

REGIONAL ABUNDANCE AND DIVERSITY OF PLANTS IN THE
NORTHWESTERN ANDES MOUNTAINS IN RESPONSE TO ABIOTIC
VARIABLES

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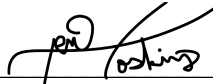
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ENVIRONMENTAL STUDIES

BY



Levi Hoskins

APPROVED:



[Type Full Name Here]
Jordan Karubian, Ph.D.
CO-DIRECTOR



[Type Full Name Here]
Nicole Katin, Ph.D.
CO-DIRECTOR



[Type Full Name Here]
Matthew Sumpter, Ph.D.
Third Reader

Levi Hoskins. Regional Abundance and Diversity of Plants in the Northwestern Andes
Mountains in Response to Abiotic Variables

(Professor Jordan Karubian, Ecology and Evolutionary Biology;
Professor Nicole Katin, Environmental Studies)

Abstract

Tropical restoration is becoming increasingly important as a worldwide effort to mitigate habitat loss and degradation. An understanding of the biotic and abiotic factors that shape patterns of diversity is essential to guiding effective efforts for restoring biodiversity. The Chocó is a highly biodiverse, yet poorly studied forest system in northwestern South America, with very little original habitat remaining due to high rates of deforestation in this region. This paper presents findings from a preliminary investigation of the species diversity index to assist a local organization, Fundación para la Conservación de los Andes Tropicales (FCAT), which was undertaken to assist with its botanical inventory and habitat restoration work. More particularly, the research focused on relating patterns of plant diversity to abiotic environmental variables. While assisting Dr. Ricardo Perdiz and the FCAT team with plant identification and mapping in a 125 x 125 m parcel of intact primary restoration rainforest on the FCAT Reserve, I collected data on soil type and pH, slope, and diameter at breast height (DBH). Through my analyses, I examined associations between these abiotic variables and plant species richness and conclude that soil type and slope were closely correlated with species abundance and diversity. Although soil pH fluctuated with soil type, there was no association between species richness and soil pH, perhaps due to a small sampling effort of pH relative to plot size. Overall, abiotic factors influence species richness and should be prioritized in future studies to both improve biological restoration efforts and to understand basic patterns of biodiversity.

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Introduction

Reforestation practices are at the forefront of conservation efforts due to the wide-scale impacts humans have had on the degradation of ecosystems, global climate change, and loss of biodiversity (Diaz et al., 2019). Restoration practices can help to counteract some of those negative impacts, effectively resulting in the removal and storage of carbon, and reducing island effect consequences (Mir et al., 2022; Strassburg et al., 2020). The global imperative for nations to mitigate the human consequences of deforestation and desertification has been actively promoted by the United Nations General Assembly (United Nations, 2019). To that end, they have declared that this decade (2021-2030) is the period for restoring ecosystems (United Nations, 2019). Since that pivotal declaration, countries have been using passive and active reforestation techniques to achieve restorative success (Fagan et al., 2020). Passive and active reforestation tactics consider biotic factors and are slowly incorporating more abiotic factors into the predetermined characteristics that are correlated with intact forests (Bare, 2014).

An active restorative approach refers to reforestation practices that have a hands-on approach: often planting seeds, seedlings, or saplings while removing environmental stressors. Passive restoration refers to a more hands-off approach: omitting the area of environmental stressors, such as agriculture or grazing, and allowing for natural regeneration. Between the two strategies, passive restoration has proven to be the most successful and cost-effective for larger-scale forest regeneration (Mir et al., 2022; Fagan et al., 2020; Condon et al., 2020; Chazdon and Guariguata, 2016; Bare, 2014). Overall, restoration techniques vary depending on the environmental stressors that were formerly

in the region. For example, an area deforested from agriculture benefits from active restoration, while pastures and agricultural lands with remnant forest parcels can typically be reestablished solely through a passive approach (Trujillo-Miranda et al., 2019).

Considering that success rates are often evaluated by growth occurring after about a ten-year period and are generally limited in scale, both spatially and temporally; this measure excludes deforestation rates that could occur in the same geographical location after the ten years and fails to adequately address the ongoing need for monitoring the reforestation process (Bare, 2014; Morrison and Lindell, 2010). In the tropics, forests are the primary source of carbon sequestration; these are also the areas with the vastest extant species diversity (Harris et al., 2012). Given the significance of these areas for both carbon sequestration and the possibility to affect thousands of species on a small scale; the area holds the vastest extant species biodiversity and holds a global impact through the storing and release of carbon (Mir et al., 2022; Strassburg et al., 2020; Bare, 2014). Understanding the factors influencing species diversity will globally improve restoration efforts (Strassburg et al., 2020; Bare, 2014).

The tropical region of the Andes Mountains in Northwestern Ecuador is a highly biodiverse region, but that diversity is under threat, as it has been estimated that only 25% of the native forest remains intact (Conservation, 2022; IUCN, 2022; Etter et al., 2008). In the Chocó Rainforest, over 90% of primary forests have been destroyed by agriculture, from the creation of pastures to the monoculture production of oil palms, cocoa, coffee, corn, and rice (FCAT, 2022; NICFI, 2022). The high level of habitat disturbance alongside the high level of native and endemic species has earned the Choco

designation as a biodiversity hotspot (Conservation, 2022; IUCN, 2022; Bare, 2014). As such it is considered a global priority for habitat restoration efforts (Conservation, 2022; IUCN, 2022; Bare, 2014). To conceptualize this biodiverse region, few acres in the Chocó Rainforest can contain more tree species than the entire United States (FCAT, 2022; Harris et al., 2018; Etter et al., 2008). There is such a high rate of endemism in the tropics that when considering plot to plot botanical surveys, the plant biota between plots can be vastly different (FCAT, 2022; Harris et al., 2018; Etter et al., 2008). A better understanding of how abiotic factors shape plant species richness in this region can be used to improve restoration efforts as well as to understand basic patterns of diversity.

Deforestation from agricultural practices has altered the chemical balances in the soil, increased atmospheric carbon, shifted the topographical landscape, and influenced the water cycle (Lawrence et al., 2022; Longobardi et al., 2016). With greater than 50% of deforestation in the Chocó Rainforest having occurred in the past 40 years, people in these regions can see the results of these abiotic shifts (Barrancos et al., 2022; Holl et al., 2018). Due to concerns for reforestation, specifically in the Chocó Rainforest, it is crucial to note that if reforestation efforts are implemented inadequately then attempts could negatively impact the remaining ecosystem (Holl et al., 2018; Holl et al., 2016).

Furthermore, poor restoration efforts have impacts on a global scale and lead to a large influx of carbon released into the atmosphere (Holl et al., 2018; Holl et al., 2016). For example, a forest replanted and allowed to regenerate for 20 years and then deforested again releases more net carbon, thus accelerating the geographic warming associated with climate change (Holl et al., 2016). Alternatively, if a forest is planted back sustainably

and left to regenerate, it will absorb more carbon than is emitted into the atmosphere (Holl et al., 2018; Holl et al., 2016). The example exemplifies the importance of a better understanding of sustainable reforestation patterns. Namely, the need for an interdisciplinary approach informed through ecological and earth sciences. As Bare (2014) pointed out, there are two major abiotic factors influencing forest health; those being soil and climatic variables. For this study, the focus was on soil variables and geographic slope, which are detailed in the following paragraphs.

I. Soil pH

Patterns of regional diversity and abundance are often pre-dispositioned by environmental conditions, including slope, soil pH, elevation, and climatic variables (Nepali et al., 2021; Silva et al., 2021; Zeng et al., 2014; Peña-Claros et al., 2012). These non-living components, or abiotic factors, are often overlooked in studies concerning the tropics, but several studies undertaken within the past 15 years have recognized the importance of these factors. For example, Peña-Claros et al. (2012) looked at the importance of soil nutrients in tropical forests and found that nutrient composition plays a wider role in moist tropical forests than in dry tropical forests. While the study looked at soil composition, the researchers excluded soil pH and composition. Soil pH determines the microbiome of the substrate, and if the microbiome is changed, plant growth can be stunted (Peña-Carlos et al., 2012). Soil pH also naturally changes with variations in weather patterns; it is impacted by rainwater (acid rain) and climactic events like El Ninos which occur over short or seasonal time frames (Peña-Carlos et al., 2012). Heightened attention to soil pH and its fluctuations is therefore essential for providing a more in-depth

understanding of the ecological impacts of deforestation and implement more streamlined conservation methods.

II. Soil Types

There are many different types of soil; each type has a distinct nutrient composition which in turn influences the root systems anchoring the flora that can grow in a particular area (Rodrigues et al., 2016; Lathwell and Grove, 1986). Soil can be categorized as silt, sand, or clay, based on its composition. Clay substrates are defined by a particle size smaller than 0.002 mm, a sticky texture that allows for stronger binding of particles to occur, and a nutrient-rich composition often high in potash and water but deficient in phosphates (Lathwell and Grove, 1986). Clay soils tend to allow for higher tree growth because clay substrates inhibit the loss of phosphorus from the environment (Soong et al., 2020; Lathwell and Grove, 1986). Silty soils are defined by a particle size between 0.002 and 0.06 mm and a smooth or silky feeling that is accompanied by a medium adhesive level. Silt holds less water than clay soils and have increased calcium and nitrogen levels but decreased potash levels compared to clay (Markgraf et al., 2006; Lathwell and Grove, 1986). Sandy soils are defined by particles between 0.06 and 2.0mm in diameter with a low capacity to bond to itself; typically having a gritty texture (Lathwell and Grove, 1986). Sand has less water content and is the least nutrient-dense of the soils (Lathwell and Grove, 1986). The low water content of sand leads to difficulties with roots being able to bond to the substrate; and are associated with a lower species abundance, on average, in the kingdom Plantae (Lathwell and Grove, 1986). For forest ecology, soil

composition dictates the types of species capable of growing in a particular area. As such, the consideration of soil type is integral in reforestation approaches, locally and globally.

III. Slope

In the Chocó Rainforest, much of the land can be described as shifting topographical landscapes: from a well-defined sloping peak to plateaus and valleys, which are nearly flat. Nepali et al. (2021) found that the slope aspect ratio had a significant impact on species composition but not species richness, in a similar forest system in West Nepal. Further research has corroborated these findings, which strongly suggests that different species inhabit different niches based on slope aspect ratio (San-Jose et al., 2022). At the top of the hill, for example, where the area plateaus, the soil composition tends to be silty, clay soils that allow for larger root systems, which are typical of overstory plants (San-Jose et al., 2022). At the bottom of the slope, in contrast, where the landscape plateaus, terrains tend to be sandier and muddier, and floral assemblages tend to be comprised of understory plants with more shallow root systems (San-Jose et al., 2022). In the Northwestern Andes Mountains, it is therefore essential to account for slope as a factor driving species composition to learn which species grow better in the mountainous region on a larger and a smaller scale.

IV. Research Objectives

The primary goal of this study was to determine how soil type, soil pH, and slope are correlated with species abundance and diversity in the Chocó Rainforest. The research hypotheses were as follows: 1) sandy soils will exhibit lower species diversity and

species abundance due to a lack of nutrients and water content within the substrate. 2) Lower soil pH will lead to lower species diversity, as various species cannot withstand the acidic quality of the substrate. 3) Greater slope will lead to a lower species abundance because of the angle at which the roots must sprout.

A secondary objective of this study was to provide a preliminary botanical inventory for the FCAT Station in the Ecuadorian Chocó. This included a species richness index and a basic map of plant locations with respect to the research plot. This was the first botanical survey conducted at the FCAT station and while a preliminary effort, it offered valuable insight into the tremendous amount of diversity that can be found in the Chocó Rainforest surrounding the station.

Methods

During the summer of 2022, I worked under the direction of Dr. Ricardo Perdiz in identifying trees, palms, and lianas greater than 3.9 cm in DBH in the primary growth plot, named the 3_5 plot, near the FCAT reserve in the Chocó Rainforest of Northwestern Ecuador. Trees and lianas were identified via inner and outer bark, presence/absence of sap, leaf shape and pattern, branching patterns, and other markings associated with the fruits and flowers of the plant. Palms were identified similarly but focused more on using growth patterns around the trunk and fronds as the focal characteristics. Voucher specimens were taken for species that were not possible to identify in the field for subsequent identification with colleagues through botanical sampling (the prior identification methods) and infrared (IR) spectral analysis. All plants that could not be identified were given a field name, typically something associated with the smell of the inner bark. Each species was given a numbered plaque and the DBH was measured. Notes about the relative geographical location of trees, palms, and lianas were taken in comparison to one another in the plot and given an x, y coordinate within the 1.5-hectare plot. The 1.5-hectare plot was broken into 15 plots and subdivided into 156 subplots (*Figure 1*).

Plots #1-6 (yellow) and plots #9-13 (yellow) were 50m by 20m and were each broken into 10, 10m by 10m subplots. Plots #7 and #8 (grey) were 50m by 15m and were both broken into 10, 10m by 7.5m subplots. Plot #14 (blue) was 50m by 25m and was broken into 10, 10m by 12.5m subplots. Plot #15 (green) was 75m by 25m and was broken into 16 subplots, with 14 being 10m by 12.5m and the remaining two subplots being 5m by

12.5m. The 1-hectare plot was broken into 15 plots so that we were not aimlessly working around the perimeter and inwards. The 15 plots were broken into various sizes based on the topography, as there was one hill, almost completely at a 90° angle, that was easier to complete in one stretch than separating it into multiple plots (#15). The subplot sizes were based off the plot distribution to make measurements of the 1-hectare plot feasible and to avoid skewing of the lines on the part of mountainous terrain.



Figure 1: Plot layout

I. Soil pH

After species were mapped out and given an individual number within the plot, I conducted abiotic sampling for soil pH, soil type, and slope. While classifying the soil type, I collected five random soil samples from each of the 15 plots. I performed random collections in five of the ten subplots per plot to account for the largest area coverage and because there was not enough DI water, time, or a timeframe in which the electricity was

on to conduct 156 soil samples. The five samples were collected and sifted and then weighed out to one gram each. After being weighed out, the individual samples of each plot were combined and the soil type for each plot was recorded. During the sifting process, the soil was broken down into minuscule parts that separated from the organic matter and could be easily mixed with the other samples in the plot and water. After the samples were combined, 10 mL of deionized water was added along with a stir bar, and the mixture was moved to the centrifuge. The centrifuge was turned on for 10-minutes, and the soil mixture was stirred rapidly enough to combine the water and soil into a semi-homogeneous mixture. After the 10-minute interval, I used a pH electrode to determine the pH of the soil and the temperature of the room. The electrode was stuck in the water/soil mixture along the glass side of the beaker, leaving about two centimeters of space at the bottom so that the probe did not touch the glass, thereby preventing damage or alteration of the results. The soil pH of each sample was taken three times each to allow for consistency and to have a view of the most accurate pH value. The numbers were averaged and then used as a summation for the pH of each plot.

II. Soil Types

I collected 10 soil samples per plot, which were categorized as clay, sand, or silt using a separation method (referenced as the shake method). To separate the soil, a 10-gram collection was taken from about six cm deep in the center of each subplot and was put into a tubular, capped vial that had about 20 mL of water. From there, the soil was shaken by hand for three minutes and then left still for ten minutes to allow for soil separation. Sand composed the bottom layer, as those particles are the densest. Silt is less dense than

sand, but denser than clay, so silt composed the middle layer. Clay was the least dense and allowed for the most water to flow through it, which resulted in that being the top layer of the substrate. There was often a fourth, floating layer that was organic biomass: either leaves or decaying matter.

III. Slope

During the occurrence of the other processes, I calculated the slope for each subplot. The slope was determined via the average of three sites within each subplot, with those being the steepest, middle, and most level areas. The precise degree was calculated via an iPhone app called “SLOPE” and a protractor. In making for the most accurate measurements, the app and the protractor needed to be at the same angle. The app proved to be as accurate as the protractor, and thus the protractor was omitted after plot #3 and the app was relied on for the remaining plots.

All results were analyzed in R-studio version 4.2.2 and Microsoft Excel. T-test for soil type and slope were run through Microsoft Excel. A one-way ANOVA was run for soil pH using Microsoft Excel.

Results

	Ranking	Plant Type	Family	Genus	Species	Count	Percent Total
Family	1	Palm	Arecaceae	-	-	193	19%
	2	Tree	Myristicaceae	-	-	139	14%
	3	Tree	Lecthidaceae	-	-	117	11%
	4	Tree	Rubiaceae	-	-	81	8%
	5	Tree	Celastraceae	-	-	54	5%

Table 1: Most Abundant Families

	Ranking	Plant Type	Family	Genus	Species	Count	Percent Total
Genus	1	Palm	Arecaceae	Iriartea	-	184	18%
	2	Tree	Myristicaceae	Otoba	-	108	11%
	3	Tree	Lecthidaceae	Grias	-	66	6%
	4	Tree	Celastraceae	Salacia	-	50	5%
	5	Tree	Lecthidaceae	Gustavia	-	49	5%

Table 2: Most Abundant Genera

	Ranking	Plant Type	Family	Genus	Species	Count	Percent Total
Species	1	Palm	Arecaceae	Iriartea	deltoidea	184	18%
	2	Tree	Myristicaceae	Otoba	gordoniiifolia	108	11%
	3	Tree	Lecthidaceae	Grias	peruviana	66	6%
	4	Tree	Celastraceae	Salacia	"frutão"	50	5%
	5	Tree	Lecthidaceae	Gustavia	serrata	49	5%

Table 3: Most Abundant Species

Within the 1.5- by 1.5-hectare plot, for plants greater than 3.9 centimeters in DBH, there were 799 trees, 192 palms, 17 lianas, and 12 hemi-epiphytes. There was a total of 38 families classified (*Figure 2*), with 24 plants being unclassified/indeterminate; 71 known genera, with 90 indeterminate plants; and at least 126 different species, with only 30 being known in the tree of life (*Figure 3*). Of the 30 classified species, six are only found in Ecuador (represented by * in *Figure 3*). Overall, the most abundant species were *Iriartea deltoidea* and *Otoba gordoniiifolia* (*Table 1*; *Table 2*; *Table 3*).

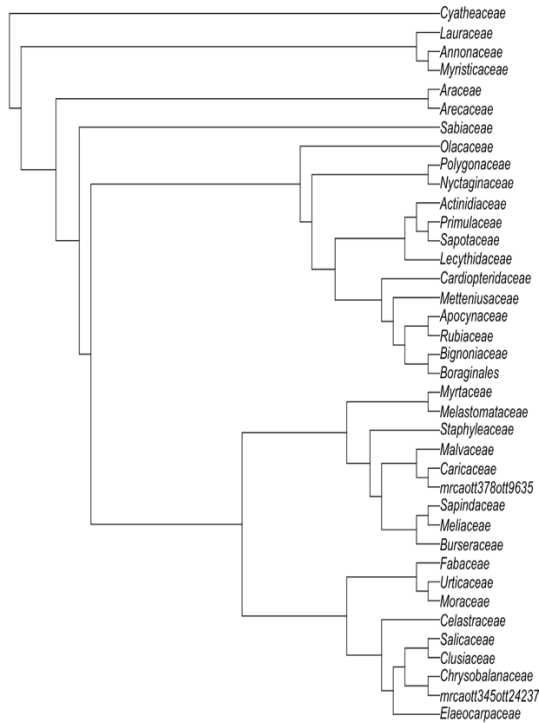


Figure 2: Family Composition in Accordance with the Tree of Life

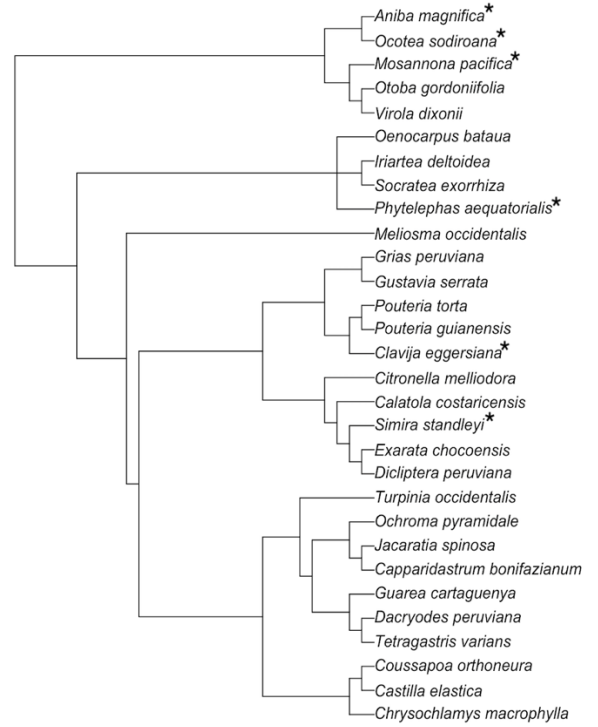


Figure 3: Classified Species Composition in Accordance with the Tree of Life

Plant density was positively correlated with the presence of *Iriarte deltoidea* and *Otaba gordoniiifolia* within the subplots. There was a significant difference in species abundance, $t(155) = 100.94$ and $p < 0.001$ (Figure 4), when considering subplots with and without the two species (Total: $M = 6.54$, $SD = 2.65$; Only *I. deltoidea* and *O. gordoniiifolia*: $M = 4.67$, $SD = 2.49$).

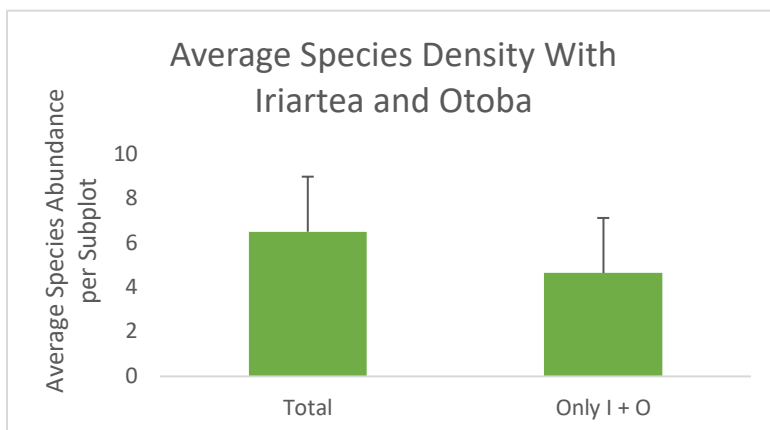


Figure 4: Complete species abundance and species abundance of only *Iriarte deltoidea* and *Otaba gordoniiifolia*

I. Soil pH

A one-way ANOVA was performed to determine variation in pH values between the three soil types: clay, silt, and sand. There was a significant difference between the three categories in terms of the average pH ($p = 0.002$), shown in the table below (*Table 4*).

Sandy soils tended to be less acidic and clay soils were more acidic, with silt being in the middle.

SUMMARY				
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Clay	653	3802.26	5.82275651	0.35184607
Silt	333	1957.04	5.876997	0.34401927
Sand	35	215.64	6.16114286	0.00984571

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	4.11143218	2	2.05571609	6.08432041	0.00236201	3.00456532
Within Groups	343.95279	1018	0.33787111			
Total	348.064222	1020				

Table 4: ANOVA for soil pH and types of soil

II. Soil Types

Soil types influenced species presence, with clay having the greatest species abundance and sand having the lowest species abundance (*Figure 5*). The variation in the soil types was as follows: silt ($M = 3.51$, $SD = 0.45$), clay ($M = 4.53$, $SD = 0.42$), and sand ($M = 2.06$, $SD = 0.51$). I ran a heteroscedastic t-test between all three soil compositions, which provided significant results when comparing silt and clay ($t(239) = 1.03$, $p = 0.03$), silt and sand ($t(111) = 1.45$, $p = 0.03$), clay and sand ($t(161) = 2.48$, $p = 0.005$).

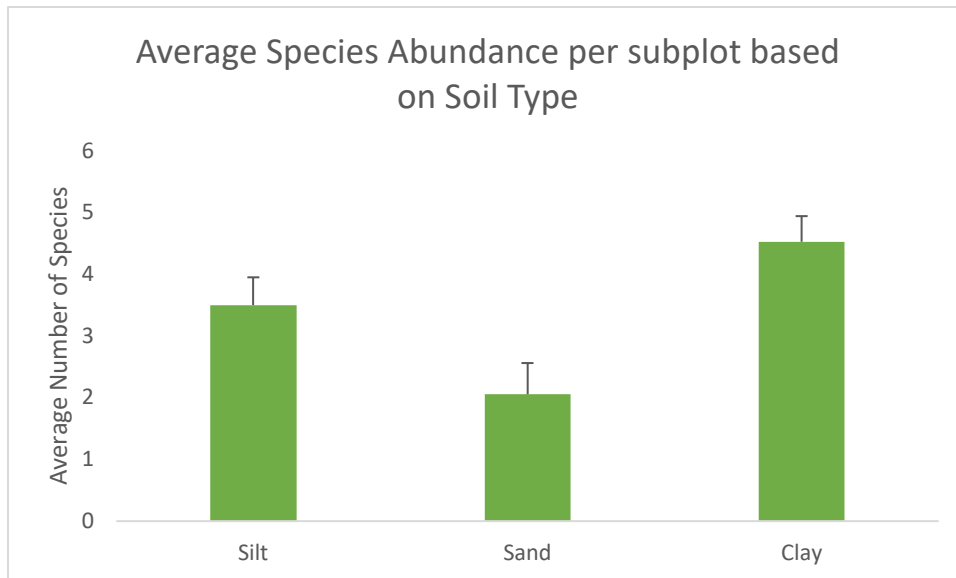


Figure 5: Average species abundance in different soil types

III. Slope

Slope was correlated with average abundance, $t(14) = 21.87$, $p < 0.001$ (Figure 6), and the overall abundance, $t(155) = 782.95$, $p < 0.0001$, between plots and subplots (Average-Slope: $M = 20.92$, $SD = 3.80$; Abundance: $M = 6.46$, $SD = 1.37$; Overall- Slope: $M = 21.19$, $SD = 9.40$; Abundance: $M = 6.54$, $SD = 2.65$). Therefore, slope was found to be positively correlated with species abundance.

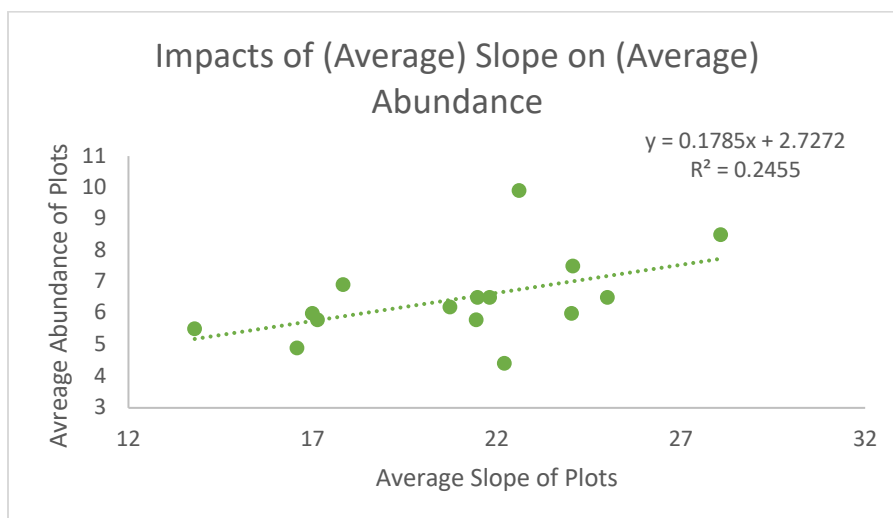


Figure 6: The impacts of (average) slope on (average) abundance.

Discussion

This study represented the first formal efforts toward documenting a comprehensive botanic inventory from the intact Chocó Rainforest on the FCAT Reserve. Further, this study was used to relate patterns of diversity to abiotic environmental variables to plant biodiversity. We found 126 species and 38 families in a 1.5-hectare plot. Compared to mature tropical forests found throughout Ecuador, Peru, Venezuela, Brazil, Costa Rica, Ghana, Uganda, Malaysia, Sabah, Sarawak, and Australia, the primary restoration plot of the Chocó has a vastly lower species richness (average for the 25 plots throughout the 11 countries: 155 species per hectare using a DBH of 10 centimeters) (Phillips et al., 1994). To break the prior down, in Ecuador, the average species richness for a 1.5-hectare plot is 200 species, and for Peru it is 185 (Phillips et al., 1994). The primary restoration plot from FCAT holds a lower species richness, likely due to the nature of the plot being in recovery and still requiring years to reach the previous index that was established in the area. The 3_5 plot at FCAT will take at least five decades to reach a species richness comparable to old-growth forests and centuries to recover species composition to that of an old-growth plot (Rozendaal et al., 2020).

The most abundant species were *Otoba gordoniiifolia* and *Iriarteia deltoidea*. *Otoba gordoniiifolia* represents one of eight *Otoba* species found in the Chocó Rainforest and was found to be the most abundant in this plot (Jaramilo-Vivanco and Balslev, 2020). The prior was surprising as *O. novogranatensis* is thought to be the most abundant species in the range (Jaramilo-Vivanco and Balslev, 2020). It is likely that the eight species are separated by distinct ranges, and that the two aforementioned *Otoba* species

compose the majority in differing ranges of the Chocó (Jaramilo-Vivanco and Balslev, 2020). *Iriartea deltoidea* is an abundant palm species that is prominent, due to toucans and commercial use (ter Steege et al., 2014; Sezen et al., 2009). In South America, *Iriartea deltoidea* is among the most common plants, ranking fifth overall (ter Steege et al., 2014). In primary growth plots throughout the tropics, palms are usually one of the earliest species, as they provide wood and food for people, and the fruits are widely dispersed by toucans, up to hundreds of meters away from the mother plant (Sezen et al., 2009).

In addition to documenting these basic patterns of abundance and diversity, another major goal of this study was to relate plant diversity to abiotic environmental factors. Below, I summarize relationships with soil pH, soil type, and slope.

I. Soil pH

Overall, the soil pH did not influence the species composition (*Figure 7*). This was likely due to two major reasons: sampling size and the sampling method. Due to a lack of access to materials (DI water) and a lack of time available to conduct the soil pH procedures (as the electric kept going off for about two weeks), the original sampling procedure was modified to the average soil pH per plot instead of subplots and/or individual plants. This led to a small sample size of 15 instead of the original 156 samples that were planned. The methods for soil pH collection resulted in a skewed bias towards a higher pH, with the average being 5.85, and having a mean of 5.81 (*Figure 7*). If the average has not of been taken, there would have been a more distinct difference in

soil pH between subplots, and likely would have resulted in a stronger correlation between soil pH and species richness. Conversely, soil pH was influenced by the soil type, which gives a hint of conceptualization that soil pH does impact species composition, although not shown in this study.

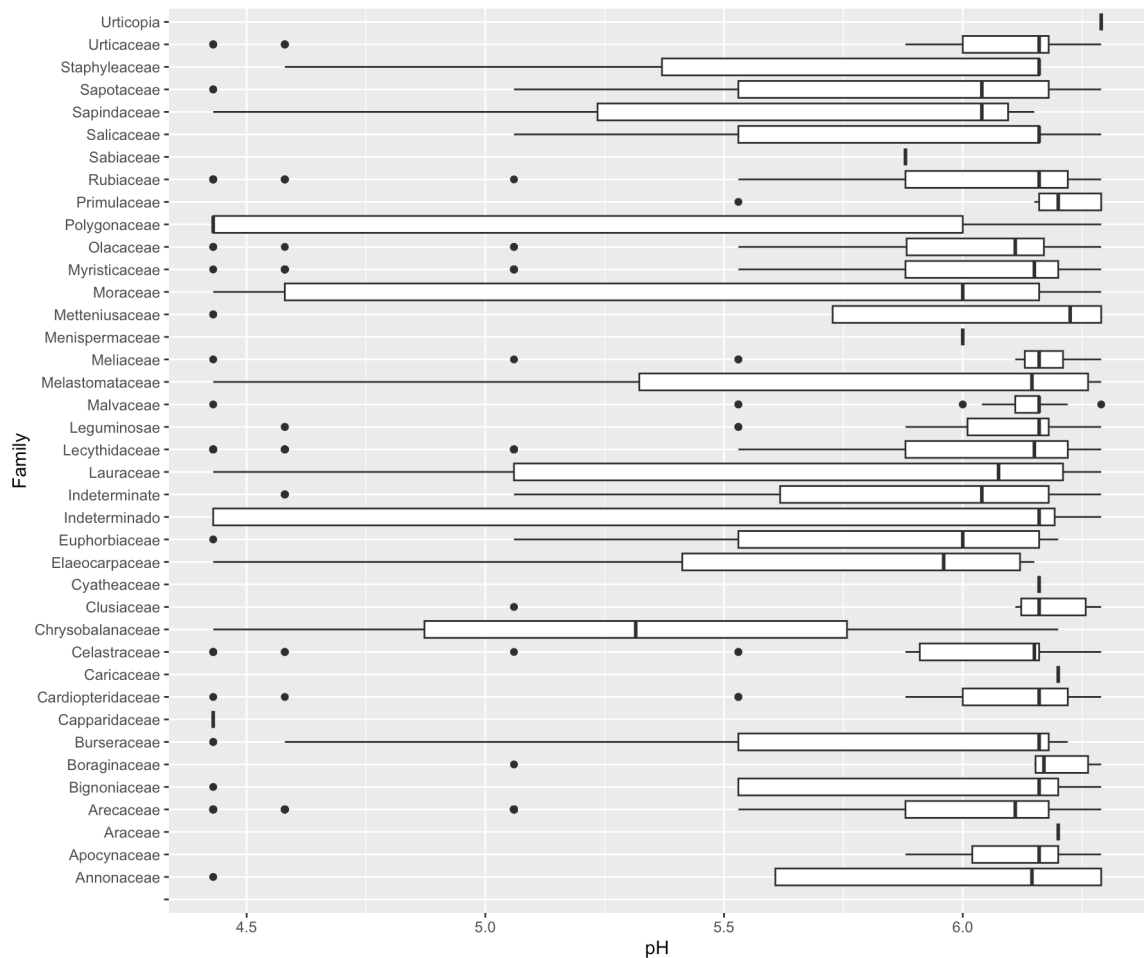


Figure 7: The influence of soil pH on family diversity.

Studies on soil pH and the influences had on species richness has mainly been conducted through botanical surveys in North America and Europe and has largely excluded the southern hemisphere (Crespo-Mendes et al., 2019; Duprè et al., 2010; Stevens et al., 2010; Crawley et al., 2005; Pärtel, 2002; Gough et al., 2000; Roem and Berendse, 2000). In recent years, there have been more studies in the neotropics and worldwide studies

(Crespo-Mendes et al., 2019; Peña-Claros et al., 2012). These prior North American studies tend to show a correlation between soil pH and plant species richness, but also recognize the influences of precipitation, nitrogen deposition, and latitude and how these factors change soil pH (Duprè et al., 2010; Stevens et al., 2010; Gentry, 1988).

Furthermore, for Brazil and other neotropical studies, there was a correlation found between optimum soil pH and species richness, noting that with subtle changes from the optimum, both more acidic or basic, the richness was decreased (Crespo-Mendes et al., 2019; Crespo-Mendes et al., 2018). The theory behind this is that the high endemism associated with tropical areas, considering these species are often highly evolved to fit certain niches, is affected with any subtle change, putting the species at risk of extirpation (Crespo-Mendes et al., 2019).

In understanding the influences of soil pH on plant endemism, we are better able to understand rates of plant species richness and create better estimates for world-wide indices of plant richness for conservation efforts.

II. Soil types

Soil type was affected by soil pH and conversely impacted species composition. The impacts of soil composition on species abundance made logical sense, with clay having the greatest species abundance per subplot and sand having the lowest species abundance. Due to the nature of the three different soil types (silt, sand, and clay), the low ability for sand to hold water and the high-water content of clay, this allowed for plants to save energy by conserving water during the dry period for clay but meant that plants in sandy

soils needed to spend more energy on conserving water during the dry periods (Fischer et al., 2018; Rodrigues et al., 2016; Lathwell and Grove, 1986). For silty soils, these tend to be in the middle for everything, so it makes sense that it would be in the middle for curating a higher species abundance (Fischer et al., 2018; Rodrigues et al., 2016; Lathwell and Grove, 1986).

Many previous studies involving soil composition have been conducted in grasslands globally but have overall avoided neotropical rainforests (Bhandari and Zhang, 2019; Fischer et al., 2018; Rodrigues et al., 2016; Arruda et al., 2015). These studies have found a close relationship between soil composition and water nutrients, which in-turn alters species composition (Bhandari and Zhang, 2019; Fischer et al., 2018; Rodrigues et al., 2016; Arruda et al., 2015). Overall, the results of my study align with those of prior studies, with one caveat. Clay was found to have the greatest species richness, but in most studies, once a soil exceeded 67% clay texture, the species richness declined rapidly (Soong et al., 2020; Rodrigues et al., 2016). In the tropics, the relationship between soil composition and plant species richness is highly correlated (Soong et al., 2020; Rodrigues et al., 2016).

III. Slope

The effect of slope on species composition had an inverse relationship contrary to my prediction. The greater the slope, the greater the species abundance both for average slope of a plot and for slope at each subplot, representing a positive correlation between the two variables. This was surprising because it takes more strain on roots to hold a plant up

when growing in a sloped area than a flatter area (Nepali et al., 2021). I think a concept that makes it less surprising is the route in which people take to deforest an area. Flatter areas that are easier to get to are often deforested first and the more sloped areas are left with more biodiversity, as they are harder to log (Clark and Covey, 2012). For future comparative studies, it would be interesting to focus on root preferences in tropical plants compared to temperate plants, especially regarding sloped and less-sloped areas.

Several other studies have focused on slope aspect ratio, but they tend to compare north and south slopes instead of more or less sloped areas (Yang et al., 2020; Dearborn and Danby, 2017). Although, this is important to understand the areas that are more or less sloped, due to the concept that north-facing slopes have the strongest effect on species richness via slope aspect ratio (Yang et al., 2020; Dearborn and Danby, 2017). In addition to the aspect of slope orientation, there was also a contrasting result as it connects to species richness. I found a positive correlation between slope and species richness, and the prior studies found a negative correlation (Yang et al., 2020; Dearborn and Danby, 2017). This could be due to a few reasons, but one major consideration is that their studies were conducted in Canada and the Mediterranean, and not in the neotropics (Dearborn and Danby, 2017; Nadal-Romero et al., 2014).

IV. Conclusion

Broadly speaking, diversity surrounding the FCAT station is still in progress of regeneration and lower than the typical plant richness indices of other neotropical regions (Harris et al., 2018; Etter et al., 2008; Phillips et al., 1994). Some possible explanations

for this contrast could relate to the characteristics of the plot and its surrounding environs, which could be described as either primary forest or pastureland (Rozendaal et al., 2020). This is important to note, as the plots were not isolated, meaning that habitat type, whether forest or pasture, could impact abiotic variables within the plot. Deforested areas, specifically pasteurized areas, lead to changes in soil pH and soil composition, and increased erosion, which effects slope All factors which, based on the results of this study, can greatly influence species composition (Barrancos et al., 2022; Lawrence et al., 2022; Holl et al., 2018 ; Longobardi et al., 2016).

While these findings are significant as it connects to restoration efforts more generally, they are particularly important for informing ongoing restoration work at the FCAT station. The station Is currently in the process of testing and assessing techniques to accelerate reforestation efforts at the site and these findings should be of great value to them moving forward, in implementing the best techniques in the Chocó Rainforest (FCAT, 2022). My research, alongside the work undertaken by Ricardo Perdiz, can aid in the selection of areas that are better suited for different species, particularly specialists/endemic species that are highly adapted to vastly specific conditions, which are all congruent with abiotic variables.

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