ecuador found, in terms of abundance, that vascular epiphytes that grew on the trunks of trees benefited from or at least tolerated higher intensity of light, resulting from lower canopy cover (Haro-Carrión, 2009). The results of Haro-Carrión are consistent with those of this study, but a key difference is that epiphytes were analyzed on the trees of a cacao plantation rather than primary forest. The same rationale that was used to explain the relationship between moss coverage and canopy cover, considering the effect of higher canopy cover on photosynthesizing organisms, can be used in this situation. If canopy cover is higher, there is less sunlight available for epiphytic organisms growing on tree trunks below. Lower levels of sunlight could result in lower levels of survival among germinating plants, and fewer individuals resulting. It would be interesting in future studies to see if canopy cover has any effect on biomass of vascular plant individuals. Another possible explanation for this phenomenon could relate to the lower moss coverage that is seen to correlate with higher canopy cover. Lower moss coverage could mean less substrate for epiphytic individuals to germinate, less substrate for climbers to use as support, and less water available within the tree for plants with aerial roots to draw from.

In consideration of other variables that could vary between elevational sites and affect the ability of epiphytes to store water and grow within trees, rainfall, topography (ridge trail versus trail along a valley), wind, average humidity, and vapor pressure deficit all would be worth analyzing. Due to equipment availability, data could not be collected on all of these variables, but in future studies, it would be interesting to analyze, if possible.

CONCLUSION

Main findings and significance:

In this study, it was found that along an elevational gradient, water capacity does appear to change significantly and is likewise correlated with changes in moss cover and number of epiphytic individuals. This study has built on aspects explored by previous studies on epiphytes within the Santa Lucia Cloud Forest Reserve and can hopefully also serve as a base for future investigation on this subject matter.

Due to the vast quantity of epiphytes and thus water that the western Ecuadorian cloud forest can store above ground, this forest provides an invaluable ecosystem service in terms of water storage and water regulation. Due to the cloud forest's role as a water reservoir, it is important to understand the mechanisms by which water is stored, and how this can change

throughout the ecosystem due to different climactic, topographic, and ecological variables. Currently, Ecuador's cloud forests face the threat of deforestation, be it for agriculture, ganadería (cattle-ranching), or lumber extraction. Past studies have shown that epiphyte diversity and moss cover can decrease drastically from primary to secondary Andean forests (Krömer, 2003). For these reasons, conservation of primary tropical montane forests is crucial so that this ecological function can continue to be studied as well as preserved.

Possible sources of error:

The trees analyzed at 1815 meters, covered a range greater than the trees analyzed at the other 4 elevations. This was due to a couple factors. At the beginning of data collection, in the first site at 1815 meters on the self-guided trail at Santa Lucia, data was only collected from 5 trees. At the next site, 1960 meters, it was decided that with timing, data could be collected from 9 trees. Unfortunately, due to a powerful storm, the site at 1815 meters on the self-guided trail was destroyed due to fallen trees. Thus, the last 4 trees had to be collected from a different site at 1815 meters. This site ended up being on the waterfall trail. Though only perhaps 100 meters away, conditions such as aspect were different (98 degrees E at the first site and 243 degrees SW at the second site). This could result in unrepresentatively high biodiversity scores for 1815 due to different conditions supporting different plant composition. It should be noted that 1815 meters was documented to have the highest biodiversity score. Due to this error, it cannot be known whether this was due to use of 2 sites or due to real conditions that 1815 had the highest calculated biodiversity.

In total, 25 families and 3 morpho-families were utilized to identify individuals. At the beginning of data collection, some families were completely unfamiliar, and familiarization took place throughout the study. Thus, misidentification, especially at the beginning of data collection, is a possibility.

The moss collected from each tree to be analyzed for water capacity was found in various states of hydration. Sometimes moss was nearly completely dry; no water was able to be strained out. Other moss, like that which was collected after heavy rain, could be quite hydrated, and while straining was done as consistently as possible, not 100% of the water could be removed. Thus, water capacities between found dry mosses and recently hydrated (by rain for example) mosses might be slightly inconsistent.

Suggestions for future studies:

Taxonomic identification of nonvascular epiphytes in addition to vascular epiphytes could prove a valuable addition to this area of study. Since different types of bryophytes are adapted to different habitats and climactic conditions, some varieties are more or less sensitive to variation in water availability (León, 2006). This could act as an indicator for what climactic conditions are affecting changes in water storage capacity by epiphytes, especially bryophytes, along an elevation gradient.

As previously mentioned in the analysis, the variable 'number of vascular epiphytes' would be more insightful if a few changes were made. As is, this variable does not make any indication to epiphyte size. Biomass can differ extensively between epiphytic individuals. To further the analysis of impacts of water storage capacity, moss cover, moss thickness, and other variables on vascular epiphytic individuals, a few methodology changes could be made. When considering the counting of all individuals within the 2-meter plot, methodological changes could range from sorting individuals into general size categories (ex. Small, medium, large) to

measuring length or diameter. As for insights on biomass, changes to the methodology of measuring water capacity, as discussed in the next paragraph, could take place.

When measuring the water capacity for moss and other non-bromeliad epiphytes, the majority of analyzed substrate was moss. However, some ferns and other vascular individuals were often included in smaller quantities. In future studies, considering nonvascular individuals (bryophytes) and vascular individuals separately would be advantageous. As nonvascular and vascular plants use different strategies to obtain, store, and reobtain water, different methodology should be used to analyze their water storage. For nonvascular individuals, the same methodology could be used. As vascular plants are structurally different, the straining methodology does not work as well to remove water, and once water is removed in this way, it cannot be reabsorbed like it can for nonvascular individuals. Thus, taking the weight of vascular individuals when found, and then again after drying completely, in an oven for example, would provide the weight of water that the plants had been storing vascularly when found (i.e vascular water capacity) as well as a weight of dry biomass. It would be interesting to compare both of these variables to elevation, moss cover, moss thickness, and canopy cover.

Finally, as mentioned in the analysis, if the necessary data collecting equipment could be acquired, it would be valuable to collect data on other climactic and external variables such as rainfall, humidity (5-7 m above the ground where trees were being sampled), windspeed, local temperature, vapor pressure deficit, and any other variables deemed to be possibly relevant in affecting epiphyte composition.

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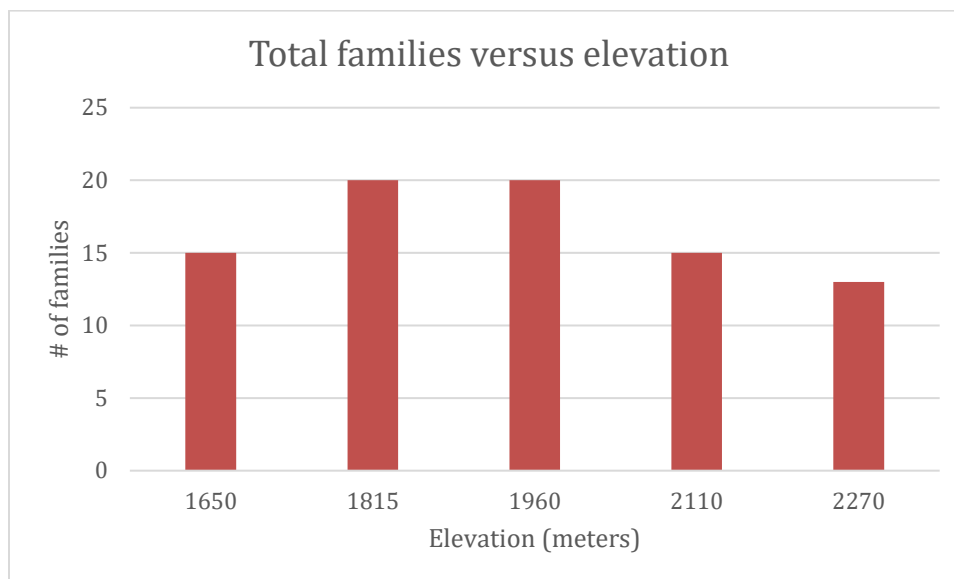
APPENDIX:

Figure 5.1: The figure above shows how many total families of vascular plants were documented between 5 and 7 meters above the ground in tree sample sites at each elevation.
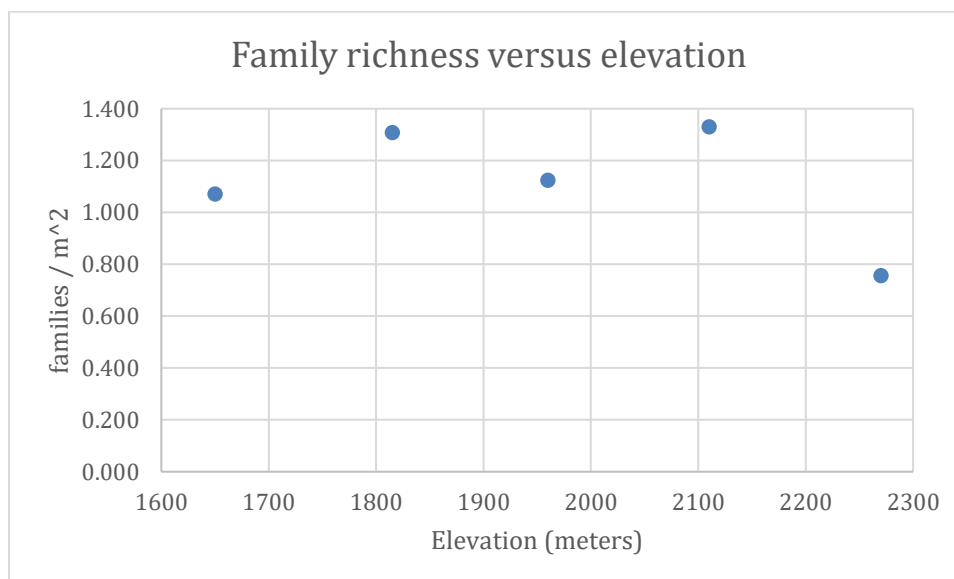

Figure 5.2: The figure above shows the family richness calculated for each elevation. This was calculated by dividing the total number of documented families (see figure 4.1) by the total surface area from which data was collected. The total surface area (m^2) was extrapolated by taking the measurement of tree circumference (m) at the top of the ladder and multiplying it by 2 (m).
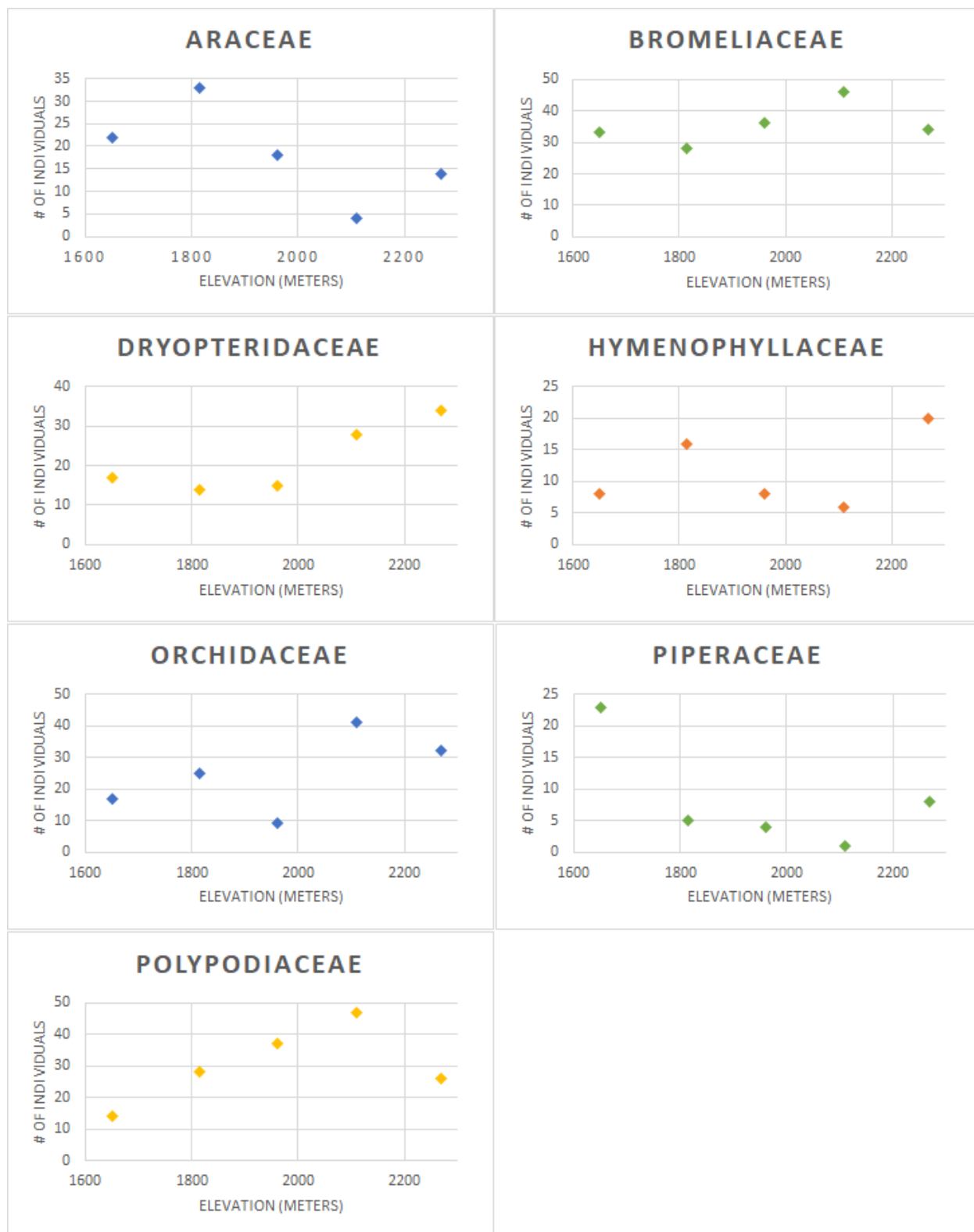
Figure 5.3: Number of documented individuals versus elevation for the 7 most abundant families observed, with between 41 to 177 individuals in each.