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Bryophyte (SL) growth and environmental factors along an altitudinal gradient on Cerro Gaital, El Valle, Coclé, Panamá

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Abstract

Research on bryophytes (SL) in the tropics has been lacking compared with the high number of species found there and the potential benefit of bryophytes (SL) as indicators of pollutants and other forms of human disturbance. This study investigated whether or not bryophyte (SL) growth patterns showed relation when compared with environmental factors on the mountain Cerro Gaital in El Valley, Panamá. Whether or not bryophytes (SL) are present, extent of the area covered by their growth, and height of their growth are all aspects of bryophyte (SL) growth that were used. In this study, these three aspects are compared with three environmental factors – substrate type, altitude, and canopy cover. Data were collected along transects at four sites at different altitudes along a trail ascending the mountain. Hypothesis tests were run on each of the nine comparisons between the three bryophyte (SL) growth aspects and the three environmental factors. The results very strongly suggested that there were positive associations between bryophyte (SL) presence and substrate type, as well as presence and altitude and growth height and altitude. They also strongly indicated associations between bryophyte (SL) cover and substrate, bryophyte (SL) cover and altitude, and growth height and substrate. Canopy cover only showed an association with growth height and failed to show one for either presence or bryophyte (SL) cover. In general, the results of the tests involving substrate types and altitudes resembled results from other studies done in the tropics and elsewhere. However, the results for canopy cover did not match with other results and the one test that passed showed a negative association between canopy cover and growth height which is the opposite of what other findings indicate.

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Introduction

Bryophytes (Sensu Lato)[1] represent a group of nonvascular plants that reproduce by spores instead of seeds and which consists of mosses, liverworts, and hornworts (Gradstein et al., 2001). Bryophytes (SL) first appeared on earth around 300 million years ago in the Devonian and the early fossils still strongly resemble modern day bryophytes (SL) (Gradstein et al., 2001; Gensel, 2008). Bryophytes (SL) today have adapted to occur in almost all climates across the globe but are often said to have the highest diversity in the tropics, with many tropical species being endemic (Chantanaorrapint, 2010; Wang et al., 2017; Gradstein et al., 2001). Bryophytes (SL) provide many services to ecosystems such as habitat for other plants and animals and holding high amounts of moisture from wet periods throughout drier ones (Chantanaorrapint, 2010; Gradstein et al., 2001). They are also more directly important to typical human concerns for their potential ability to sequester carbon. Horwath et al. (2019) found that bryophytes (SL) above 2,000m in a Peruvian cloud forest could represent from 30-50 Mg per hectare of carbon sequestration, which typically is not accounted for. Another way bryophytes (SL) can be very useful to humans is their strength as bioindicators of many kinds of anthropogenic disturbances in an area (Denayer et al., 1999; Gignac, 2001, Guerra et al., 2020). Denayer et al. (1999) found that bryophyte's (SL) trait of absorbing water very easily means they can easily accumulate waste material such as toxins or metals in their tissues. Guerra et al. (2020) examined how other anthropogenic disturbances are strongly correlated with increased temperatures and light and reduced humidity in forests, and in turn a reduction in bryophyte (SL) cover and abundance. Gignac (2001) even suggests that bryophyte (SL) growth patterns may help reveal the presence of climate change. Being strong bioindicators both makes bryophytes (SL) useful to human efforts in conservation, and clearly displays to us what is putting them at risk and threatening the benefits they provide.

Despite bryophytes (SL) often being considered to be the most diverse in the tropics and the potential benefits they offer, some sources consider there to be a lack of information on them in the tropics and in particular when compared to other regions (Chantanaorrapint, 2010; Gradstein et al., 2001). Chantanaorrapint (2010) specifically mentions that more research needs to be done on epiphytic bryophyte (SL) distributions along altitudinal gradients. In Panamá in particular, there has been a lack of information for quite some time. A source from 1950 by Crum et al. (1950) talked about all the collections of bryophytes (SL) that had taken place from 1854 to 1950 which only was 12 in total with each being small in scale, with the largest one contributing 47 species including 5 new. Crum et al. (1950) also emphasized the low number of species known in Panamá when compared with other Central American countries. Some more studies have been done on bryophytes (SL) in Panamá since then (Wagner, et al., 2013; Gradstein & Salazar Allen, 1992; Salazar Allen et al., 1991; Solano, 2022).

The study by Wagner et al. (2013) examined altitudinal gradients and focused on factors such as temperature, and light and moisture availability. They found that bryophytes (SL) tend to

[1] The term "bryophytes" was used to describe mosses, liverworts, and hornworts until recently when they have now been divided up into three separate phyla: Bryophyta (mosses), Marchantiophyta (liverworts), and Anthocerotophyta (hornworts). Mosses are now the only technical "bryophytes", but since the majority of my sources used the term to describe all three and they are functionally still very similar in the ways I will be examining them, they will just be referred to as bryophytes (SL) in this paper. See Cargill (n.d.) for more details.

acclimate very accurately to the different temperatures at different altitudes and so temperature isn't as much of a factor on their growth. However, higher temperatures lead to increased evaporation and so affect water availability making temperature have an indirect relationship to bryophyte (SL) growth. The authors also imply that the presence of clouds in montane forests provides moisture for bryophytes (SL) living there. They found that light availability also affected bryophyte (SL) growth, but which tended to not be correlated with altitude. The study by Guerra et al. (2020) that previewed how bryophytes (SL) can be strong bioindicators of human anthropogenic disturbance also did research on how type of forest affected epiphytic bryophyte (SL) growth. They found that forest type accounted for 47% of variability in bryophyte (SL) composition in their study, with more mature and less disturbed forests being very favorable for bryophyte (SL) diversity. They also found that human disturbances reducing canopy cover often resulted in changes to light availability as well as humidity and temperature. They also investigated factors such as the diameter at breast height of the trees the epiphytes were growing on. Some research on bryophytes (SL) has been done in Panamá that reviewed the kinds of substrate bryophytes (SL) grow on. It found that rocks, tree roots and bark held higher diversity among the bryophytes (SL) there than on soil or dead leaves which are far less stable (Salazar Allen et al., 1991). Gradstein & Salazar Allen (1992) specifically viewed altitudinal gradients in Darién, Panamá and found altitudes 800-1200m had significantly higher diversity and biomass of bryophytes (SL) than lower altitudes (400-500, 100, & 0-50). The 1100-1200m site had "dramatically greater" biomass than at lower altitudes (Gradstein & Salazar Allen, p.64, 1992).

There have been many studies that have investigated bryophytes (SL) in other tropical and neotropical regions outside Panamá. Sim-Sim et al. (2015) conducted a study comparing the cover and species richness for four bryophyte (SL) species along an altitudinal gradient ranging from 102m to 1496m on Madeira island (in the Mediterranean Basin). They found statistically significant relationships between the species abundance and altitude for one of the four species, with two having higher abundance at higher altitudes (although one wasn't statistically significant), one having higher abundance at lower altitudes, and the fourth seemed to be unaffected by altitude. Finding three separate trends in how bryophyte (SL) distribution can depend on altitude makes altitude an interesting topic to explore further in other areas and applying it to more species. The results from one of the studies conducted by Chantanaorrapint (2010) found a consistent relationship of increasing biomass with increasing altitude for epiphytic bryophytes (SL) over gradients from 25-700m, 400-1300m, and 400-1500m. Chantanaorrapint (2010) writes that microclimate factors such as light, humidity, and temperature are relevant to the distributions of epiphytic bryophytes (SL), microhabitat factors such as tree diameter and bark roughness may be relevant too.

All these studies provide information on bryophyte (SL) growth patterns in general and on the growth patterns in the specific areas they are conducted. Studies done in the tropics in general and at similar altitudes can reveal trends that may be consistent with other locations with similar parameters. Adding research in new places provides site specific information that can't be realized from collecting in other locations. It also helps fill gaps in the overall research of locations with similar parameters.

No known research has been done on bryophytes (SL) in the Coclé province in Panamá. El Valle, Coclé is on the Pacific side of Panamá and the local altitude is around 590-600m in the town (Climate Data, n.d.). It is also the caldera of a volcano, and so is surrounded by mountains. One of these is Cerro Gaital which has three peaks situated on the North side of town (All Trails, n.d.). All Trails (n.d.) gives the total elevation change from the base to the highest peak of the mountain as going from 636-1,153m, a difference of 517m in total. The range of 636-1153m falls within the ranges included by the studies by Chantanaorrapint (2010), Sim-Sim et al. (2015), and Gradstein & Salazar Allen (1992) making the results of that research more comparable to data collected on Cerro Gaital. Cerro Gaital is also populated by a mature mixed broadleaf forest according to a GIS map by MiAmbiente in 2021 (Solano, 2023).

This study investigated the types of substrate bryophytes (SL) appear on, the extent of coverage of the growth on those substrates, and the height of their growth. It will compare those to the measured microclimate consisting of the altitude, and the microhabitat consisting of canopy cover and the substrate present in the area (including soil, dead wood, exposed roots, trees smaller than 7cm in base diameter, tree trunks & branches for those larger than 7cm in diameter, herbaceous plants, rocks, & vines). All the data came from research on Cerro Gaital at various points along an altitudinal gradient up the mountain. This research strives to examine whether the factors such as altitude, substrate type, and canopy cover (relating to light) that have been shown to impact bryophyte (SL) growth in studies conducted in other areas show any relationship with the bryophyte (SL) growth on Cerro Gaital (Salazar Allen et al., 1991, Guerra et al., 2020, Wagner et al., 2013).

Research Question

Is there a relationship between bryophyte (SL) growth as measured through type of substrate found growing on, extent of the growth cover, and plant height, and microhabitat and microclimate as measured by altitude, substrate type, and canopy cover on Cerro Gaital in El Valle, Coclé, Panamá?

Methods

Study Area

The mountain Cerro Gaital in El Valle, Coclé is useful as a study site for a few reasons. Its humidity ranges from 77% to 83% for monthly averages from January to April, and is 88% to 91% monthy for the rest of the year (Climate Data, n.d.). This year is also notably in an El Niño event which often leads to warmer and drier weather in Panamá (NOAA, 2023). As mentioned earlier, Cerro Gaital is considered to be covered by a mature broad-leafed forest (Solano, 2023). Considering that higher humidity and mature, undisturbed forests have been shown to correlate with increased bryophyte (SL) growth, this microhabitat and microclimate provides favorable conditions for studying bryophytes (SL) (Chantanaorrapint, 2010; Gradstein et al., 2001; Guerra et al., 2020). There is one primary trail ascending Cerro Gaital that appears on All Trails (n.d.). The trail begins on the Eastern side of Cerro Gaital and curves counterclockwise as the altitude increases. The entrance of the trail is not in the forest and first encounters the forest between 740-750m in elevation. The trail reaches the Eastern peak of the mountain at 1,000m. It extends West past that point to the highest peak at 1,153m (All Trails, n.d.). Originally, a GPS and three phone apps were used to measure the altitude, but the GPS readings varied by as much as 50m from the same location and the phone apps said they didn't have a strong enough signal to measure altitude so the All Trails reading from the map was used. There are areas on the trail where running a transect perpendicular to the trail would be impractical on one side, and in some cases, both sides. There is a farm to one side of the trail with no forest buffer near the beginning. There are other points where the foliage is so thick off the trail that a person can't move through it without carving a path out, or where the drop-off is dangerously steep without special equipment. Past the 1,000m point the trail goes along a ridge and past the 1,025m point the ridge is too narrow or the foliage is too thick to fit a 10m transect perpendicular to the trail going either direction or split across the middle.

Figure 1. Study sites with elevations on Cerro Gaital, Coclé, Panamá. (Map from Google Earth)

Data Collection

The data were collected by running 3 10 meter (m) long by 1m wide transects perpendicular to the trail at 4 locations at different altitudes. The four sites were at the altitudes 746m, 841m, 938m, and 1018m. The four altitudes were chosen since 746m was the first spot on the trail that forest occurred and that a transect could be laid out, and 1018m was the last spot. The other two locations were chosen by being the closest spots to 1/3 and 2/3 of the 276m altitude change between the top and bottom sites where transects could practically be laid. For each location, the first 10m transect was run at the site of the specific altitude starting from the center of the trail. The transects were always perpendicular to the direction of the trail and, if applicable, which side of the trail the transect was laid on was randomly chosen. After the first transect, the second transect was run 15m along the trail away from the first one in a randomly chosen direction if applicable. The third was placed 15m on either side of the first two transects and which of those locations was chosen in the same way.

Each transect consisted of securing the end of a roll-out measuring tape in the center of the trail and extending it 10m out into the forest in the chosen direction, then randomly choosing a side to place 1m x 1m quadrats. The first quadrat would be placed adjacent to the first meter showing on the tape and would be moved for each subsequent meter. Only the items found within the quadrat were recorded for each transect with rooted plants only counting if some portion of the base appeared in the quadrat. Before beginning the transect the GPS UTM reading was recorded, as well as the date, start time, weather condition observations, direction in degrees of the transect, the direction in degrees of the mountain slope, and any additional notes about the site.

The first step involved measuring the canopy cover every two meters starting with meter 1 using a spherical densitometer. To record the canopy cover, the densitometer was held out at elbow height in one of the cardinal directions and then observed to see how many points on 24 squares etched on a concave mirror were covered if the points were imagined to appear like the dots on the four-side of a six-sided die. That same count was made for all four cardinal directions and then the mean was taken of those four readings and finally multiplied by 1.04 to represent the percentage of gaps in the canopy coverage. To get the actual percent canopy coverage, that number was subtracted from 100 to represent the amount less than 100% canopy coverage there was.

Next, what items appeared in the quadrat were marked down. These items consisted of soil, rocks, any form of dead wood (including sticks, logs, decaying wood fragments, and stumps), vines, exposed roots, trees with base diameter 7cm or smaller, trees with base diameter of 7cm or larger, and herbaceous plants. Tree diameters were measured at the base and recorded. These items were only marked down as being present or not, and didn't include any information about where in the quadrat they appeared or additional specific measurements. If multiples with the exact same descriptions using these parameters were noted only one entry was made. Any additional notes were recorded as well. These items present represented the different substrates that would be investigated for different growth patterns of bryophytes (SL).

Next, all items that had any visible amount of bryophyte (SL) growth on them were noted. For trees, whether the bryophytes (SL) appeared on the trunks or the branches was noted. Next, for each item, the extent of coverage for the substrate it appeared on was marked down as extremely low (1-5% coverage), very low (5-15% coverage), low (15-30% coverage), low medium (30-40% coverage), medium (40-60% coverage), high medium (60-70% coverage), high (70-85% coverage), very high (85-95% coverage), and extremely high (95-100% coverage). Coverage was measured as how much of the substrate was showing whether it was through gaps throughout the bryophyte (SL) growth or if only one side of the substrate item was covered. Height of bryophyte (SL) growth was measured (all through the naked eye and measured in height risen out from substrate in whichever direction it was tallest in) separately as extremely low (color is visible but no structure apparent), very low (structure visible but too little to be discernable), low (structure discernable; less than 1mm), low medium (1-2mm), medium (2-5mm), high medium (5-15mm [1.5cm]), high (1.5-2.5cm), very high (2.5cm-5cm), and extremely high (>5cm). The scales for both cover and height were formed based on observed patterns of how the bryophytes appeared. The levels are not evenly spaced as many bryophytes had cover in the 1-5% range and then were more spaced out in frequency over the 5-15% range, for example. When bryophyte (SL) growth appeared as a range of cover over multiple substrate items, the coverage was marked down as the coverage of all of those grouped together. When the height of bryophyte (SL) growth appeared in different amounts across the surface of one individual substrate item or multiple of the same item, the highest presence was written down in order to determine how high it could potentially reach in that area. Higher cover and height are both intended to represent increased bryophyte (SL) growth, along with the substrate they appear on in some cases.

Data Preparation

The intention of this study was to determine if there were demonstratable relationships between the different factors of bryophyte (SL) growth and the different factors of the environment they appeared in, so hypothesis testing was needed to evaluate each potential relationship. In order to represent the categorical data as numerical to be able to use them for testing, whether or not bryophytes (SL) appeared on any given substrate was written as 1 to represent presence or 0 to represent absence. For extent of coverage of bryophytes (SL), the nine categories of percent coverage (extremely low to extremely high) were converted to numbers 1-9, with extremely low being represented by 1, extremely high represented by 9, and all the categories in between being represented by 2-8, respectively. The exact same conversion was made for height measurements of the bryophyte (SL) growth (using the 1-9 system for extremely low through extremely high). This conversion was intended to represent them in a numerical way so that comparisons between them could represent higher or lower extent of bryophyte (SL) coverages or heights when involved in data analysis.

Since the research objectives involving altitude were comparing the altitudes of the four sites, the specific altitude measurements for each site were calculated as the average of the altitude measurements for the three transects that appeared at that site since the total difference between the highest and lowest readings was no more than 4m at each site. These four altitude calculations were used for all data analyses investigating relationships with altitudes. For canopy cover, since measurements were made only every two meters, the first measurement represented the first two meters, the second represented meters 3 and 4, and so on until the end of the transect.

Data Analysis

There were nine hypothesis tests in total: one for each comparison between one of the three bryophyte (SL) growth patterns (which substrate present on, extent of coverage, and height of growth) and one of the environmental factors (altitude, substrate present, and canopy coverage). Each test used a significance level (alpha) of 0.05. All tests were conducted in R-Studio.

For the four tests comparing growth height or extent of coverage to substrate type or altitude, one-way ANOVA tests were used as the comparisons were each between a category (substrate type or altitude – altitude measurements have numerical values but they are restricted to just 4 and so they behave more like categorical values here) and a numerical value (the growth height). In the first test between growth height and substrate type, substrate type was the independent variable and growth height (on the 1-9 scale) was the dependent variable. The null hypothesis that was being investigated was that the average height of bryophyte (SL) growth for each substrate type would be the same while ignoring all other factors. Thus, the test was determining if there in fact was a difference in average bryophyte (SL) height across the different substrates. The other three tests followed the same lines. For growth height and altitude, altitude was the independent variable and growth height was the dependent variable again. For both of these tests where extent of coverage was involved it was the dependent variable and the respective independent variables were substrate type and altitude.

Since the two tests growth height or extent of coverage each compared with canopy cover compare two numerical variables, correlation tests were used for each. For both tests canopy cover was the independent variable. In each one, the null hypothesis was that the average growth height or the average extent of coverage, respectively, would not be different based on differing canopy coverage. Thus, the tests were determining if there were in fact differences in average extent of coverage or average growth height based on the canopy cover.

The test comparing bryophyte (SL) presence with substrate type and the test comparing bryophyte (SL) presence with altitude both were Pearson's chi-squared tests, since they were comparing a binary variable (bryophyte (SL) present or not) with a categorical variable. In both tests bryophyte (SL) presence was the dependent variable.

The last test comparing bryophyte (SL) presence to canopy cover needed a point-biserial correlation since it was comparing a binary variable (bryophyte (SL) presence) to a numerical variable (canopy cover).

Results

Bryophyte (SL) Presence

Two of the three tests investigating bryophyte (SL) presence had statistically significant results. Those were bryophyte (SL) presence vs. substrate type and bryophyte (SL) presence vs. altitude. For bryophyte (SL) presence vs. canopy cover the results were not shown to be statistically significant.

Bryophyte (SL) Presence vs. Substrate

The chi-squared test comparing bryophyte (SL) presence across the different substrate types.

Substrate	Absent	Present
Dead wood	38	103
Herbaceous plant	66	14
Rock	10	79
Root	9	44
Small tree	8	187
Soil	64	30
Tree branch	0	10

Tree trunk	0	35
Vine	5	21

Table 1 (above). Table of bryophyte (SL) presence for each substrate type.

Substrate	Absent	Present
Dead wood	0.27	0.73
Herbaceous plant	0.83	0.17
Rock	0.11	0.89
Root	0.17	0.83
Small tree	0.041	0.96
Soil	0.68	0.32
Tree branch	0.00	1.00
Tree trunk	0.00	1.00
Vine	0.19	0.81

Table 2. Proportions of bryophyte (SL) presence for each substrate type.

For this test, chi-squared was 284.26 with 8 degrees of freedom which gave a p-value less than 2.2 e^{-16} which is much lower than the significance level of 0.05. Therefore, we rejected the null hypothesis of no association which provided statistically significant evidence that an association exists between bryophyte (SL) presence and substrate from the population studied.

Bryophyte (SL) Presence vs. Altitude

The chi-squared test comparing bryophyte (SL) presence across the different altitudes.

Altitude	Absent	Present
746	0.41	0.59
841	0.29	0.71
938	0.34	0.66
1018	0.10	0.90

Table 3. Proportions of bryophyte (SL) presence for each altitude.

For this test, chi-squared was 50.73 (3) which gave a p-value of $5.6e^{-11}$ which is again lower than the significance level of 0.05. Therefore, we rejected the null hypothesis of no association which provided statistically significant evidence that an association exists between bryophyte (SL) presence and altitude from the population studied.

Bryophyte (SL) Presence vs. Canopy Cover

The point-biserial correlation between bryophyte (SL) presence and canopy cover was -0.03 with a 95% confidence interval of (-0.10, +0.047) and had a p-value of 0.479 which was higher than the significance level of 0.05. Since the p-value was greater than our significance level we cannot reject the null hypothesis of no association and thus have not provided sufficient evidence that there is a relationship between bryophyte (SL) presence and canopy cover.

Extent of Bryophyte (SL) Coverage

Two of the three tests investigating extent of bryophyte (SL) coverage had statistically significant results. Those were bryophyte (SL) coverage vs. substrate and bryophyte (SL) coverage vs. altitude. Bryophyte (SL) coverage vs. canopy cover failed to reject the null hypothesis and thus was not shown to be statistically significant.

Bryophyte (SL) Coverage vs. Substrate

The one-way ANOVA comparing the average extent of bryophyte (SL) coverage across the different substrate types.

Substrate	Mean	SE	Lower CL	Upper CL
Dead wood	4.08	0.19	3.71	4.45
Herbaceous plant	3.36	0.51	2.35	4.36
Rock	4.82	0.22	4.40	5.25
Root	4.11	0.29	3.55	4.68
Small tree	4.03	0.14	3.76	4.31
Soil	2.63	0.35	1.95	3.32
Tree branch	5.50	0.61	4.31	6.69
Tree trunk	4.89	0.32	4.25	5.52
Vine	4.57	0.42	3.75	5.39

Table 4. Means, standard errors (SE), and lower and upper bounds of the confidence intervals for extent of bryophyte (SL) coverage for each substrate type.

The F-statistic for the one-way ANOVA was 5.346 with degrees of freedom 8 & 514 and gave ap-value of $1.81e^{-6}$ which is below the significance level of 0.05. Therefore, we rejected the null hypothesis of no association which provided statistically significant evidence that an association exists between bryophyte (SL) coverage and substrate for the population studied.

Bryophyte (SL) Coverage vs. Altitude

The one-way ANOVA test comparing the average extent of bryophyte (SL) coverage across the different altitudes.

Altitude	Mean	SE	Lower CL	Upper CL
746	3.72	0.19	3.35	4.09
841	3.82	0.19	3.46	4.18
938	4.13	0.18	3.77	4.49
1018	4.66	0.14	4.39	4.94

Table 5. Means, standard errors (SE), and lower and upper bounds of the confidence intervals for extent of bryophyte (SL) coverage for each altitude.

The F-statistic for the one-way ANOVA was 7.239 with degrees of freedom 3 & 519 and gave a p-value of $9.14e^{-5}$ which is below the significance level of 0.05. Therefore, we rejected the null hypothesis of no association which provided statistically significant evidence that an association exists between bryophyte (SL) coverage and altitude for the population studied.

Bryophyte (SL) Cover vs. Canopy Cover

The correlation test comparing the average extent of bryophyte (SL) coverage across extents of canopy cover gave an $r = -0.057$ and a p-value of 0.20, which is greater than our significance level of 0.05. Since the p-value was greater than our significance level we cannot reject the null hypothesis of no association and thus have not provided sufficient evidence that there is a relationship between extent of bryophyte (SL) cover and canopy cover.

Height of Bryophyte (SL) Growth

All three tests investigating height of bryophyte (SL) growth showed statistically significant results.

Growth Height vs. Substrate

The one-way ANOVA test comparing the average height of bryophyte (SL) growth across the different substrates.

Substrate	Mean	SE	Lower CL	Upper CL
Dead wood	4.09	0.18	3.73	4.45
Herbaceous plant	3.07	0.50	2.09	4.05
Rock	2.80	0.21	2.39	3.21
Root	3.48	0.28	2.93	4.03
Small tree	3.93	0.14	3.66	4.19
Soil	3.57	0.34	2.90	4.23
Tree branch	5.50	0.59	4.34	6.66
Tree trunk	4.49	0.32	3.87	5.10
Vine	4.38	0.41	3.58	5.18

Table 6. Means, standard errors (SE), and lower and upper bounds of the confidence intervals for height of bryophyte (SL) growth for each substrate type.

The F-statistic for the one-way ANOVA was 5.659 with degrees of freedom 8 & 514 and gave a p-value of $6.66e^{-7}$ which is below the significance level of 0.05. Therefore, we rejected the null hypothesis of no association which provided statistically significant evidence that an association exists between height of growth and substrate for the population studied.

Growth Height vs. Altitude

The one-way ANOVA test comparing the average height of bryophyte (SL) growth across the different altitudes.

Altitude	Mean	SE	Lower CL	Upper CL
746	1.98	0.14	1.70	2.26
841	2.80	0.14	2.52	3.08
938	4.46	0.14	4.18	4.73
1018	4.98	0.11	4.77	5.20

Table 7. Means, standard errors (SE), and lower and upper bounds of the confidence intervals for height of bryophyte (SL) growth for each altitude.

The F-statistic for the one-way ANOVA was 116.9 with degrees of freedom 3 & 519 and gave a very low p-value of $2.2e^{-16}$ which is below the significance level of 0.05. Therefore, we rejected the null hypothesis of no association which provided statistically significant evidence that an association exists between height of growth and altitude for the population studied.

Growth Height vs. Canopy Cover

The correlation test comparing height of bryophyte (SL) growth across extents of canopy cover gave an r = -0.13 and a p-value = 0.0029, which is less than our significance level of 0.05. Therefore, we rejected the null hypothesis of no association which provided statistically significant evidence that an association exists between height of bryophyte (SL) growth and canopy cover from the population studied.

Discussion

There were a few major trends that stood out. The different substrate types and varying altitudes both had strong associations with all three of the quantifications of bryophyte (SL) growth: presence on certain substrates, extent of coverage of those substrates, and height of growth. Bryophyte (SL) height also showed statistically significant associations across the three different environmental factors. Canopy cover compared with any of the bryophyte (SL) growth patterns had a strong trend of either not showing any associations at all, or in the case of growth height, a weaker association by at least a factor of thirty (with the test between bryophyte (SL) coverage vs altitude being the next lowest) than any for substrate or altitude.

Test	P-value
Substrate	
Bryophyte (SL) Presence vs. Substrate	**$2.2\ e^{-16}$**
Bryophyte (SL) Coverage vs. Substrate	**$1.81e^{-6}$**
Growth Height vs. Substrate	**$6.66e^{-7}$**
Altitude	
Bryophyte (SL) Presence vs. Altitude	**$5.6e^{-11}$**
Bryophyte (SL) Coverage vs. Altitude	**$9.14e^{-5}$**
Growth Height vs. Altitude	**$2.2e^{-16}$**
Canopy Cover	
Bryophyte (SL) Presence vs. Canopy Cover	0.479
Bryophyte (SL) Cover vs. Canopy Cover	0.20

Growth Height vs. Canopy Cover	**0.0029**

Table 8. The nine hypothesis tests listed by topic of comparison and the respective p-values of those tests to show which were found to be statistically significant. P-values lower than the significance level of 0.05 are in bold.

Substrate

Bryophyte (SL) presence vs. substrate had an extremely low p-value of $2.2e^{-16}$ which strongly indicates an association exists between them. Soil and herbaceous plants were the only two substrate types where bryophyte (SL) appearance was less than 50% (32% for soil and 17% for the plants). Dead wood had the lowest rate of appearance above 50% of 73%. Non-small tree branches and non-small tree trunks stood out by having a 100% bryophyte (SL) appearance rate.

These findings are somewhat related to the findings from the study that reviewed substrate in Barro Colorado Island by Salazar Allen et al. (1991). Of a moss species distribution of 81 species in the study, 62 appeared as corticolous (on tree bark), 17 were epipetric (appeared on rocks), 12 appeared on dead logs, and a few species were found growing on soil. Although these proportions consider number of species, which may or may not correlate with presence of mosses in general, the trends such as very high presence on trees and very low on soil certainly match the trends found from this study. A different study that investigated the liverwort species *Lophozia silvicola* in Finland found its colonies growing on dead logs 43.8% of the time, on rocks 11.6%, and on soil the other 44.6%. These percentages alone don't give an idea of what proportions of these substrates were available in the area, but the author addresses it on page 90 by writing "When considering the substrate preference by comparing frequencies of occurrence of *Lophozia silvicola* on potential substrates, all substrates available can be considered equally suitable." (Laaka-Lindberg, 2000). Colonies appeared on rocks 26% less than they appeared on either soil or logs, but that might have been due to less rock availability than availability of the other two. However, soil was certainly not as equally suitable as rocks or logs (grouped under 'dead wood') based on the results of the chi-squared test we conducted comparing substrate to bryophyte (SL) presence in our study. Possible proposals for the cause of the difference could be the difference between mosses and liverworts. It could also be that Laaka-Lindberg (2000) viewed one specific species while our study viewed bryophytes (SL) of any kind, or it could suggest that the different climates based on latitudinal differences could be relevant.

Bryophyte (SL) coverage vs. substrate had a low p-value of $1.81e^{-6}$ that strongly indicates that an association exists between them. Soil and herbaceous plants were the two lowest again, but the spread of the means across the substrate types does not appear to have as extreme variation as the proportions from comparing bryophyte (SL) presence to substrate which is supported by the much lower p-value from that test than the p-value from this one.

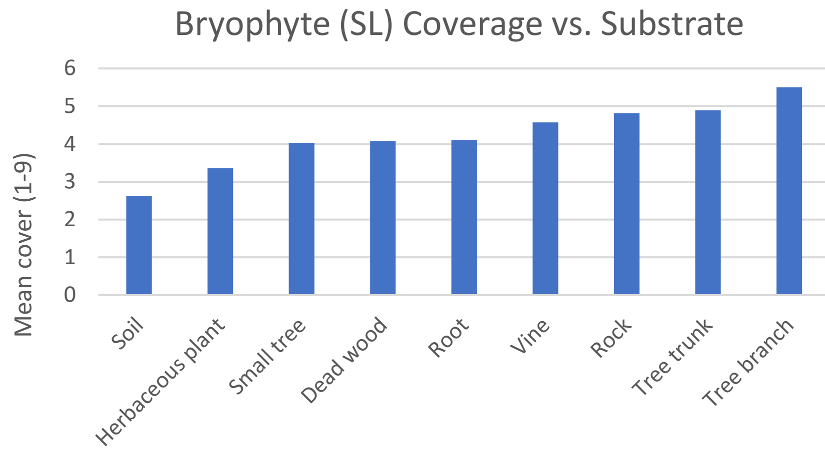

Figure 2. Bar chart comparing the means of bryophyte (SL) coverage (on the 1-9 scale) for each substrate type.

A study by Scott (1970) included coverage of epiphytic bryophytes (SL) (appearing on trees) to ground epiphytes (appearing anywhere else) in their study. It measured coverage with different gradient scales for each species. The analyses it ran were comparing sites rather than substrates. It noted that 86 species appeared as epiphytes only, 52 were found on both the ground and as epiphytes, and 39 were found only on the ground. They also noted that the ones that appeared on both the ground and as epiphytes were primarily ground found. Our data show a preference for trees over soil (or any other substrate found on the ground). It's difficult to compare the different substrates when some species appear on both. However, the trend of there being more species of bryophytes (SL) found as epiphytes than just on the ground would seem to align with this trend in our study, except considering that the comparison between cover and species abundance is inexact similarly to the comparison from bryophyte (SL) presence vs. substrate.

Growth height vs. substrate had a low p-value of $6.66e^{-7}$ that strongly indicates an association exists between them. The shape of the distribution looks similar to the distribution for bryophyte (SL) cover vs. substrate, but here rock is the lowest and soil is actually fourth lowest. Rock being this low is interesting as it had an 89% coverage rate in bryophyte (SL) presence. Of the 89 rocks found in the whole study, 0 were found in the 1018m altitude site, 16 at the 938m, 37 at the 841m, and 46 at the 746m site. This distribution between substrate and altitude appears to have strong a trend of fewer rocks at higher altitudes although no statistical tests were run on it. While this is only hypothetical, the extremely low p-value indicating that growth height is higher at higher altitudes would match with the low rock bryophyte (SL) coverage well.

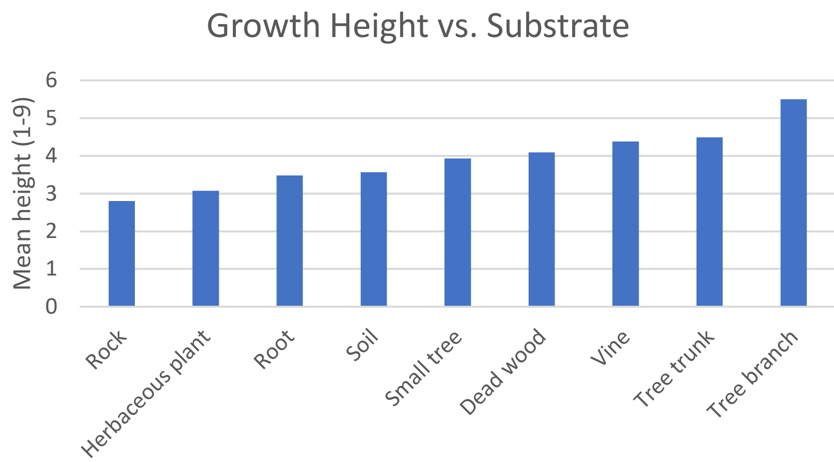

Figure 3. Bar chart comparing the means of growth height (on the 1-9 scale) for each substrate type.

Altitude

All three comparisons between bryophyte (SL) growth and altitude showed strong associations with higher bryophyte (SL) growth measurements being associated with higher altitudes. These results are in line with the results of other studies that have investigated the relationship between bryophytes (SL) and altitude. Sim-Sim et al. (2015) had examined cover when comparing the four bryophyte (SL) species and found a statistically significant increase in cover in relation to altitude for one of them. Bryophyte (SL) cover was shown to have a strong positive relationship with altitude by our results, which is similar to one part of what Sim-Sim et al. (2015) found that showed a statistically significant association, but differs from the three species that did not. Other studies have investigated biomass which could be related to presence, cover, or growth height. Although there isn't a direct relationship between cover or growth height with biomass, the two represent the two dimensions bryophytes (SL) would be growing in and so hypothetically have similar trends. Gradstein & Salazar Allen (1992) found a higher biomass at the 1,100-1,200m altitude range than at the 800-1,100m altitude range in Darién in Panamá. Wolf (1993) also found that epiphytic bryophytes (SL) increased in biomass at higher altitudes. Whether higher cover or height is more correlated with higher biomass, both have very strong correlations in our study which would indicate that biomass would be higher overall.

Canopy Cover

Canopy cover stood out by not being shown to have associations with presence or cover, and showing the least confidence in the existence of an association when it was compared to height among any of the tests that passed. This result was the most surprising. Lower canopy cover means there will be more light present which has a negative impact on bryophyte (SL) growth in rainforest environments with some exceptions of species adapted for higher light conditions (Guerra et al., 2020; Chantanaorrapint, 2010). For bryophyte (SL) height, the r of -0.13 also indicates that an increase in canopy cover is associated with a decrease in growth height overall, which is the opposite of the results found by Guerra et al. (2020) and stated by Chantanaorrapint (2010). Why bryophyte (SL) growth was shown to have no association or a negative one with canopy cover is by far the result that would most inspire more investigation. It may potentially be a result of measurement techniques, specific location, or something else specific such as the particular species present.

Conclusion

All bryophyte (SL) growth factors (presence of bryophytes (SL), coverage of substrate, and growth height) and microclimate and microhabitat factors (substrate, altitude, and canopy cover) were involved in associations found by the hypothesis testing at the Cerro Gaital site in El Valle, Panamá. Strong associations were shown to exist between each of the three growth factors and substrate type, as well as each of the growth factors and altitude. Canopy cover stood out by failing to show an association with either bryophyte (SL) presence or coverage, and having a weaker indication of a correlation, even a negative one, with growth height than either of substrate or altitude. The substrate patterns somewhat resemble findings of other studies, although presence, cover, and growth height are different than diversity. The combination of the strong associations shown by substrate and bryophyte (SL) growth and the results observing substrate and diversity in other studies, suggest that a relationship between the bryophyte (SL) growth patterns observed here and diversity seems likely. Altitude patterns were most expected to follow the way they did and were very strong despite having a smaller altitudinal gradient than some other studies that observed altitude differences as a factor. The canopy cover patterns were the least expected. The fact that these results were entirely contrary to any others indicates that there was some variable in this study that was noticeably different, whether that was a mistake in data collection or potentially a unique factor of the location Cerro Gaital.

Ethics

No interviews were conducted and no people or other animals were worked with in this research. A request to the Institutional Review Board (IRB) was made for this research proposal and the research did not begin until it was approved. The various bryophytes (SL) were observed but no brush or undergrowth was cleared to maneuver through denser areas. No tests were done on the observed plants and none were detached to weigh or a similar measurement that would potentially kill the plants. The equipment was all fairly light and small and didn't use any chemicals so it was expected to not cause any damage to the environment. No littering was done during the collecting.

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