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How elevation affects epiphyte distribution: An analysis in epiphyte distribution changes at different elevations and tree strata in Santa Lucia Cloud Forest Reserve, Ecuador

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Abstract

Cloud forests are unique ecosystems due to their tropical nature, high elevations, and extremely high presence of epiphytes that serve many important roles for the ecosystem's biotic and abiotic components. As epiphytes can make up anywhere from one-quarter (Foster 2001) to a half (Gómez González et al. 2017) of all local plant species in cloud forests, it is essential to understand how their habitat distributions change with elevation and whether climate change will have a significant effect on that. This study used observational survey methods to record the amount of monocots (separately counted bromeliads and orchids), dicots, ferns, and percent moss cover of thin, medium, and thick mosses on multiple trees at every 50 meters (m) of elevation increase along trails in Santa Lucia Cloud Forest Reserve in Pichincha, Ecuador. These data allowed for results to analyze the microclimatic distributions and overall ecosystem distributions of these epiphytic plants to test whether the changes in their prevalence across an elevation gradient were significant and could be used to predict how they will shift as the climate continues to change due to increased atmospheric Carbon Dioxide (CO^2). This study concluded that there were increasing trends in the average numbers of ferns, bromeliads, and medium moss per tree as elevation increased. It also used differences between counts from 0-5 m on tree trunks and 5-10 m on tree trunks to analyze how distributions changed only on tree trunks across the studied elevation range (1,600-2,200 m). The number of ferns on the 0-5 m sections significantly increased ($R = 0.7405$) and the same for bromeliads, although not significantly. On both sections of the trees, medium moss coverage significantly increased along with elevation which allows for conclusions on water storage potential and the optimization of mosses in more humid environments to be made. The results of this study could be used in conjunction with other studies that research how plant distributions change with climate change in order to predict how certain epiphyte distributions may change as climate change progresses.

Resumen

Los bosques nublados son ecosistemas únicos debido a su naturaleza tropical, sus altas elevaciones y la presencia extremadamente alta de epífitas que cumplen muchos papeles importantes para los componentes bióticos y abióticos del ecosistema. Desde las epífitas pueden constar de desde una cuarta parte (Foster 2001) hasta la mitad (Gómez González et al 2017) de todas las especies de plantas locales en los bosques nublados, es esencial entender cómo cambian sus distribuciones de hábitat con la elevación y si el cambio climático tendrá un impacto significativo. Este estudio utilizó métodos observacionales para registrar la cantidad de monocotiledóneas (bromelias y orquídeas contabilizadas por separado), dicotiledóneas, helechos y porcentaje de cobertura de musgos delgados, medios y gruesos en múltiples árboles a cada 50 m de aumento de elevación a lo largo de los senderos en la Reserva del Bosque Nublado de Santa Lucía en Pichincha, Ecuador. Estos datos permitieron que los resultados analizaran las distribuciones microclimáticas y las distribuciones generales de los ecosistemas de estas plantas epífitas para probar si los cambios en sus prevalencias a través de un gradiente de elevación fueron significativa y podría usarse para predecir cómo cambiarán a medida que el clima continúe cambiando debido al aumento del dióxido de carbono atmosférico (CO^2). Este estudio concluyó que había tendencias crecientes en el número promedio de helechos, bromelias y musgos medios por árbol a medida que la elevación aumentaba. También se utilizaron diferencias entre recuentos de 0-5 m en troncos de árboles y 5-10 m en troncos de árboles para analizar cómo cambiaron las distribuciones sólo en troncos de árboles a través del rango de elevación estudiado (1.600-2.500 m). El número de helechos en las secciones de 0-5 m aumentó significativamente (R = 0,7405) y lo mismo para las bromelias, aunque no significativamente. En ambas secciones de los árboles, la cobertura media de musgos aumentó significativamente junto con la elevación, lo que permite llegar a conclusiones sobre el potencial de almacenamiento de agua y la optimización de musgos en ambientes más húmedos. Los resultados de este estudio podrían utilizarse en conjunto con otros estudios que investigan cómo cambian las distribuciones de plantas con el cambio climático para predecir cómo ciertas distribuciones de epífitas pueden cambiar mientras que avanza el cambio climático.

Acknowledgements

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Introduction

Cloud forests are unique ecosystems due to their tropical nature and high elevations that form only in very select regions of Central and South America, southern Mexico, parts of the Caribbean, Southeast Asia, eastern Africa, and New Guinea. One of their main characteristics is that they have an extremely high presence of epiphytes that serve many important roles for the ecosystem’s biotic and abiotic components. One of their biggest roles they fulfill is for water retention and being important members of the hydrologic cycle of cloud forests. The main way they do this is by intercepting and regularly releasing large amounts of water collected from passing fog (Ah-Peng et al. 2017). Nonvascular epiphytes, made up of mosses, liverworts, and hornworts (Whitton 2013), mostly execute this act while also making up about 75% percent of epiphyte biomass in cloud forests. They will take in water through the whole shoot surface and externally store it in *inter alia* (Ah-Peng et al. 2017) which significantly contributes to the high humidity present in the canopy of cloud forests as well as the understory - though to a lesser degree. It has been proven that forests with less epiphyte coverage also store significantly less water in the canopy (Köhler et al., 2010; Lakatos, 2011) due to the fact that in temperate coniferous rainforests about 25% of total ecosystem evaporation comes from the contribution of epiphytes to forest water vapor (Barbour et al. 2005). These high differences between forests with high epiphyte presences and those without contributes to the dependency of cloud forests on epiphytes. This means that bryophytes are good bioindicators of moisture content in a cloud forest due to their large role in the hydrologic cycle. Ah-Peng et al. (2017) mentions the possibility that climate change could affect bryophyte species presence and density (Scholl et al. 2010), having extreme impacts on the water cycles within cloud forests.

Another key role epiphytes fill in cloud forests is comprising up to 50% of the within-crown leaf area which means they make up a large portion of above-ground biomass in forests as well. Epiphytes are made up of plant litter, canopy humus, associated invertebrates, fungi, and microorganisms (Gómez González et al. 2017) as well as the epiphytic plant bodies themselves. Because of this high diversity of biomass components, they create another type of ecosystem in trees that is deeply vital to the overall cloud forest ecosystem and its nutrient cycle. Their biomass has been documented through many studies to account for several tons per hectare (Gómez González et al. 2017) although these estimates vary between locations. In addition to being essential for biomass in cloud forests, they also contribute to the biodiversity of flora in these areas because vascular epiphytes make up approximately 10% of all know vascular plant species and up to 50% of local plant species in cloud forests (Gómez González et al. 2017).

This understanding of the vast importance of epiphytes as part of the cloud forest ecosystem leads to the question of how their distributions change with elevation and whether climate change will have a significant effect on that. As about one-quarter of all plant species may be epiphytic in cloud forests, a subsequently high percentage of them are often endemic (Foster 2001). This means that studies must be done in cloud forests to more fully understand the impacts climate change could have on the vertical distributions of epiphytes in microclimates such as trees as well as the larger ecosystem across the elevation range of cloud forests - which is usually 1,000 m to 2,500 m. Randin et al. (2009) supports the persistence high-elevation habitat hypothesis that states that suitable habitats for certain locally adapted species will move upwards in elevation as global climate change persists (Randin et al. 2009) due to an overall warming trend that will make current habitats less ideal and higher elevation habitats more suitable due to cooler temperatures being found at higher elevations, but global warming trends making those more comfortable for species adapted to certain temperature habitats. This study's results do however stress the importance of studying species distributions affected by climate change on several scales to gain an accurate representation of how they may change locally to globally (Randin et al. 2009). Another study by Kelly and Goulden (2008) confirms these results by finding that their observed vegetation redistribution is accountable to climate change due to four replications of the study in California, USA. They also hypothesized based on their results that species redistribution happened episodically with accelerated mortality rates at lower elevations, usually during dry periods, and infilling of the species at new, higher, elevations mostly during wet periods (Kelly & Goulden 2008). Finally, Lenoir et al. (2008) further confirmed these results by stating that the optimum elevation for forest plant species shifted mostly upward toward the end of the 20th century with high statistically significant results.

This study used this background information to specifically analyze the prevalence of certain epiphyte types in a tropical montane cloud forest in Ecuador across a set elevation gradient. The study area was within Santa Lucia Cloud Forest Reserve (Figure 1) that has an elevation range of 1500 to 2500 m. This study only observed sites within 1600 to 2200 m due to some limitations that will be discussed later. The aim of this study was to assess the prevalence of monocots, dicots, ferns, and mosses on trees across this elevation range in order to gauge their habitat preferences in this cloud forest's ecosystem as well as how their distributions change at higher elevations. An important addition to this research is the inclusion of separate counts at each tree observed from 0-5 m and 5-10 m on the trunk. Moss was measured in categories of thickness and percent coverage. By observing the preferences of these types of epiphytes for how high they grow on a tree trunk, results could analyze their microclimatic distributions as well. Bromeliads and orchids were also counted separately from monocots - although their counts were included in the monocot category - because they serve very important roles for water storage and pollination, respectively, and this was information that held significance to the overall functioning of this ecosystem.

This study hypothesized that average percent moss cover will increase with elevation due to more potential to obtain water from air moisture and the number of epiphytes will overall decrease with elevation due to higher humidity and moisture at higher elevations. Finally, in reference to the distribution of epiphytes on tree trunks, the lower halves of trunks will have more vascular epiphytes than the top ones observed.

Figure 1: Screenshot taken from Google Earth Pro of the location of Santa Lucia Cloud Forest Ecolodge in the Santa Lucia Cloud Forest Reserve.

Methods

Data collection for this study began at 1600 m of elevation on the waterfall trail in Santa Lucia Cloud Forest Reserve. Observations were made on four trees at every 50 additional meters of elevation gained along the trail from that point up to 2,200 m of elevation on the main trail in the reserve - these locations are addressed as “sites” in this report. The four trees at each site were chosen to prevent selection bias by surveying the four closest trees that fit the predetermined requirements for viable trees. These parameters included each tree being at least ten centimeters in diameter, not split into multiple trunks for the first ten meters, and must be relatively accessible so that both sides of the trunk could be seen and circumference at breast height (CBH) could be measured with a tape measure. A minimum trunk diameter was set in order to exclude very small trees that would have less epiphytes on them due to their smaller surface area and to prevent those data from affecting the outcome of the survey counts. The parameter of the tree needing to only have one trunk for the first ten meters was set into place because trees with more than one trunk would have more epiphytes than with just one due to more potential surface area from them to grow from. In addition, if trees with extra branches or trunks had been included but only the main trunk was surveyed, there would have been a part of the main trunk that was blocked by the second where epiphytes could not grow - for these reasons the second condition of selection viable trees for this study was put in place. Finally, the last condition was necessary because some trees that could have been surveyed would not have had a fair representation because they were either unable to be observed from all sides or could not be measured for CBH. The forest on the sides of the trails at times was very steep or the soil was loose, and this made reaching the trees or seeing the non-trail-facing side impossible so they were excluded as options. Outside of these trees, when the correct elevation was reached - as seen on the compass app of an iPhone - the four closest trees were selected to be surveyed in order to replicate the data for each elevation and obtain an average later to represent the epiphyte communities more realistically. Each tree was divided into two sections of 0-5 m of the trunk and 5-10 m where binoculars were used to accurately see which types of plants there were. For each section the percent moss coverage of thin, medium, and thick moss was recorded, the number of monocots, dicots, and ferns, as well as separately the number of bromeliads and orchids. Some notes were also taken of relevant information on potential water storage abilities of the tree based on the thickness and coverage of moss as well as number and size of bromeliads. When surveying a tree, one half of the trunk was first observed and counted and then the other half; the second counts of monocots, dicots, ferns, bromeliads, and orchids were added to the first half counts and the second moss coverage percentages were averaged with the first side.

The methods of this study were very noninvasive and during observations, no existing epiphytes or surrounding plants were harmed. Observation and measurement methods did require going off the trail at times, but much care was taken not to damage plants in the way.

Data analysis for this study was primarily done on Microsoft Excel, but Vassar Stats was used to conduct the t-tests and ANOVA tests. All figures were also made on Excel.

Results

For the first part of data analysis in this study, scatterplots were made on excel. There was a general downward trend in CBH as elevation increased (Figure 2), but this trend was not significant with an R-value of 0.646 (0.7 was the accepted value of significance). Monocots had almost no trend (Figure 3) whereas the average number of dicots per tree showed a slight downward trend when compared to elevation change with an R-value of 0.389.

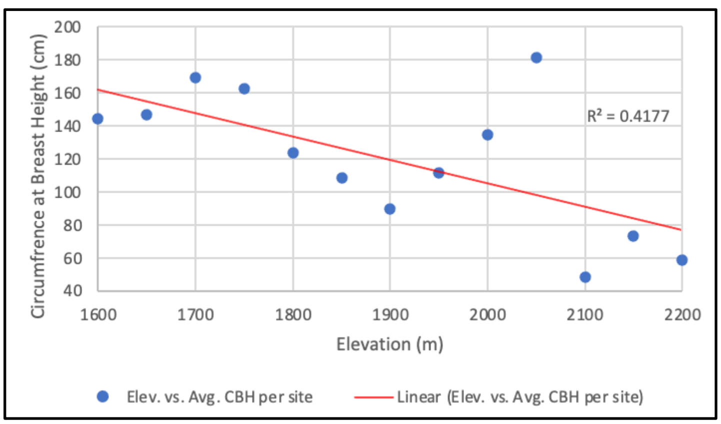


Figure 2: Average circumference at breast height per tree at each elevation that was observed in Santa Lucia Cloud Forest Reserve with a linear trendline and R^2 value.

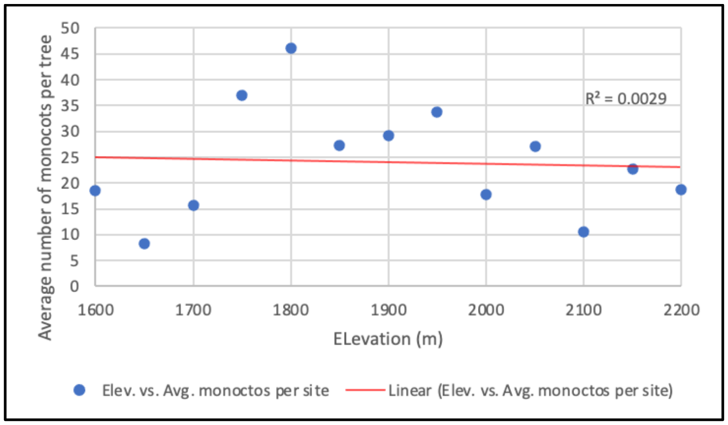


Figure 3: Average number of monocots per tree at each elevation that was observed in Santa Lucia Cloud Forest Reserve with a linear trendline and R^2 value.

The average number of ferns and bromeliads per elevation site had very similar direct relationships with elevation increase (Figures 4 and 5 respectively) with R-values of 0.525 and 0.381 respectively. They were not significant but show a clear increasing trend.

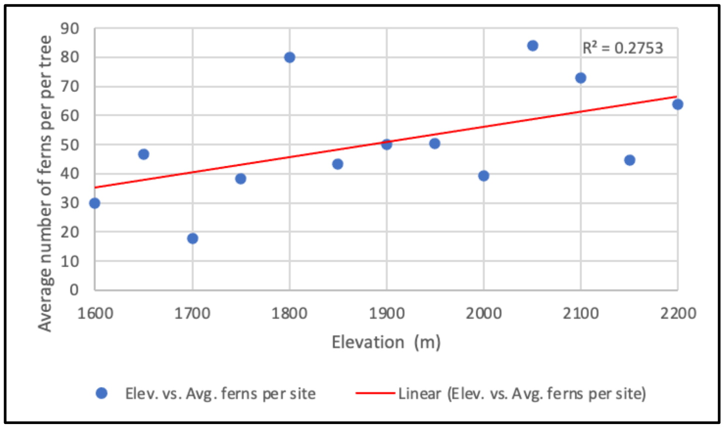


Figure 4: Average number of ferns per tree at each elevation that was observed in Santa Lucia Cloud Forest Reserve with a linear trendline and R^2 value.

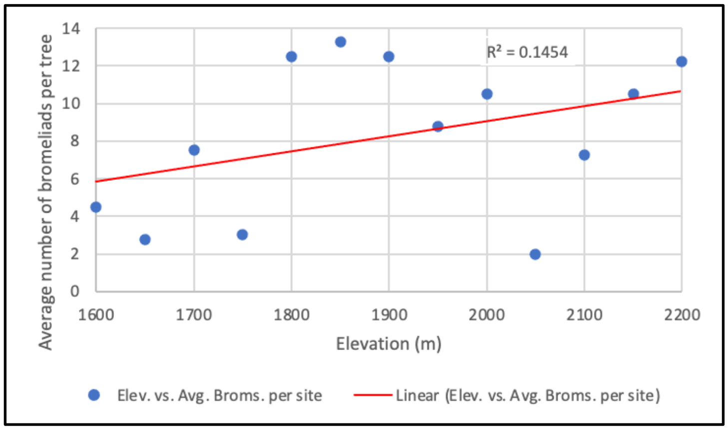


Figure 5: Average number of bromeliads per tree at each elevation that was observed in Santa Lucia Cloud Forest Reserve with a linear trendline and R^2 value.

The average number of orchids per site had a very small downward trend as elevation increased with an insignificant R-value of 0.214 (figure 6).

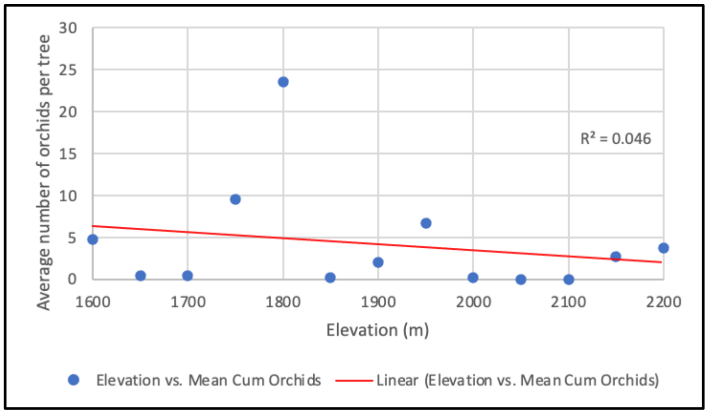


Figure 6: Average number of orchids per tree at each elevation that was observed in Santa Lucia Cloud Forest Reserve with a linear trendline and R^2 value.

In figure 7, the total monocot (including bromeliads and orchids), dicot, and fern counts are shown as they relate to elevation change and an insignificant positive trend is seen with the total number of ferns per tree, but little to no trend with monocots and dicots. This graph compared with the figure 8 box and whisker plot shows that the total number of ferns per tree was higher than both monocots and dicots and had the largest error due to two high outliers in the data collected. Figure 9 shows a comparison of the average numbers of monocots, dicots, and ferns for trees at each elevation to further demonstrate why the average number of ferns seen in figure 6 was higher than monocots and dicots.

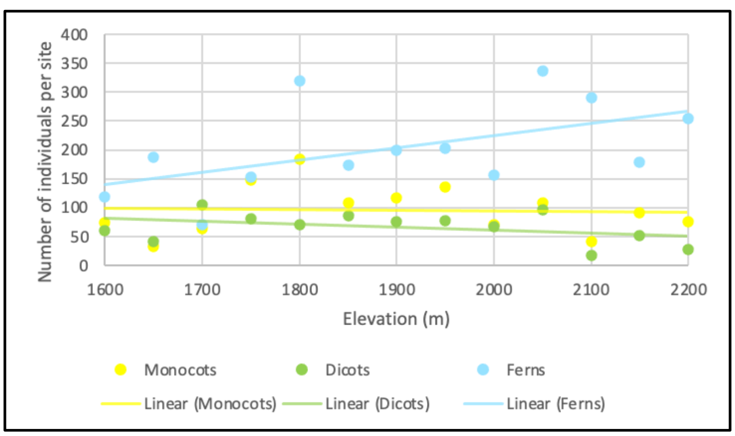


Figure 7: Average number of monocots, dicots, and ferns per tree at each elevation that were observed in Santa Lucia Cloud Forest Reserve with respective linear trendlines and R^2 values for all.

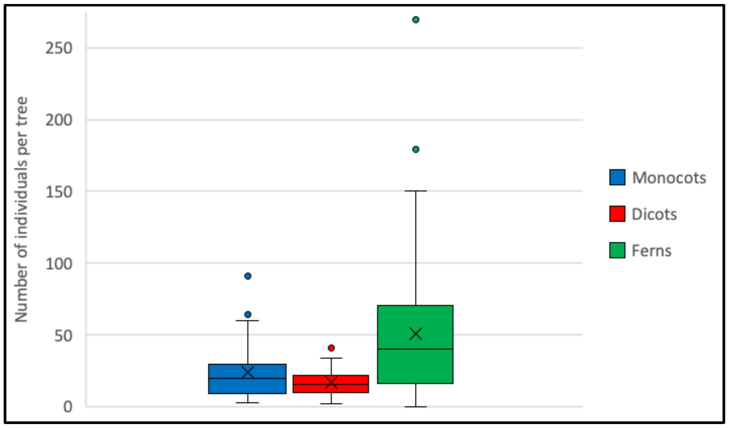


Figure 8: Box and whisker plot showing a comparison between quartile values and means of monocots, dicots, and ferns at each site, including outliers.

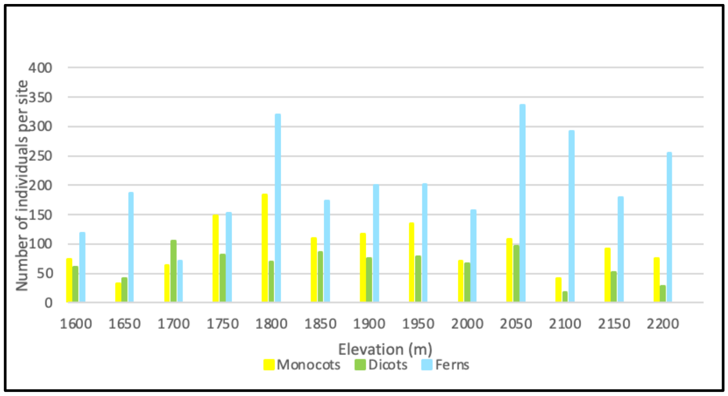


Figure 9: Comparative bar chart of monocots, dicots, and ferns using the number of individuals per site.

In terms of changes in moss thickness with elevation increase, figure 10 shows that thin and thick moss had almost no trend, but thin moss was more common than thick moss at almost all sites as seen by a trend line y-intercept of 24.34% coverage and thick moss being at 7.44%. In the same plot, it is seen that average medium moss thickness significantly increased with elevation throughout the whole tree with an R-value of 0.776. Total moss coverage of any thickness also increased, although not significantly, with elevation increase (figure 11) with an R-value of 0.593.

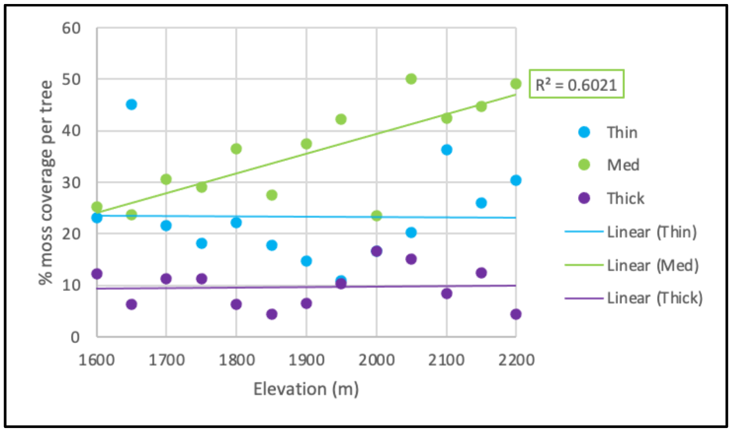


Figure 10: Scatterplot comparing the average percent moss coverage per tree at each site for thin, medium, and thick moss including trendlines. The R^2 value shown represents a significant R-value for medium moss.

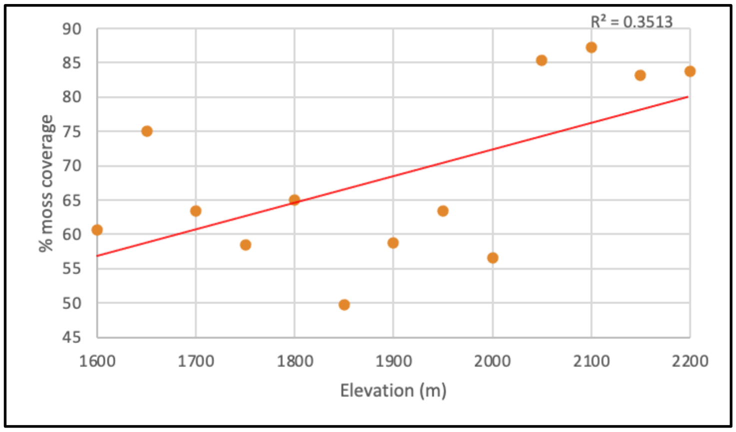
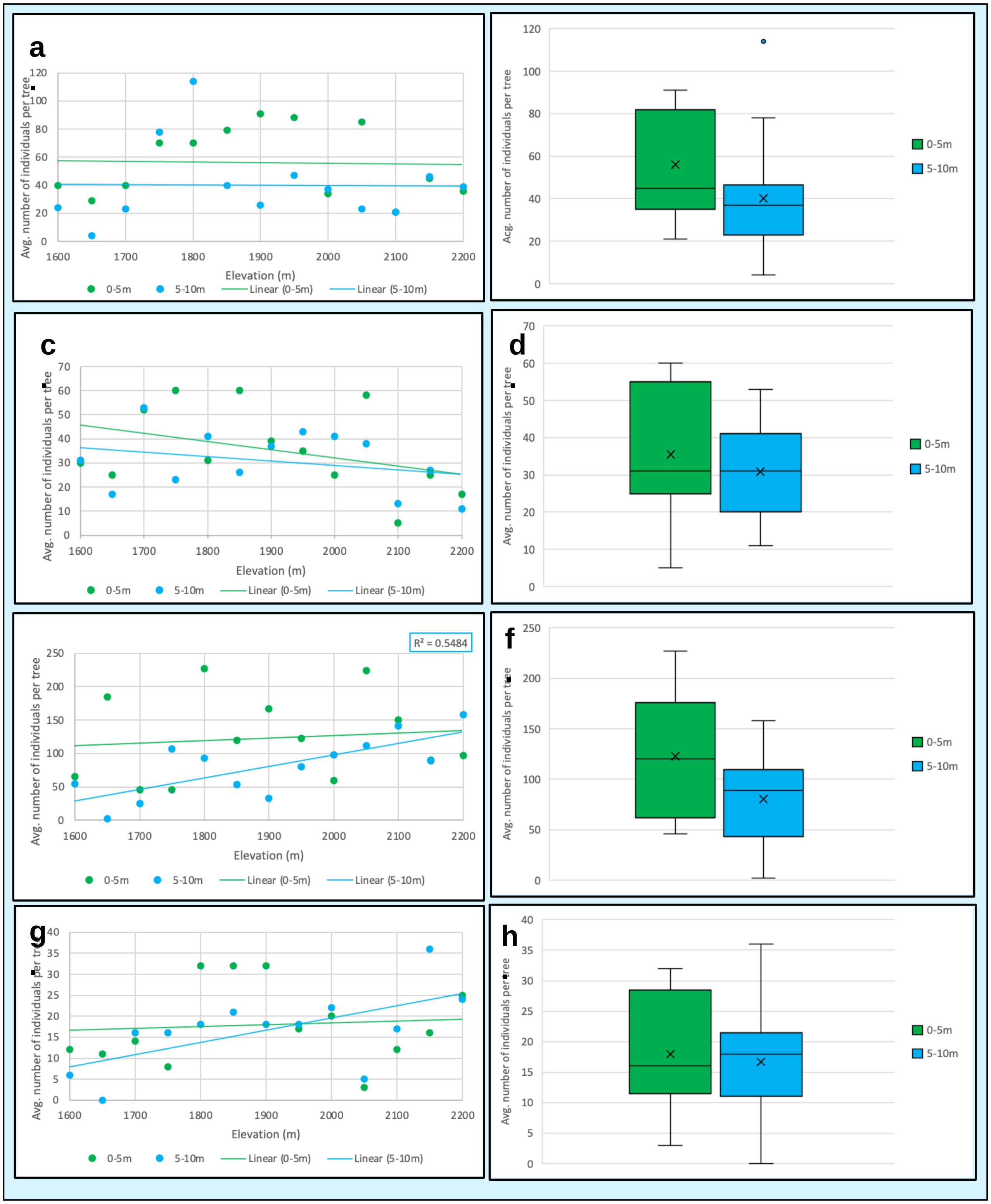


Figure 11: Scatterplot of total percent moss cover per tree at each elevation with a linear trendline and R^2 value.

The second part of data analysis for this study was comparing the differences in counts and observations between the bottom five meters of the trunk and the next 5 meters above that. There was no change in the number of monocots at 0-5 m or 5-10 m across changing elevations (figure 12a), but the average number of monocots per tree was higher from 0-5 m than 5-10 m at 56 versus 40.154 respectively (figure 12b). The same was not true for dicots as both 0-5 m and 5-10 m sections had downward trends (figure 12c) with the section of 0-5 m being slightly more dramatic, but still not significant. As can be seen in figure 12d, the means were relatively similar with 0-5 m higher at 35.538 average individuals per tree compared to 30.846 average individuals per tree. The average number of ferns per tree per site along the whole elevation gradient on 0-5 m of the trunk stayed constant and figure 12e shows a very slight upwards trend as elevation increases. However, the line for 5-10 m shows a significant increase in the number of ferns on the higher section of trees as elevation increases as can be seen with an R-value of 0.741 (above the 0.7 significance value). The mean number of ferns from 0-5 m on the trunk was also higher than for 5-10 m with values of 122.923 and 80.385 respectively (figure 12f). Neither trend of the number of bromeliads on 0-5 m and 5-10 m section of the trees were significant, although 5-10 m was more dramatic than 0-5 m (figure 12g) showing a general increase in the number of bromeliads higher on the tree trunks (5-10 m). The mean numbers of bromeliads for the 0-5 m sections and 5-10 m sections were very similar with 0-5 m being 18 and 5-10 m being 16.692 (figure 12h). The average number of orchids per each section of the tree at every elevation did not show much of a trend as elevation increased. There were slightly more orchids overall in the 5-10 m region but both lines have a slight downward trend (figure 12i). The difference in prevalence of where most orchids were found on trees across the whole reserve can be seen in figure 12j with the mean for 5-10 m as 12.385 whereas the mean for 0-5 m was 4.308.



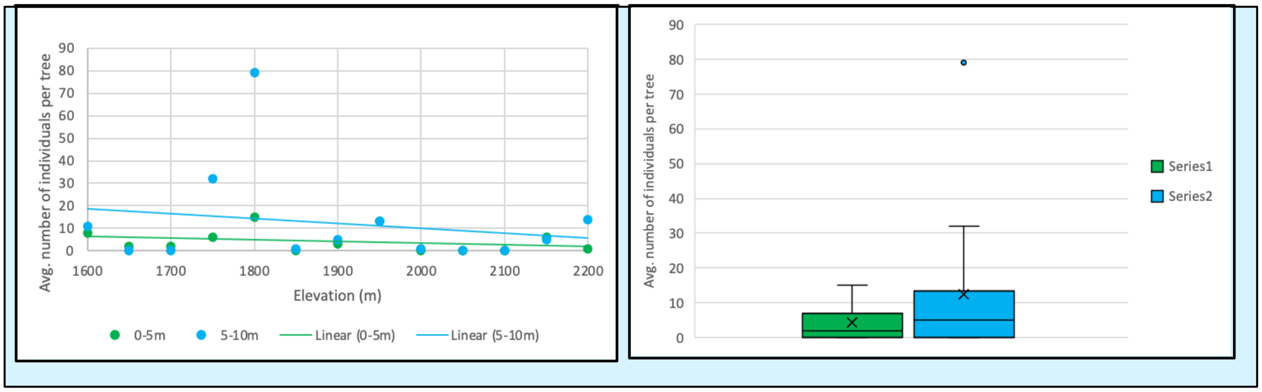


Figure 12: Average number of individuals per tree at each elevation for 0-5 m and 5-10 m on the tree trunks (including linear trend lines) and their corresponding box and whisker plots that compare the distributions of the average number of individuals per tree for each elevation between 0-5 m and 5-10 m. **a.** and **b.** monocots, **c.** and **d.** dicots, **e.** and **f.** ferns, **g.** and **h.** bromeliads, **i.** and **j.** orchids, respectively.

After completing a one-way ANOVA test on Vassar Stats to test the potential significance between the average numbers of monocots, dicots, ferns, bromeliads, and orchids in relation to elevation change, it was determined that there was no significant change in the prevalence of any of these groups as the P-value was 0.156 (df = 48) - using a 0.05 significance value for all significance tests in this study. When the same one-way ANOVA test was completed using thin, medium, and thick moss coverage values, the results were also not statistically significant (P = 1.39, df = 2). T-tests were also done to test the significance between 0-5 m and 5-10 m of the tree trunks for average counts per elevation of monocots, dicots, ferns, bromeliads, orchids, thin moss, medium moss, and thick moss. None of these results were statistically significant in their P-values (table 1). However, when Chi-square tests were done to test for statistically significant independence between the average numbers of plant counts between 0-5 m and 5-10 m on the tree trunks, there were some significant results (table 2). Monocots (X^2 = 135.165, df = 12, P = 5.651^{-23}), dicots (X^2 = 42.612, df = 12, P = 2.626^{-5}), ferns (X^2 = 352.846, df = 12, P = 3.519^{-68}), bromeliads (X^2 = 34.53, df = 12, P = 0.0006), and thick moss (X^2 =72.687, df = 12, P = 1.003^{-10}).

Discussion

Overall, the starting hypothesis that overall percent moss coverage will increase with elevation was accepted, although not significantly as figure 11 shows with a dramatic and clear trend. However, all epiphytes did not decrease in average amount per tree as hypothesized due to the trends seen in figures 11, 12e, and 12g where, respectively, percent moss coverage, ferns, and bromeliads increased on average per tree as elevation increased. The potential reasoning for this will be discussed later with the explanation of each studied epiphyte type in relation to its climate condition growing preferences. Interestingly, the lower halves of tree trunks (0-5 m) did mostly have more vascular epiphytes than the higher observed region (5-10 m). All vascular epiphyte types observed (figures 12b, 12d, 12f, and 12h) followed this trend except for orchids which were slightly more common from 5-10 m on trees (figure 12j).

Though insignificant, there was a clear downward trend in the CBH of trees as elevation increased in this study (figure 2). According to a study by P. Foster (2001), plants generally grow smaller with thicker leaves when exposed to higher UV light that is characteristic of higher altitudes and confirms the outcome of this data from this study by stating that tree size will decrease as altitude increases (Foster 2001). This stunting due to UV exposure is due to polyphenols, which are hypothesized to possibly interfere with photosynthesis, cell division in fine roots, transpiration, and ion uptake (Foster 2001) which would logically prevent plants from growing as large, especially trees as they are the most exposed to sunlight with their canopies. Trees also generally grow more stunted on exposed ridges and peaks (Foster 2001) which is the common location of many that were observed in this study as the trail to reach the highest elevations in the Santa Lucia reserve was along a ridge with pastures on the slopes at times. Increased wind that comes at higher elevations and more exposed areas also causes twisting of trees and more branches (Foster 2001) to grow which made finding trees to include in this study more difficult as one of the requirements was not to have branches before 10 m of uninterrupted, singular trunk. This leads to overall more sparse forests that aren't as dense as forests at lower elevations.

Monocots and dicots both showed little or no trend in figures 3 and 13 respectively, although due to a potential error in the monocot data collection that will be explained later, a more dramatic downward trend would have been expected due to possibly counting ferns as monocots because of a lack of knowledge. The decrease in monocots and dicots is likely due to the lack of moisture and increase in relative humidity that comes with an increase in elevation (Foster 2001). In this study, dicots were typically found to be climbers that used the tree to grow up from the soil and therefore likely utilized the soil moisture more than humidity to sustain their water needs. The only climbing monocots that were found were of the family *araceae* and grew from the ground rather than the tree itself or a thick moss layer. Most other monocots grew from these areas on the trees and dicots that were not climbers grew directly out of the tree regardless of if there was thick moss or not. The monocots were likely able to survive in these thick moss areas of the trunks due to the water storage ability of thicker mosses that collect humidity from the air - especially at higher elevations since there is higher humidity. The higher air moisture content overall is due to the fact that higher altitudes have lower temperatures and tend to have higher humidity due to the decreased amount of evaporation and subsequent increase in fog.

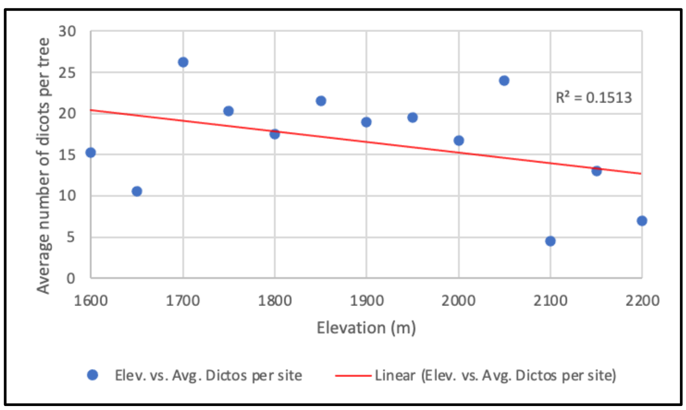


Figure 13: Average number of dicots per tree at each elevation that was observed in Santa Lucia Cloud Forest Reserve with a linear trendline and R^2 value for it.

It makes sense then that the average number of bromeliads per tree increased overall (figure 5) because they are able to survive by acting as tanks and storing water (Ladino et al.

2019) in the bowls that they create with their overlapping leaves. They are able to use their roots and direct rainwater storage abilities to optimize the lower moisture of the higher elevations but do not have to completely rely on their roots for nutrient uptake as other epiphytes do (Ladino et al. 2019). Additionally, there was hardly a difference in the number of bromeliads at 0-5 m and 5-10 m on tree trunks as seen by the means in figure 12h plot. The air moisture content between ten meters of the same elevation does not vary enough to have a dramatic effect on the ability for bromeliads to grow at different areas in the tree, especially when placed on top of one another at times. Ferns had a very similar trendline result to bromeliads (figure 12e) although it was still not a statistically significant R-value as stated above. Overall, the trend for average number of ferns per tree for each site was positive with more ferns being seen on each tree on average as elevation increased but at much higher numbers than bromeliads. Ferns also were the most abundant per site when compared to monocots and dicots (figure 8) with a mean number of 50.827 versus 24.038 and 16.538, respectively. This implies that, as epiphytes, ferns are more successful in terms of sheer population size than monocots and dicots. They did also have a higher variability in amount per site although the lower border of the second quartile (16.25) in figure 12f is almost higher than both medians of monocots (15.5) and dicots (20). Ferns were seen both growing out of thick bryophyte layers as well as directly out of tree trunks at all sites. As an additional observation, fern size also greatly varied between all sites with no pattern being able to have been determined. The trends on average number of ferns per tree at each site in 0-5 m trunk zones versus 5-10 m zones varied as elevation increased because, from 0-5 m, the number of ferns per tree stayed relatively consistent with only a slight positive trend whereas, from 5-10 m on the trunk, the average number of ferns per site significantly increased with elevation (figure 12e) to the point where the two average quantities were about the same at 2,200 m of elevation since the 5-10 m averages started much lower than those of 0-5 m. This is likely due to the fact that ferns are wind pollinated and, as elevation increases, forest density decreases - as was discussed above. This allows wind speeds to be greater around trees at higher elevation as it can permeate the canopy more easily (Hiertz & Briones 1998), allowing the wind pollination for ferns to be more effective at higher points in the canopy and at higher elevations - as seen in figure 4 - which explains why their prevalence at 5-10 m on tree trunks significantly increases with elevation.

Orchids had a slight and insignificant downward trend in terms of average number of orchids per tree per site (figure 6) as elevation increased which implies that the changing climatic conditions that come with increased elevation do not have a significant effect on the prevalence of orchids as epiphytes except for a slight decrease - it is impossible to know without more data and observations whether this trend is true though. There was also very little change in the average number of orchids per tree at each site on both 0-5 m of the trunks and 5-10 m. Neither were significant although 5-10 m showed a slightly more dramatic indirect relationship than 0-5 m (figure 12i). There were overall more orchids found in the 5-10 m observed level of the trunk when compared to the mean of average orchids found at each site for 5-10 m as seen in figure 12j. It’s also important to mention that the number of orchids visible from the base of the tree could have been reduced to the abnormally dry climate that was present at the time of these observations and could have caused the orchids to drop their leaves.

Figure 10 shows that there was no change in thin and thick percent moss coverage as elevation increased, but a significant increasing trend in medium percent moss coverage across the elevation range with an R-value of 0.776. Based on this result and the known fact that mosses are extremely important to the water holding capacity of cloud forests (Lew 2016), the percent medium moss coverage likely increased with elevation due to the higher humidity and higher water storage potential from air water vapor. It is more advantageous for epiphytic moss mats to increase in thickness with elevation gain as they can store more water in order to sustain themselves and the other epiphytes growing from the thickest mats. This also likely explains figure 11 which shows that overall percent moss cover increased as the sites increased in elevation. Interestingly, both medium moss coverage from 0-5 m and 5-10 m increased significantly with greater elevations (figure 14) which signifies that this increase in thickness is due to elevation increase and not specifically the positioning of one tree level that is more conducive to moss growth with elevation. If this solely happens for water storage potential, it demonstrates how vital the ability is at higher elevations in the cloud forest as nonvascular epiphytes have no ability to store water within themselves due to their leaf structure and lack of deep roots.

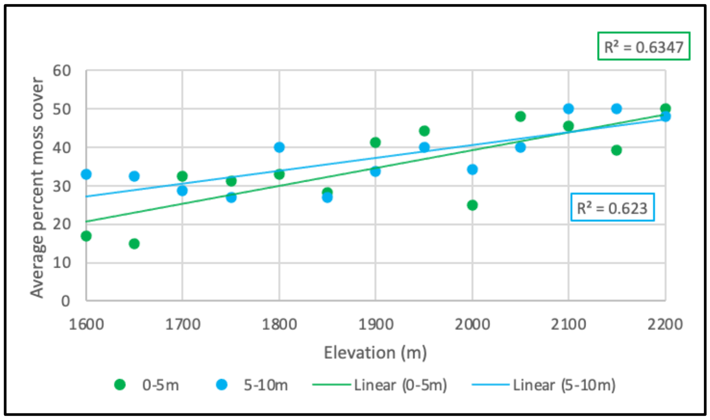


Figure 14: Average percent medium moss cover per tree at each elevation for 0-5 m and 5-10 m on the tree trunks along with their corresponding linear trendlines and significant R^2 values.

To finish analyzing the 0-5 m and 5-10 m observations from this study for monocots, dicots, and bromeliads, monocots had very flat trendlines for both 0-5 m and 5-10 m (figure 12a) meaning the average number of monocots per tree per site barely changed along with elevation. There were more monocots on the 0-5 m section than 5-10 m which can be seen in figure 12b, probably signifying a difference in growing condition preferences of the species of monocots found in this cloud forest. Lower sections of trees have less light, humidity, wind, and lower temperatures (Hiertz & Briones 1998) which could be some of the more common growing preferences for these types of epiphytes. Dicots had more of a downward trend (figure 12c) on both 0-5 m and 5-10 m levels of the trunks at each site, but neither were significant. At the lower elevations, there were slightly more dicot epiphytes from 0-5 m, but as elevation increased, both levels ended up being about equal as 0-5 m had a more dramatic trendline than 5-10 m and therefore they met. The difference between total numbers of dicots per site can be seen in figure 12d as the mean for 0-5 m dicots is slightly higher - likely due to most dicots being found from 0-5 m at the majority of sites across all elevations studied. Figure 12g shows the average number of bromeliads per tree per site across elevations with very little to no trend from 0-5 m on the tree trunks but an interesting switch to more bromeliads being observed per average tree after 1950 m of elevation when they started lower than the counts from 0-5 m before 1950 m. As stated before from the Hietz and Briones (1998) study, there is greater humidity higher in the canopy of trees and with the already increased humidity at higher elevations as well, they are likely better able to capture and store water as tanks at higher elevations. This has a multitude of implications that include bromeliads being brooding sites for mosquitoes and habitats for other insects as well as important model ecosystems for applied research on smaller communities (Schmelz et al. 2015).

Due to the insignificance of all results of the two-tailed t-tests that tested whether the means between 0-5 m and 5-10 m trunk levels were significant by using the average number of each observed epiphyte type and moss type at each elevation (table 1), this study cannot conclude that the difference between these two strata was meaningful even if there was a numerical difference. This implies that, even though the differences between means was referenced in the discussion of the results above, none of them were significant and different enough to conclude anything other than general trends and observations.

Table 1: Table showing the t-test results to compare the means between 0-5 m and 5-10 m trunk levels were significant for the average number of individuals and moss thickness per tree at each elevation.

	Diff b/t means	P	df
Monocots	8.24	0.357025	48
Dicots	2.44	0.66912	48
Ferns	22.12	0.239899	48
Bromeliads	0.68	0.826804	48
Orchids	-4.2	0.232204	48
Thin Moss	2.9223	0.335294	72
Med Moss	-0.9122	0.834261	72
Thick Moss	-1.5	0.32066	72

Contrastingly, when 0-5 m and 5-10 m on the trunks of average trees at each elevation were tested for significant independence with Chi-square tests, all but orchids, thin moss, and medium moss were significantly independent samples not due to random chance. For most of these it can be reasoned that the significant differences in preferences for what height in the forest strata to live is most ideal for growth and pollination. For example, the difference between ferns at each trunk level was so significant ($P = 3.519^{-68}$ (table 2)) because there were significant trends for both levels in figure 12e.

Table 2: Table showing Chi-square test results including X2 values, degrees of freedom, and P-values to test independence between average counts of individuals per tree for 0-5 m and 5-10 m per site. Orchids are red because the confidence values were too small to complete the test. 0.05 was used as the minimum level of significance.

	X^2	df	P
Monocots	135.1650731	12	5.65085E-23
Dicots	42.61243996	12	2.62581E-05
Ferns	352.8460068	12	3.51942E-68
Bromeliads	34.52987637	12	0.000556199
Orchids			
Thin Moss	19.88716117	12	0.069250828
Med Moss	16.47083158	12	0.170609945
Thick Moss	72.68694858	12	1.00323E-10

The one-way ANOVA tests that were done to compare the means between vascular epiphytes and nonvascular epiphyte thicknesses were both insignificant p-values that conclude there is not a significant difference between the average numbers between these two categories of epiphytes per tree per site. A problem that could have prevented significant results for these ANOVA tests in this study is that there was not enough elevation change observed to get a holistic view on how the mean counts per tree at every 50 m of elevation changes across the whole elevation gradient of the cloud forest.

These results are extremely important for understanding how climate conditions affect epiphyte growth and their preferences for growing conditions in both the microclimate of a tree trunk as well as microclimate variation within an elevation gradient of the tropical montane cloud forest. A study by Still et al. (1999) concluded that as climate change progresses caused by more CO_2 content in the atmosphere, temperature will continue to rise and with that, moisture and temperature conditions will shift to higher altitudes as is seen constantly in the Northern Hemisphere. High altitude sites are expected to warm more than lower sites due to their higher climatic variability (Foster 2001). Also, as surface temperatures rise as predicted, there will be an increase in relative humidity that will cause a reduced frequency of water contact and less horizontal precipitation which has significant biological and hydrological implications to the cloud forest structure and functioning (Still et al. 1999). This information in conjunction with the results from this study would mean that the changes of types of epiphytes observed will be more prevalent at higher altitudes and the trends seen from this study will likely just shift up about 500 m if atmospheric CO_2 concentrations doubled (Still et al. 1999). There will also likely be an increase in water loss through evapotranspiration in plants because of increased average temperatures and less rainfall (Foster 2001) which will increase direct water stress for non-epiphytic plants. For epiphytic bryophytes, this is not as much of a problem because they will grow thicker and cover more area as relative humidity increases as seen in figures 10 and 11. This may also mean that more bromeliads will grow higher in trees and at higher elevations than with the current climate because there will be more moisture. This does contrast, however with Foster (2001) because their study predicts more intense rainfall events that will increase wind damage to trees and cause thinner vegetation which would prevent bromeliads from growing more abundantly higher in trees where it’s more exposed. Wind seed dispersal would also be a more successful reproduction strategy in this more exposed environment at higher elevations and it’s reasonable to conclude that ferns would be more numerous at higher elevations in treetops because they will be more exposed to the wind. Monocots, dicots, and orchids however will probably be more numerous at lower altitudes if the current climate continues to shift. The results of this study show that they favor lower altitudes and if, climate moves upwards, that will create more available and ideal habitat space at lower elevations for them to occupy. Foster (2001) hypothesizes that due to epiphytes' relatively fast response rate to changed climate conditions, they will be able to reorganize themselves within the canopy to take advantage of shifted moisture and overall climate regimes in order to succeed.

Whether epiphytes are able to withstand current changing climate conditions is extremely important to understand due to the vast roles they serve in the cloud forest ecosystem such as being parts of the light cycle, water cycle, and nutrient cycle that affects numerous other species (Foster 2001).

There were some potential sources of error in this study that included a precursory lack of knowledge to help identify some morphologically alike plants as either monocots, dicots, ferns, or orchids. This problem was mostly encountered between monocots and ferns and when to classify a monocot as an orchid. To tell the difference more accurately between these, binoculars were used to see the farther away individuals more clearly, but there is still room for error on identification because some were very difficult to tell or the veins in the exposed leaves were not visible. Another potential source of error was missing some individuals in the observations due to thick hanging vines or moss mats. Sometimes these obscured the view of one part of the tree trunk and it's possible there were individuals under them or blocked that were impossible to see. Finally, as previously mentioned, the weather was unusually dry for the beginning of the wet season in this region and there had been little to no rain for the two weeks leading up to this study and it was relatively dry throughout observations. This could have affected the visibility of some plants - particularly orchids - and in turn, reduce their counts in this study.

If a study were to continue this project, observing a greater range of elevation would produce more definitive and accurate outcomes when analyzing data because the cloud forest spans from 1,000 m to 2,500 m and this study only observed 600 m of that range. The whole elevation range could not be surveyed due to muscular injuries affecting the possibility to hike to higher survey sites. If a following study also completed more observations at each elevation site, there would be a more accurate average count of each epiphyte type at each elevation observed due to more replications of the methodology and counts for each tree.

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