Liana abundancy in forests of different ages in Costa Rica

Researcher: Kees Evers

Place of research: Cloudbridge reserve, Costa Rica

Date: 03-06-2021

Educational institution: Van Hall Larenstein, The Netherlands

Thesis coordinator: Peter v/d Meer

Abstract

There was no clear data on the presence or growth of lianas within the Cloudbridge reserve in Costa Rica. Because of this it was not known whether the liana population in Cloudbridge follows an expected or healthy growth pattern. Therefore the goal of this research project is to find out if the forests of Cloudbridge show a healthy growth pattern or if intervening is necessary. This was researched through the research question: '*What is the liana abundance in the forests of the Cloudbridge reserve and how does it vary between forests of different ages?'* To answer this, 48 plots of 100 m^2 were established over four different forest age classes (with a forest age of 19, 30, 35 and a primary forest respectively). Here all lianas were counted, measured for dbh and an invasiveness value was determined. This resulted in the following answers to the research question; The average forest in the Cloudbridge reserve has per hectare an estimated above ground liana biomass of 3,09 metric tonnes (around 1,4% of the total forest biomass), an average of 2160 lianas, an average dbh of 1,45 cm and an average invasiveness of 2,46. These results do not show a statistical difference in liana growth between the forest age classes however. This is true for biomass, average dbh, quantity of lianas and invasiveness. With this it can be concluded that there is no statistical proof for assuming a difference in liana abundancy between forests of different ages. This puts Cloudbridge at odds with the general literature where there often is a statistical difference. This is however explainable given the limited age range in the reserve, giving ultimately no cause for alarm. It is however important that Cloudbridge keeps monitoring its liana population to ensure the general forest health.

Table of contents

1. Introduction

1.1 General introduction

Lianas have a strange reputation in the academic field. It is widely known that these plants are common in most tropical forests, from a forests earliest moments to the oldest primary forests (Schnitzer et al., 2005). Lianas shape their growth and even their deaths (Schnitzer & Bongers, 2002). But what are lianas exactly? Lianas are: "… climbing plants that produce true wood (i.e., xylem tissues derived from a vascular cambium) and that germinate on the ground but lose their ability to support themselves as they grow, so they have to rely on external physical support to ascend to the canopy." (Gerwing et al., 2006). This sets them apart from trees, shrubs and most importantly 'non-woody' vines. Garguillo et al. (2008) define the difference with non-woody vines in their classification as woody vines (i.e. lianas) vs. herbaceous vines. In our current forestry culture lianas have a reputation as parasitic plants that take from their hosts what they need most; sunlight, water and space. However recent scientific publications have pointed at the positive effect's lianas can have on a forest (Andrew R. Marshall et al., 2020). Both of these effects intertwine to create a unique forest wherever lianas are present. But how exactly do these positive and negative effects change a forest? Is a forest from its earliest moments shaped by lianas or do the effects appear later in a forest's lifetime? How overwhelming are these lianas? Are they more present at a younger forest age or do they only become successful at a later forest stage?

1.2 Problem description

Andrew R. Marshall et al. (2020) note that "Of the 1.2 million documented forest inventory plots across the world, <1% have liana records." This problem is also very prevalent at Cloudbridge. To this date there have been no liana orientated studies done in the reserve while there have been at least thirteen done on the trees (Cloudbridge Reserva, n.d.). This prompted both Cloudbridge and the researcher to wonder if the lianas where actually doing well. Where they following the normal growth pattern? Were interferences needed? This was vital to their mission: "Reforest areas of degraded agricultural land and nurture those areas back to a climax forest composition (Reserva Cloudbridge, 2017)." For the Cloudbridge reserve to be able to reach a natural climax forest composition, lianas are an important part (Perez-Salicrup et al., 2004). They shape their host forests in many different ways and provide a unique vertical layer to the forest (William F. Laurance et al., 2001). Lianas do not develop on their own but in close connection to their host trees (Pérez-Salicrup et al., 1999) and the rest of the natural environment (Baldassarre, 2020).

To understand if these lianas follow a healthy growth pattern in Cloudbridge this paper will research if there is a link between the presence of lianas and the age of the host forest. An answer to this question would provide future Cloudbridge researchers and those outside to have a clearer picture of what lianas growth in the reserve looks like. This data can not only benefit Cloudbridge but also the larger scientific community. Schnitzer & Bongers (2002) and Andrew R. Marshall et al. (2020) note that this community is suffering from a deficiency in data on lianas. An additional beneficiary could be those interested in accurately calculating biomass. Having a more exact idea of how lianas grow can help make estimations more precise. Lastly, information on when and where liana grow provides a valuable insight for (forest)plantation owners to decide when and where to cut lianas as an anti-pest measure (Diego R. Pérez-Salicrup, 2006).

1.3 Literature study

According to the literature, liana growth changes with its host forest. Campanello et al. (2007) have concluded that in sub-tropical native forest in Argentina the number of lianas climbing the tree is inversely correlated to the height of the tree. They also concluded that half of the studied liana-free trees grew 100% faster than liana-laden trees, explaining that lianas do have an effect on tree growth. Schnitzer et al. (2005) also explain that lianas limit tree growth but specifying this for saplings, so lianas do not only limit tree growth for older trees but also at their youngest moments. Lastly Lai et al. (2017) say the same for secondary forests. It can therefore be concluded that lianas limit growth of trees for both older and younger forests. Bandaging effects as theorized by Andrew R. Marshall et al. (2020) do not seem to weigh up to the parasitic qualities of the lianas.

The literature points out that there are lianas in forests of all ages and that they affect all of these forests. But comparing these findings from different papers reveals that the presence of lianas will lead to wildly different results. Schnitzer et al. (2005) prove in their paper that small differences in their field methods can lead to significantly different outcomes. To see if the liana abundance differs between forests of different ages, a study is needed that directly researches this. Luckily there is such a study, Yuan, et al. (2009) have researched the liana abundance in four secondary forests of different ages. A 100-year-old forest, a middle-aged forest and two younger secondary forests. They conclude that: “The [numeral] abundance of lianas was relatively higher in the two younger and middle-aged secondary forests than in the old-growth secondary and primary forests.” From their data it can be concluded that older forests have on average a lower number of individuals, a higher mean basal area (i.e. more biomass) and a higher number of species when compared to younger forests. This study unfortunatly does not specify the exact standing age of the different forests (only a rough estimate) and does not mention the invasiveness in the canopy per individual tree. It is important to remember that this study was conducted in East-Asia. A paper done on the same topic but than in Latin-America could be very usefull. Relatively little studies can be found that give usefull data on this topic, or as Schnitzer and Bonger (2002) put it: ”Our current understanding of the ecology of lianas and their role in forest dynamics, however, has lagged well behind that of most other vascular plant groups”.

1.4 Location

This paper will take a closer look at this topic by researching the diverse forests of the Cloudbridge reserve, situated in the heartland of Costa Rica. The park has an elevation of 1550m to 2600m and a total size of 283 hectares (The Cloudbridge Reserve, n.d.). The rainfall can vary between 407.9 mm in July and 163.1 mm in September, the temperature can vary between 28.9°C for September and 21.7°C for January and February (weather-atlas, n.d.). According to databasin (n.d.) there are around two main soil types present in the park, cambisols in the lower parts and andosols higher up in the mountains. On this location the question of liana behavior will be more closely researched with the central goal to increase our understanding on how the presence of lianas changes throughout differently aged forests.

2. Main question and sub questions

To reach the established goal a research question is needed to guide the research process. To understand how or if lianas differ between forests of different ages the following research question has been created:

What is the liana abundance in the forests of the Cloudbridge reserve and how does it vary between forests of different ages?

In this research question there are two words that need to be further defined. The first is the word 'abundance of lianas'. This was derived from the paper of Yuan et al. (2009) and means the prevalence of lianas within a forest. 'Forests' are in this paper defined as 'forests with a different standing age'.

This research question can be subdivided in three sub questions, these will guide the method used to answer the main research question:

1. How does the quantity and size of lianas differ between forests of different ages at the Cloudbridge reserve?
2. How does the dry above ground liana biomass differ between forests of different ages at the Cloudbridge reserve?
3. How does the invasiveness of lianas in their hosts differ between forests of different ages at the Cloudbridge reserve?

3. Objective

The goal of this paper and accompanying field research is to understand how or if lianas differ between forests of different ages. To determine this, the paper will look at four attributes; Average diameter, quantity of lianas, above ground biomass and invasiveness per liana. The first two attributes, average diameter and quantity of lianas, will give a depiction of what the forest looks like. It will also provide the data for the third attribute. The above ground biomass will be the main indicator for examining whether there is a difference in liana abundancy between the forest age classes. This will answer the question 'Do the forests differ in liana abundancy?' and is the factor the paper will focus on most. To provide context it will be compared to the tree biomass of the forest the lianas are situated in. This will show what part of the total dry above ground biomass[1] is made up of lianas. The last attribute will provide a supporting role to the first three and answer 'How do the forests differ in liana structure?'. The invasiveness per liana will provide a clearer picture of what the lianas in the forest actually look like. It will show in what way the lianas kill or make use of their host trees. Understanding how fast lianas entangle themselves in the canopy has been of interest in multiple liana orientated studies (R-L Wang et al., 2011) (Joseph S. Vitelli et al., 2009). Having a clear understanding of their invasiveness can help Cloudbridge understand if lianas are overly parasitic in their reserve or that they follow a natural relationship with their host trees with minimum destruction to them. Since trees are the main focus of most forests, this effect is very important to understand. It will capture their relationship with their surroundings.

[1] Lianas and trees make up most of the biomass in the forest, dead branches, leaves as well as other small biomass holders are left out of the equation due to time constraints.

4. Methodology

4.1 General method

The methodology of measuring lianas in plots was mainly based on Schnitzer et al. (2005). From establishing a plot (§4.2), collecting data (§4.3 and §4,4) to processing the data (§4.5). In their paper Schnitzer et al. (2005) have created an equation that allows a researcher to calculate an estimated dry above ground biomass for an individual liana on the basis of its diameter. It was designed to be used in a wide range of tropical countries. The paper also had an acompaning research method and raw data processing technique. This paper forms the basis of how the following field research has been conducted.

The dry above ground biomass that can be calculated from the equation was used as an indicator to calculate 'liana abundance'. To put this liana abundancy in perspective it was compared to an estimated forest biomass. For this, a tree biomass formula from Chave et al. (2014) was used. With these two biomass values together a percentage of liana biomass in the total forest could be calculated. From this field data the final conclusions could be drawn.

4.2 Plot location

Following the method of Schnitzer et al. (2005) 10x10 meter plots were used. There were 48 of these throughout the Cloudbridge reserve, situated 25 meters from the trails that go through the reserve, 25 meters from any borders the forest age class may have and 10 meters from any waterways. A maximum border of 150 meters from any trail was also established to keep the possible plot locations within an achievable range. Lastly, areas that were shown as unreachable or dangerous were also excluded from the research process. These restrictions were put in place to negate most border effects, keep research achievable and give enough space for all plots. All available area for plots is visualized in appendix 3. This number of plots was decided upon because of the available time for field work and the local accessibility of the plots. (There are twenty preliminary plots given in appendix 3, the twelve in appendix 1 are those that have been researched.) These plots were distributed among the four main forest age classes that were sampled, these were forests with an age of 19, 30, 35 and a primary forest (as baseline). In both appendix 1 and 3 this stands denoted by their planting age; 2002 for 19 years old, 1991 for 30 years old and 1986 for 35 years old. All dated forests have naturally regenerated from being former pastureland. A further description of the determining of the plot location can be found in §6.1. The different forests and the exact location of the researched plots used can be found in appendix 1. Appendix 3 contains a map with the previously decided upon plot points and the terrain defined as suitable for plot points.

For determining the tree biomass per forest age class, three tree plots of 20 by 20 meters had been established in each forest age class. The three tree plots cover 1200 m^2 per forest age class. (This was done because the liana plots also covered 1200 m^2 per age class.) The plots were established based on sightings of suitable terrain. This was often limited to around the trails because the area around it did not allow for 20 by 20 plots. The location of these plots can also be found in appendix 1.

4.3 What was measured?

The main goal was to determine the weight of dry above ground biomass for lianas in metric tonnes per hectare (sub question 2) (Harwardcommunications, 2012). Following the commonly agreed on academic measurement this has been done in metric tonnes (Mg) per hectare (ha) (J. Castellanos et al., 1991) (Jérôme Chave et al., 2003) (Adrien N. Djomo et al., 2011). To find the above ground biomass the diameter has been measured and written down per liana, through this the average diameter and quantity of lianas has simultaneously been measured (sub question 1). To give the biomass data meaning, the biomass of the trees has also been determined as a comparison. The invasiveness of a liana has also been determined (sub question 3). This represents how lianas affect their host trees, ranging from mild to a complete takeover of the crown.

4.4 How was it measured?

4.4.1 Establishing the plot

To find the plot site, a map with coordinates and plot locations (appendix 1) has been used. The exact locations of the plots have been determined by GPS. Once the plot site was found the north-western corner was marked by planting a marked stick (SW-point). From this 'anchor' the next corner was placed 10 meters to the north (NW-point). Than the next point 10 meters to the east (NE) and lastly one back to the south (SE-point). Than the distance between this point and the anchor was measured as a check. If it was of by more than 30 centimeters from the intended 10 meters the plot would be redone. With these four marked boundaries in place the researcher could start measuring. The same method was used for the tree plots, but then with borders of 20 meters.

4.4.2 Measuring in the plot

Measurements of the lianas has been done at 130 cm from the ground (dbh). All lianas that were larger than 0,5 cm in diameter at dbh were included. Lianas with a diameter at dbh below 0,5 cm were only counted, not measured[2]. For determining whether a liana was in a plot or how to count them, the same method was used for both lianas above 0,5 cm and under 0,5 cm. This method was as follows; Any liana that was at dbh in the plot was part of the plot, regardless of its root system or crown was inside or outside the plot. If a liana went across the dbh limit outside of the plot and later entered the dbh limit inside the plot it was not counted. So where a liana first reached above dbh is the place where the measurement would be done, this way lianas wouldn't be counted twice. The liana stem was inside the plot if 50% or more of its basal area at dbh was in the plot. A further and more detailed description of what was and was not included can be found in appendix 6.2. The field method used does not require the calculation of height, so that was not recorded. In the tree plots the same method was used but than applicable to trees. Here however both the tree dbh and height was measured.

To understand the way in which lianas make use of their host trees they have been divided in four categories of invasiveness. From 1 in which they had no effect on the host tree to 4 which means the liana had completely enveloped the host tree. This will be written down for every liana that was larger than 0,5 cm in diameter at dbh, including dead ones. The visual aid used for this classification can be found in appendix 2. The table was derived from lecture material used on the University van Hall Larenstein. The final liana field form can be seen in appendix 4. The field form for the tree plots can be seen in appendix 5.

4.5 Data processing

With the data gathered an estimated dry above ground biomass could be calculated. This was done using the equation from Schnitzer et al. (2005). It requires the dbh (call this '130 cm from the ground') as an input to generate the outcome. In this case 'oven-dry weight of the liana in kilograms'. The equation used is the following:

$$\mathbf{AGB = \exp[-1.484 + 2.657 \ln(D)]}$$

ABG= The predicted aboveground oven-dry weight of the liana in kilograms.

-1.484= The intercept (The theoretical statistical value if the diameter is 0)

[2] And therefore not included in the calculation of the average dbh and invasiveness.

2.657= Slope (Conversion value for In(diameter))[3]

This equation is created for measuring 130 cm from the roots, not at dbh which is defined as '130 cm above the ground'. Luckily, the authors have included a conversion table in the paper (table 1 of Schnitzer et al.(2005)). In this conversion table the following equation is given to convert dbh values to the correct D (diameter 130 cm from the roots) value.

D_130 = 0.070 + 1.02 (D_passing 130)

D_130= D (diameter 130 cm from the roots)

D_passing 130= dbh (130 cm above the ground)

This D_130 value that follows could be used in the previous formula as a D and give the wanted above ground biomass in kilograms.

When all lianas were converted into above ground biomass there was a list with biomass per liana. These biomass values were then divided between the four forest age classes. Then the sum off all biomass per forest age class was divided over the twelve plots to get an average liana biomass per plot per forest age class. Finally the biomass values in kilos per 100 m2 could be converted to metric tonnes per hectare. For this the values were divided by 10 (since 100 kg per 100m2 (one plot) is 1000 Mg per ha). This biomass could then be compared to the tree biomass that was calculated as follows; First the total biomass per tree (in kilograms) was calculated using the conversion formula from Chave et al. (2014). This is:

$$\mathbf{AGB_{est} = 0.0673 \times (\rho D^2 H)^{0,967}}$$

ρ= The density of the wood. (The value used was 0,65, this was the average value from table 1 from Chave et al. (2014))

D= dbh

H= height

The result could then be added to all other results from the forest age class. And then, just like with calculation the liana biomass this total value was divided by twelve and then divided by 10 to get the average tree biomass per forest age class per hectare in Mg. This could then be compared to the average biomass of lianas to show how liana abundancy changes between forests of different ages. So to sum up:

- The formula D = 0.070 + 1.02 (dbh) was used to calculate the needed diameter above roots.
- Than the formula above ground biomass = exp(−1.484 + 2.657 ln(D)) was used to estimate the total above ground biomass per liana.
- All individual values were combined per forest age class and then divided by twelve and by 10 to establish an above ground liana biomass per ha in Mg.
- The formula $AGB_{est} = 0.0673 \times (\rho D^2 H)^{0,967}$ was used to calculate the biomass per tree.
- The biomass of all trees per age class was divided by twelve and by 10 to get the average tree biomass in Mg per ha.

[3] More information of how these values have been chosen can be found in the main paper used. See table 2 for determining intercept and slope and page 5 for final equation.

4.6 Statistical analysis

First it was calculated what fraction of the total forest biomass lianas take up. The way this was done is described in the paragraph above ('Data processing'). With these results both the percentage of liana biomass in each forest age class and the average over all forest age classes could be determined. With these values further statistical analysis could be done.

To establish whether the percentage of liana above ground biomass value significantly differs between the forest age classes, the P-value was calculated. To do this IBM SPSS (version 27) was used. Here a test for linear regression between 'forest age' and 'percentage of liana biomass per hectare' was carried out. This gave the P-value (sig.) and the effect size (R^2). An ANOVA test was also done to see if there is a specific connection between two individual forest age classes. A boxplot and a histogram (with the average percentage of liana biomass per forest age) was also provided. This result formed the basis of the conclusion.

The three other attributes (of the first and last sub questions) served to give a more detailed account of the conclusion that was drawn before. These three attributes are average diameter, quantity of lianas and invasiveness per liana (sub question 1 and 3). They were analyzed by applying the same linear regression as for the first attribute. But this time between 'forest age' and 'average diameter of lianas per hectare', 'forest age' and 'sum of lianas (both >0,5 cm and <0,5 cm) per hectare' and 'forest age' and 'count of invasiveness value per hectare' respectively. The results for diameter and quantity included both a regression and ANOVA P-value, a boxplot and a histogram. For the invasiveness a regression P-value and a histogram were given, ANOVA P-values where also checked. The histograms include the average diameters, sum of counted lianas and a count of invasiveness per forest age class. In these histograms the lianas with a diameter <0,5 cm and >0,5 cm was stacked but colored differently. The invasiveness values were also stacked and colored to their values. The boxplots include every dbh measured and the number of lianas per plot (<0,5 cm and >0,5 cm combined).

5. Results

5.1 Field results

These two tables show the results of the raw data. Table 1 shows the overall results and table 2 gives the results per forest age class. Together they give an overview of the whole research project.

Table 1: Overall results of field research

Results of all forest age classes:	
Average biomass per hectare (in Mg)	3,09
Average dbh (in cm)	1,45
Average nr. of lianas <0,5 cm per hectare	585
Average nr. of lianas >0,5 cm per hectare	1575
Average total nr. of lianas per hectare	2160
Mode of invasiveness (most common value)	3
Average invasiveness	2,45

Table 2: Results per forest age class

Results per forest age class:				
	19	30	35	PF
Average biomass per hectare (in Mg)	3,60	3,22	2,19	3,33
Average dbh (in cm)	1,61	1,53	1,33	1,35
Average nr. of lianas <0,5 cm per 0.01 hectares	500	683	500	658
Average nr. of lianas >0,5 cm per 0.01 hectares	1742	1883	1333	1342
Average total nr. of lianas per 0.01 hectares	2242	2567	1833	2000
Mode of invasiveness (most common value)	3	3	3	3
Average invasiveness	2,44	2,55	2,36	2,46

5.2 Statistical results

The results will be presented per sub question. Here the statistical analyses of all gathered data are shown in a way relevant to each sub question.

1. How does the quantity and size of lianas differ between forests of different ages at the Cloudbridge reserve?

Quantity:

The difference in quantity of lianas over all forest age classes is not significant (P = 0,600). A Post Hoc ANOVA test (Tukey HSD) points out that there is also no significant difference between the forest age classes (with a P varying between 0,571 and 0,991). The total number of lianas counted per forest age class and the average amount per ha can be seen in table 3. The total number of counted lianas per plot can be seen in the histogram (figure 1). The following boxplot shows the total number of lianas (both <0,5 cm and >0,5 cm) per plot, divided over the forest age classes (figure 2).

Figure 1: Sum of small and large lianas per forest age class

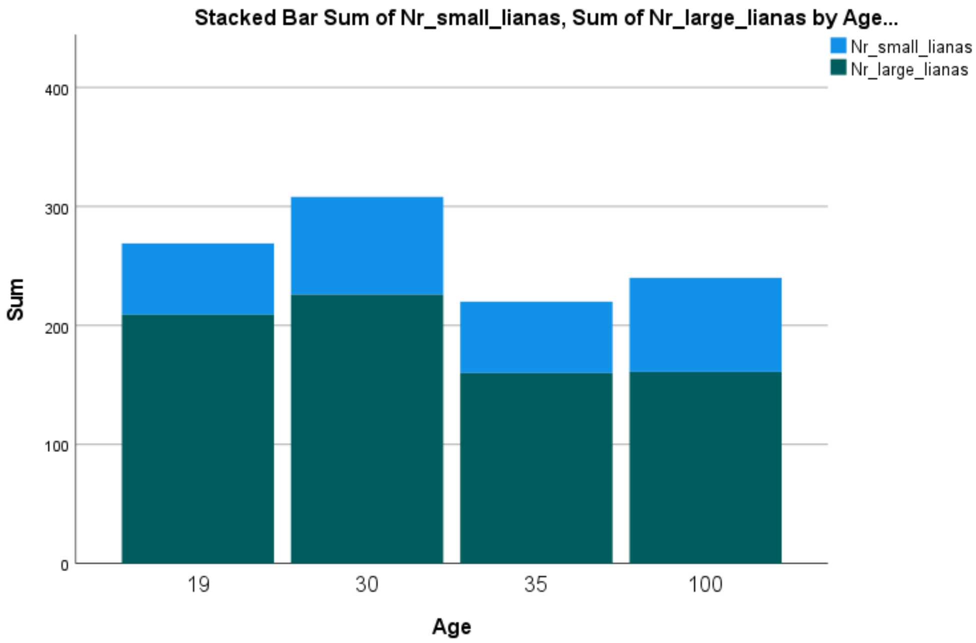


Figure 2: Boxplot with number of small and large liana counts combined per plot.

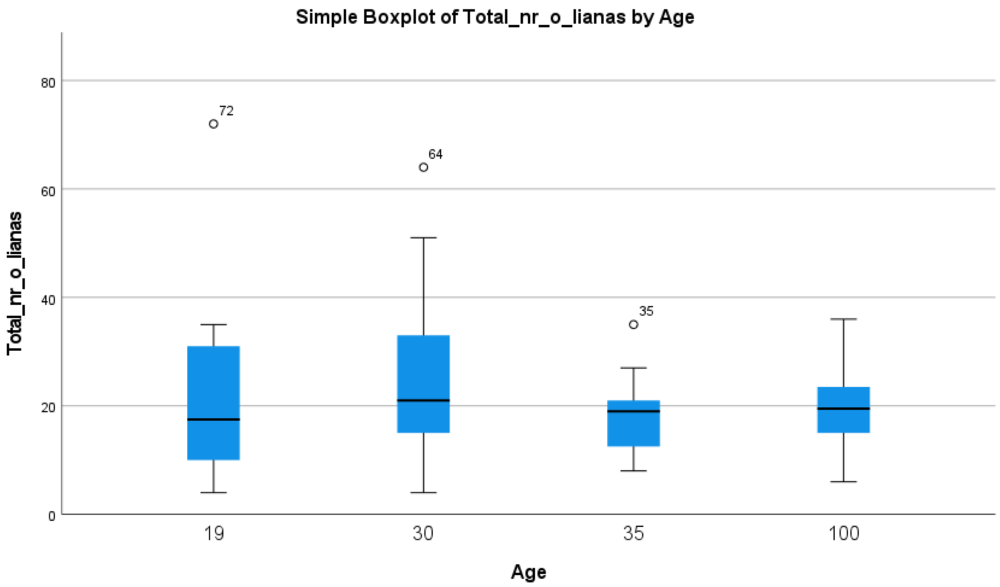


Table 3: Results of all lianas counted and the amount of lianas per hectare.

Results per forest age class:					
Total number of lianas counted					
	19	30	35	PF	Total:
Total nr. of large lianas (>0,5 cm)	209	226	160	161	756
Total nr. of small lianas (<0,5 cm)	60	82	60	79	281
Total nr. of lianas	269	308	220	240	1037
Estimated number of lianas per hectare					
	19	30	35	PF	Average:
Total nr. of large lianas (>0,5 cm)	1742	1883	1333	1342	1575
Total nr. of small lianas (<0,5 cm)	500	683	500	658	585
Total nr. of lianas	2242	2567	1833	2000	2160

Diameter:

The difference in the average dbh between the forest age classes does not show significance (P = 0,137). A Post Hoc test (Tukey HSD) for ANOVA shows that none of the forest age classes show any significance (with a P varying between 0,072 for 19-35 years and 0,998). The average dbh can be seen in table 2 and in the histogram below (figure 3). The boxplot shows all measured diameters. (figure 4).

Figure 3: The average dbh per forest age

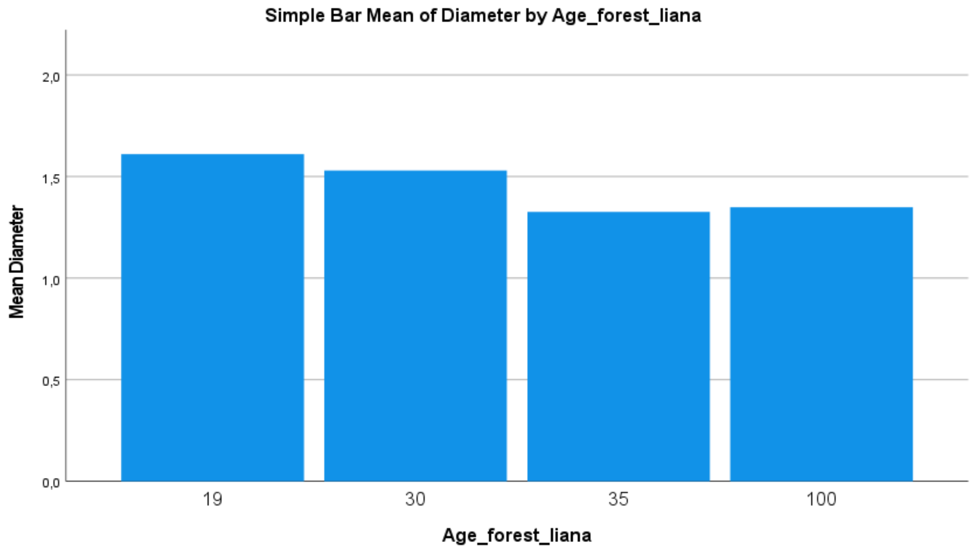
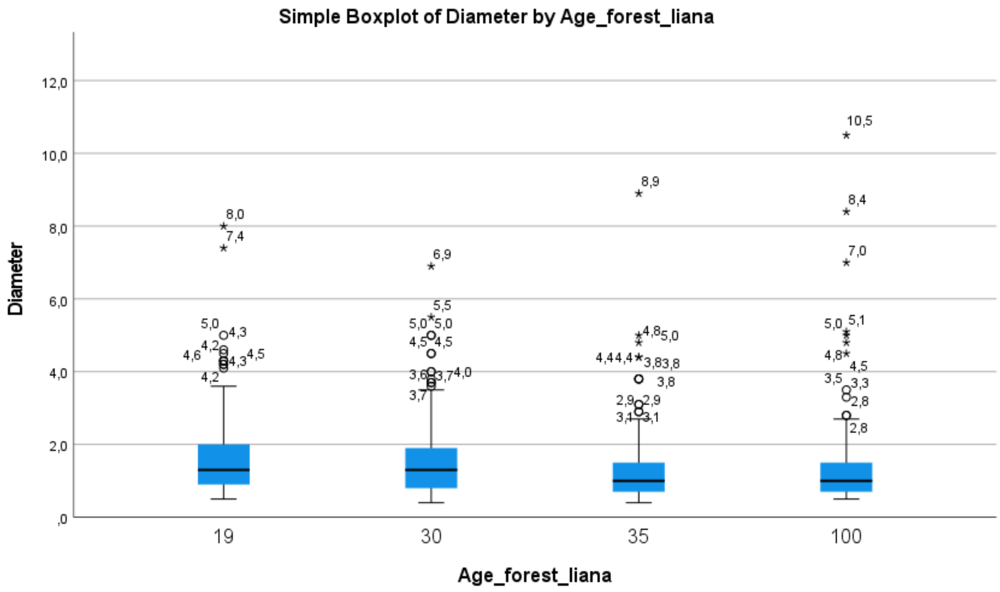


Figure 4: All measured diameters per forest



2. How does the dry above ground liana biomass differ between forests of different ages at the Cloudbridge reserve?

Lianas take up an average biomass of 1.4% of the average forest age class in Cloudbridge. The younger forests (19: 1.61% and 30: 2.14%) have a larger percental liana population than the older forests (35: 0.92% and PF: 0.93%). A test of regression gives a P-value of P = 0,202 for an effect size of r^2 = 0,035. An intercept and slope are irrelevant due to the small effect size and high P-value given. The boxplot below (figure 5) shows the results visually (were 100 stands for primary forest). Even though it may look like the younger (19 and 30) differ from the older (35 and PF) this is not significant as a Post Hoc test (Tukey HSD) for ANOVA points out. This gives a minimal P-value of P = 0,228 for comparing 30 and 35 (the most significant result). Removing the outliers gives a P of 0,01 for this same comparison however (see discussion). The histogram (figure 6) shows how the average percentages compare to each other. More detailed information on how the liana biomass percentage was calculated can be found in table 4.

Figure 5: Boxplot with % of liana biomass for every plot..

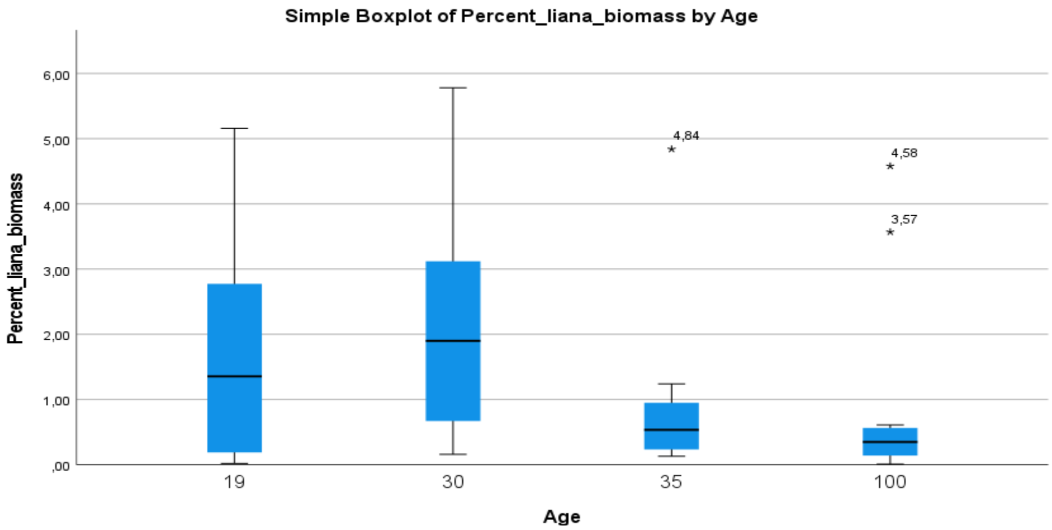


Figure 6: Mean percentage of liana biomass per forest age

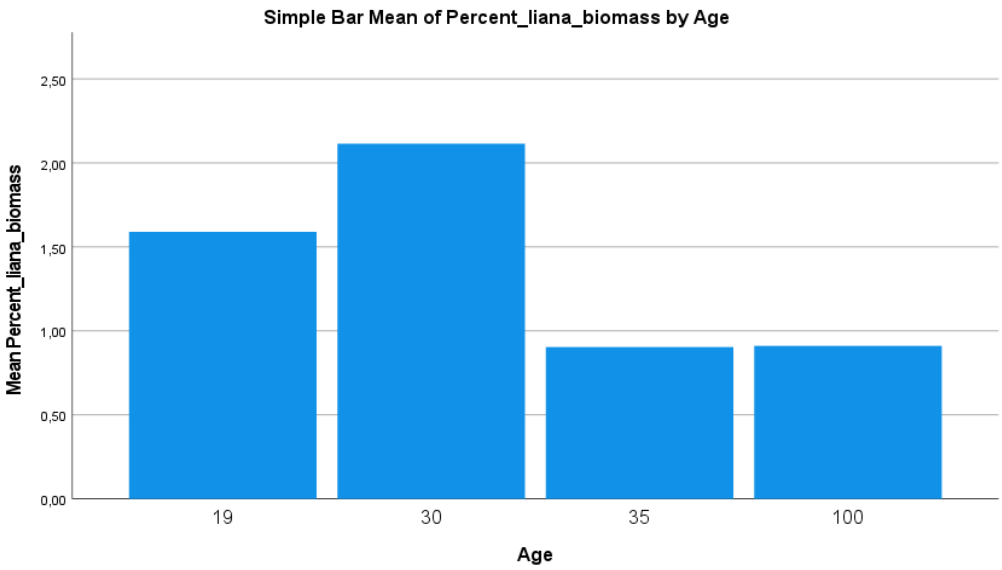


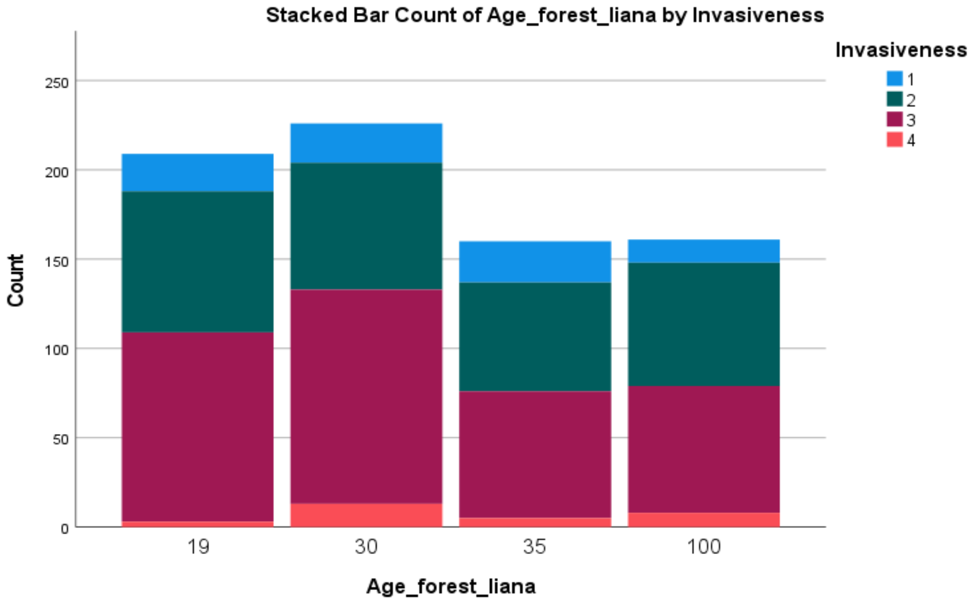
Table 4: Tree-liana comparison (Mg per ha).

	19	30	35	PF	Total average:
Total forest biomass	222,93	150,39	238,08	357,88	242,32
Biomass trees	219,33	147,16	235,89	354,54	239,23
Biomass lianas	3,60	3,22	2,19	3,33	3,09
% is lianas	1,61	2,14	0,92	0,93	1,40
Average tree dbh	22,80	25,21	21,02	21,98	22,75
Average height (m)	11,44	11,59	14,46	13,86	12,84

3. How does the invasiveness of lianas in their hosts differ between forests of different ages at the Cloudbridge reserve?

The difference in the invasiveness between the forest age classes does not show significance (P = 0,986). A Post Hoc test (Tukey HSD) for ANOVA shows that none of the forest age classes show any significance, although the significance between 35-30 years comes close with 0,066. The P varies between 0,066 and 0,989). The differences can be more clearly seen in the histogram below (figure 7).

Figure 7: Invasiveness per forest age class.



6. Discussion

6.1 Discussion on results

For all results it is shown that there is no statistical correlation to be found, not even a significant growth difference between two forest age classes. This is strange however, Yuan, et al. (2009) showed that lianas in older forests have a higher basal area and lower quantity of lianas. This could not be reproduced in this study. A explaination for this may be that the forest age classes that were chosen were very close in age. Disregarding the baseline 'Primary forest', the other three forest age classes only differed 16 years from one another (19-35). This was unavoidable since the forests at Cloudbridge are relatively young, but it may explain the difference with the results of Yuan et al. (2009) which handled larger age differences. It may therefore also be insightful to do a similar research project but with a broader spread of forest regrowth ages.

Quantity and diameter

Looking at more detailed results from the first sub question reveals that the quantity of lianas per forest age class (table 1) show the expected pattern given by the literature. The results for average dbh seem to follow a reverse trend, in contrast to the literature, were young forests have the largest average dbh and it decreasing per forest age class. What the reason for this reverse pattern is, is mostly unknown. An explaination may be that in some plots in older forests there were large multi-stemmed lianas growing below dbh, only their branches reaching above it. This meant that only the largest branch was above dbh was measured, resulting in a warped view on its average dbh. Another factor that may have impacted the findings was that the lianas with a dbh below 0,5 cm did not have their dbh and invasiveness measured. (As mentioned in Methodology -> Measuring in the plot.) This meant that the average dbh and the invasiveness values that were calculated excluded all lianas with a dbh below 0,5 cm. Lastly, most lianas that were under 0,5 cm turned out to be sub-woody. This meant they were hard to distinguish from vines, certain shrubs or roots of epiphytes. The final <0,5 cm liana count may thus have been affected by this close resemblance of the different categories of plants. This problem could also be found to a lesser extend by lianas with a dbh above 0,5 cm. This may partially explain the uncharacteristic outcome of this study (i.e.: not following the 'low quantity, high dbh' observation in old forests and the opposite in young forests). While these three factors may have contributed, a single, clear cause for this unexpected result could not be found.

Biomass

Looking at the results of the percentage of liana biomass in the forest (sub question 2) a pattern can be seen (figure 5). Young forests show a large spread of liana biomass in different plots while old forests have a clear occurrence value (around 35: 0.92% and PF: 0.93%). This difference is not significant however, with the closest case giving a P-value of 0,228 for comparing 35 and 30. But there are three outliers to be seen in figure 5. If these are removed both the difference between 30-35 and 30-PF become significant with P = 0,02 and P = 0,01 respectively. However this means removing values that are still accepted by age class 19 and 30, giving a warped view of the results. Another concern is the sudden drop between 30 and 35. Why is there such a large difference between forests that only differ 5 years in age? An answer may be the location of the forests. Older forests were generally in a higher altitude than young forest, this was most likely the cause of the sudden difference. In the fieldwork it was noted that areas closer to water contained a larger number of individual lianas. This may mean that younger forests (lower lying with more access to water) could have more lianas, not due to forest age but forest location. This can be seen in appendix 1, where both 19 and 30 are clearly grouped together near the river and streams lower in the valley whereas the older two from clearly a higher lying area. For this reason it has been decided not to exclude the outliers since they show that the answer is not as clear at is may appear to be.

Invasiveness

Invasiveness showed also no pattern at all between the forest age classes. It followed a normal distribution were class 2 and 3 were most common and class 1 and 4 only made up a small part. This shows that most lianas either solely use the trunk of the tree or both the trunk and a modest part of the canopy. From this it can be concluded that the parasitic qualities of lianas are relatively limited and they have a healthy relationship to their surrounding forest.

6.2 Field observations

Separate from researching the main research question, patterns in liana growth where noticed by the researcher. This paragraph discussed these and checks if these observations were statistically correct or coincidence.

- In the field it was noted that wet areas had more lianas. To test this an independent sample T-test for the difference between forests noted as 'wet' and the rest of the database ('dry') was done. This looked at the total number of lianas per plot (above and below 0,5 cm in dbh) and average biomass per plot. Both of these turned out as not significant but the number of lianas showed a pattern. In a two-tailed test it gave a significance of 0,17. While this is most likely due to the fact that only 5 plots were marked as wet forest, it shows that there might be a pattern (see 'Recommendations for future research'). A counter point to this is that, with the exception of one, all 'wet' plots were located in young forest (19 and 30). This may have influenced the results the other way around. It explains the high number of individual lianas and the difference in average biomass. The final results of this test can be seen below in table 5 (with biomass in Mg).

Table 5: Results dry-wet forest comparison.

Forest type	Nr. o. plots	Total nr. o. lianas	Average biomass (per liana)	Average nr. o. lianas per plot
dry	43	632	0,21	21
wet	5	123	0,15	31
		Significance (two-tailed)	P = 0,17	P = 0,42

- Only two liana species could be identified, they were identified on a family level. These were of the Smilacaceae species and the Araceae species (most likely philodendron aurantiifolium). Their abundance (number of individual recordings) per forest age class is show in table 6 below. It seems that the Smilacaceae species is more common in young forest, a conclusion on the Araceae species is harder to reach.

Table 6: Species abundancy.

Forest age	19	30	35	PF
Smilacaceae	32	7	0	0
Araceae	0	24	5	10

- While doing field research, the lianas that were dead were noted as such. Therefore a percentage of dead lianas in the total liana population can be established. First the average dead liana biomass per plot was established (see table 7 below). With this the percentage of dead liana biomass of the total liana biomass could be calculated. This was on average around 5,6% of all liana biomass. The forest age classes 19, 30 and the primary forest all show a percentage between 4%-5%. Strangely 35 has a staggering 11,6%. The reason for this in unknown.

The same test was also done for the number of lianas that were dead and above >0,5 (since those below <0,5 have not been marked as dead or alive, only tallied). The average number of individuals per plot that were dead made up an average of 11,4% of all lianas. As can been seen in table 6; the spread of percentage values differs much more between the forest age classes with seemingly no pattern. An aspect to note is that the percentage of number of dead lianas is much higher than the percentage in biomass of lianas. This shows that most lianas that are dead have a rather small amount of biomass (i.e. small lianas), while the larger ones are percentage wise more likely to be alive.

Table 7: Percentage of liana biomass and individuals dead (biomass in Mg).

	19		30		35		PF		Total	
	Dead	Dead & alive	Dead	Dead & alive	Dead	Dead & alive	Dead	Dead & alive	Dead	Dead & alive
Average biomass per individual	0,0006	0,00206	0,00098	0,00171	0,0009	0,00164	0,00317	0,00248	0,00097	0,00196
Total biomass measured	0,01738	0,43154	0,01661	0,38685	0,03057	0,26313	0,019	0,39981	0,08356	1,48133
Average biomass per ha	0,145	3,596	0,138	3,224	0,255	2,193	0,158	3,332	0,174	3,086
% dead biomass per ha	4,03		4,29		11,62		4,75		5,64	
Total nr. o. lianas measured	29	209	17	226	34	160	6	161	86	756
Average nr. o. lianas per ha	242	1742	142	1883	283	1333	50	1342	179	1575
% of individual lianas dead	13,88		7,52		21,25		3,73		11,38	

6.3 Cloudbridge compared to the rest of the world

Concluding this discussion the findings will be put in a larger perspective. As can be seen in table 8 below Cloudbridge follows an average dbh of lianas, with one paper reporting higher and on lower than what was found in the reserve. Biomass appears to be something different however. All entries score significantly higher than Cloudbridge, this can also be seen in the percentage that lianas take up in these forests. This might be due to the fact that all these other papers have measured in relatively low lying areas compared to Cloudbridge. Suzanne R. Yorke et al. (2013) measure in a similar area to Cloudbridge in Costa Rica and gave a 3,2% liana basal area compared to the rest of the forest. While this is not exactly the same calculation as biomass it can show that there is indeed a trend for higher areas to have less liana biomass. Given this, the liana population of Cloudbridge appears to be on the lower end of the international scale but this seems to be correlated to altitude.

When looking at Yuan et al. (2009) Cloudbridge appears to be more uniform over all its forest age classes than other places. Those researchers found a statistical difference but this couldn't be replicated in Cloudbridge. This might be due to the different ages of the forests, as theorised in §6.1. So while the common concensus is that older forests have larger and less lianas, the results at Cloudbridge show that this effect is limited over a shorter period of growth. While this effect may dissolve over time when the reserve becomes older, it is something of note to keep an eye on.

Table 8: Cloudbridge and the world liana population.

	Average dbh (in cm)	Average biomass in Mg per ha	% of total forest biomass
Cloudbridge	1,45	3,09	1,4
Nouragues, French Guiana (Schnitzer et al., 2006)	1,71	11,15	No data
Rio Negro Basin, Venezuala (Putz, 1983)	No data	15,7	4,5
Central Amazonian Forest (Gehring et al., 2004)	1,4	No data	No data
Eastern Amazonian Forest (Gerwing et al., 1999)	No data	43	14

7. Conclusion

Given the statistical results of the field data it cannot be said that there is a connection between forest age and liana abundancy. The answer to the main research question '*What is the liana abundance in the forests of the Cloudbridge reserve and how does it vary between forests of different ages?'* can in answered in two parts. 'What is the liana abundance?' and 'How does it vary between forests of different ages?'

The answer to the question 'What is the liana abundance?' is: The average forest in the Cloudbridge reserve has per hectare an estimated dry above ground liana biomass of 3,09 metric tonnes (around 1,4% of the total forest biomass), an average of 2160 lianas per hectare, an average dbh of 1,45 cm and an average invasiveness of 2,46 (but a mode of 3).

The answer to the second question 'How does it vary between forests of different ages?' is: The forests of the Cloudbridge reserve do not appear to statistically differ in liana growth between the forest age classes. This is true for biomass, average dbh, quantity of lianas and invasiveness. This results in a final conclusion that Cloudbridge seems to have lesser liana abundancy than the average tropical forest. The liana population also seems to be more uniformly spread over all the forest age classes than in the average tropical forest. This is however explainable given the limited age range in the reserve, giving no cause for alarm. It is however important that Cloudbridge keeps monitoring its liana population to ensure the overall forest health.

With these results an overview has been created of the liana population at the Cloudbridge reserve and an addition has been made to the global database on lianas. It has provide the Cloudbridge staff and researchers with a picture of the liana population in the reserve. Furthermore it takes the next step to realizing their mission: "Reforest areas of degraded agricultural land and nurture those areas back to a climax forest composition" by ensuring that their forest has a healthy liana population that lives in balance with its hosts. It has also put a questionmark behind the common perception of 'older forest, bigger lianas'. For both Cloudbridge and the general scientific world it is important to keep monitoring lianas to ensure the health and our continued understanding of tropical forests.

8. Recommendations for future research

- It was noted that areas in lower lying or wetter areas seemed to have more lianas than in dryer or higher areas. There was not enough data collected in lower lying/wetter areas to say this with certainty however. Therefore it would be an interesting topic for those studying lianas in similar high altitude forests.
- Determining what is a liana and what is not was a big bottleneck in the research done. Lianas span many families and often overlap with definitions of other plants. Giving a clear picture of what a liana actually is was lacking. An example is when differences are only described by growth. Things like: 'A epiphyte doesn't germinate from the ground like a liana.' are hard to check when in the field. A clear overview, description or definition of what a liana is and what not (i.e. an epiphyte, shrub or herbaceous vine) could eliminate this problem and ensure more accurate field data output in the future.
- It was evident that the small range of forest ages caused a problem for determining the main research question. It was the main hypothesized reason for the difference with the literature. It would be interesting if Cloudbridge researched the liana population at a later date to see if a larger spread of forest ages caused a statistical difference in the liana population.

9. Acknowledgements

9.1 Partners and obligations

This paper was created by a student at the university 'van Hall Larenstein'. The university provided the student with professional feedback and guidance in the research process. The Cloudbridge organization provided the student with accommodation (against a fee) and with access to the reserve. It also had a scientific coordinator on site which answered any questions the student had regarding the research location. The student has presented the findings to both the Cloudbridge reserve and the university. Both these institutions have permission to access the final paper.

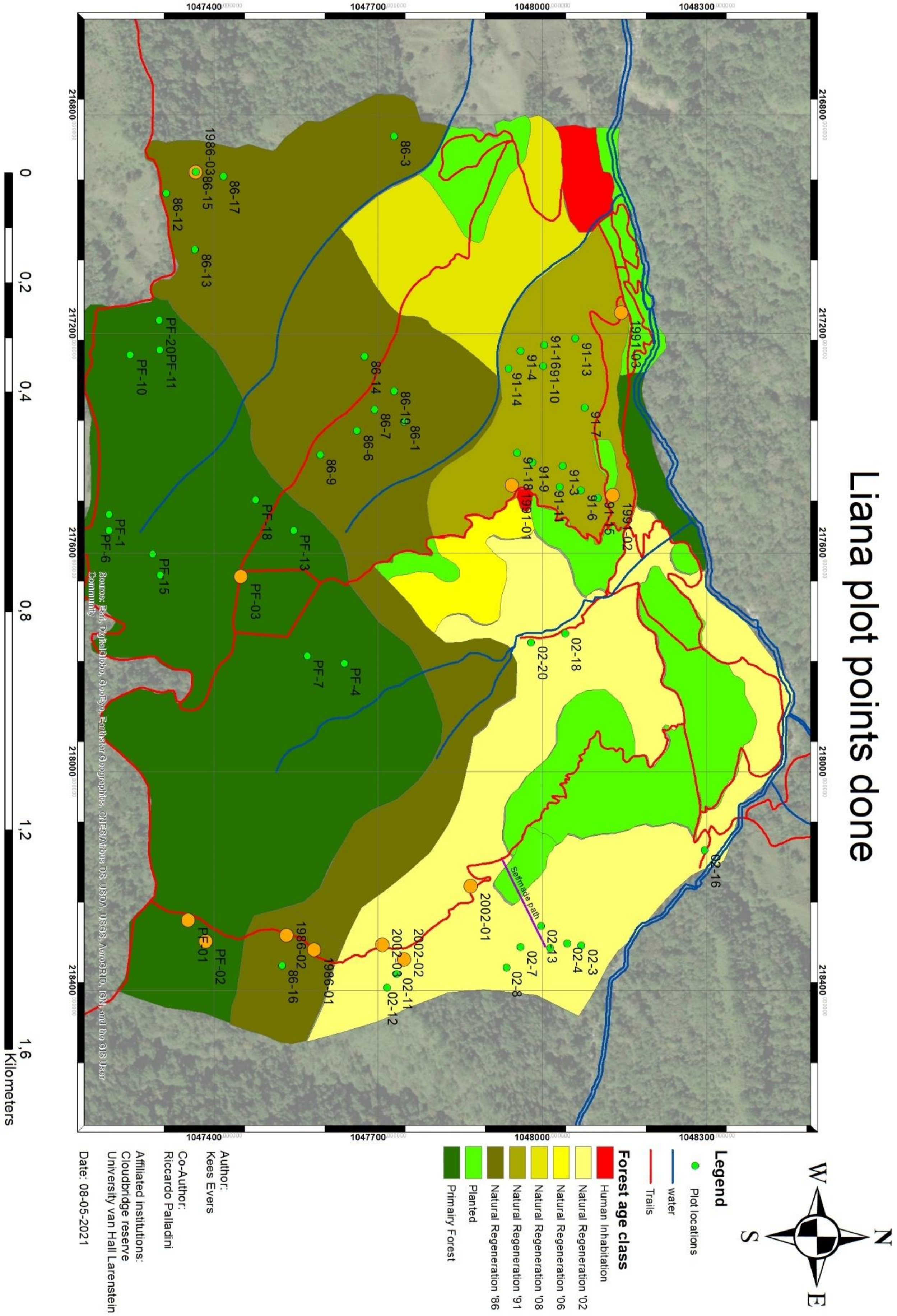
9.2 Contributions

I would like to thank Cloudbridge and all its amazing volunteers, their great research coordinators (Paula Pebsworth and Clara E. Moreno Vicente) and their staff (Casey McConnell, Mayi and Valeria). Without your indispensable help this entire research plan would have been impossible to do. I would also like to thank my thesis coordinator (Peter van de Meer) for his help with my research, writing and for his professional support and feedback.

10. Appendix

Appendix 1: Actual plot locations and forest age classes

Coordinate system used: WGS_1984_UTM_Zone_17N



Coordinates liana plots:

Name	X_long	Y_lat
PF-20	217176	1047300
PF-18	217504	1047476
PF-17	217642	1047302
PF-15	217603	1047288
PF-13	217560	1047545
PF-11	217230	1047301
PF-10	217239	1047247
PF-7	217789	1047570
PF-6	217560	1047208
PF-5	210303	1047360
PF-4	217803	1047638
PF-1	217531	1047208
86-19	217305	1047729
86-17	216913	1047417
86-16	218355	1047524
86-15	216905	1047367
86-14	217242	1047675
86-13	217047	1047365
86-12	216944	1047313
86-9	217422	1047594
86-7	217339	1047693
86-6	217378	1047661
86-3	216840	1047729
86-1	217361	1047747

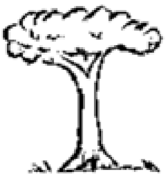
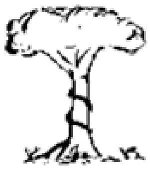
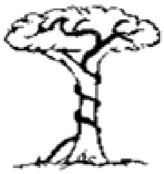
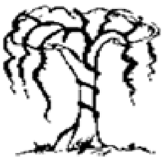
Name	X_long	Y_lat
91-18	217418	1047953
91-16	217221	1048003
91-15	217500	1048101
91-14	217264	1047938
91-13	217209	1048060
91-11	217480	1048031
91-10	217259	1048001
91-9	217435	1047982
91-7	217335	1048077
91-6	217487	1048070
91-4	217232	1047960
91-3	217442	1048037
02-20	217764	1047979
02-18	217748	1048041
02-16	218144	1048296
02-15	218323	1048014
02-13	218282	1047997
02-12	218395	1047716
02-11	218370	1047733
02-8	218358	1047934
02-7	218321	1047960
02-4	218314	1048045
02-3	218318	1048071

*In this map 2002/02 = 19, 1991/91 = 30, 1986/86 = 35 and PF = Primary forest

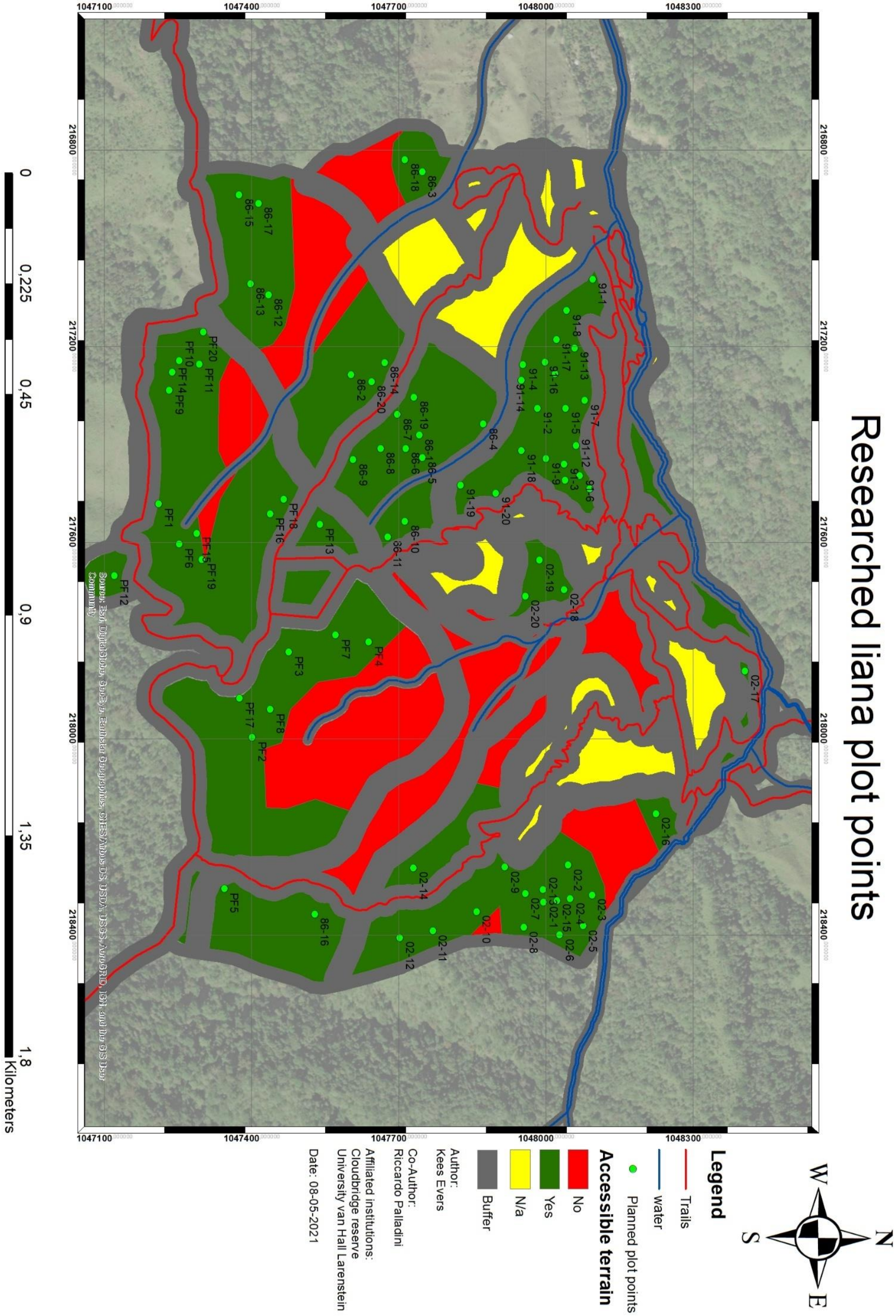
Coordinates tree plots:

19		30		35		PF	
Long_X	Lat_Y	Long_X	Lat_Y	Long_X	Lat_Y	Long_X	Lat_Y
218209	1047869	217477	1047944	218325	1047583	218271	1047353
218319	1047715	217495	1048128	218299	1047533	218310	1047385
218316	1047708	217161	1048144	216905	1047367	217643	1047449

Appendix 2: Invasiveness of lianas

Image	Description	Code
	Does not affect tree	1
	Liana on stem	2
	Liana is present in crown	3
	Liana is presence in stem and crown, severely affecting its growth	4

Appendix 3: Map with predefined plot points and area for possible plot points



Coordinates initial liana plots:

Plot_num	Long_X	Lat_Y
PF1	217522	1047210
PF2	217998	1047400
PF3	217824	1047475
PF4	217803	1047638
PF5	218103	1047399
PF6	217604	1047251
PF7	217789	1047570
PF8	217940	1047437
PF9	217291	1047232
PF10	217230	1047252
PF11	217237	1047292
PF12	217668	1047119
PF13	217564	1047538
PF14	217253	1047238
PF15	217583	1047287
PF16	217543	1047437
PF17	217918	1047375
PF18	217512	1047465
PF19	217636	1047298
PF20	217171	1047301

Plot_Nu	Long_x	Lat_Y
86-2	218295	1047362
86-3	216845	1047747
86-6	217409	1047713
86-7	217340	1047696
86-14	217234	1047670
86-16	218358	1047528
86-1	217382	1047741
86-4	217359	1047871
86-5	217428	1047747
86-8	217409	1047662
86-9	217432	1047606
86-10	217558	1047712
86-11	217589	1047676
86-12	217096	1047434
86-13	217073	1047397
86-15	216893	1047374
86-17	216910	1047413
86-18	216820	1047712
86-19	217305	1047730
86-20	218350	1047353

Plot_num	Long_X	Lat_Y
91-1	217064	1048094
91-2	217327	1047982
91-3	217441	1048036
91-4	217238	1047952
91-5	217327	1048039
91-6	217465	1048068
91-7	217311	1048078
91-8	217128	1048041
91-9	217430	1047999
91-10	217257	1048017
91-11	217474	1048038
91-12	217403	1048060
91-13	217205	1048057
91-14	217270	1047949
91-15	217491	1048088
91-16	217233	1047997
91-17	217187	1048020
91-18	217413	1047949
91-19	217484	1047825
91-20	217500	1047897

Plot_nu	Long_X	Lat_Y
02-1	218334	1047994
02-13	218308	1047993
02-15	218330	1048021
02-2	218258	1048044
02-3	218319	1048093
02-4	218327	1048048
02-5	218382	1048074
02-6	218400	1048027
02-7	218316	1047957
02-8	218385	1047954
02-9	218262	1047915
02-10	218353	1047857
02-11	218392	1047768
02-12	218406	1047701
02-14	218264	1047729
02-16	218154	1048223
02-17	217863	1048405
02-18	217697	1048036
02-19	217637	1047986
02-20	217710	1047957

Appendix 4: Field form lianas

Forest age:	Plot nr:	Altitude (m):	
Coordinates:			
ID liana:	Diameter:	Invasiveness value:	Remarks:
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Appendix 5: Field form trees

Forest age:	Plot nr:	Altitude (m):	Coordinates:

ID Tree:	Diameter:	Height:	Remarks:
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Appendix 6: Field research details

6.1 Extra information on determining plot location

The plot locations were chosen with the 'Create Random Points' from ArcMap. These were used as plot locations, given that they were within the restrictions mentioned at the start of this paragraph. Due to the nature of the mountainous terrain of Cloudbridge the exact plot points were used as indicators when there were unforeseen obstacles on the given spot. This means that it gave the general location of where the plot should have been established. If possible, the exact location. But it has proved necessary to shift this. The naturally regenerated forest that was 15 years old (2006) was not included as its surface is too small, the forest had been regenerating for 13 years (2008) was not included due to the inaccessibility of the terrain (too steep for research).

6.2 Measuring specifics

Here a more detailed explanation follows of how measurements were done inside the plot. Firstly, to identify an individual liana it had to be observed whether the lianas are connected to one stem or one root system. If this was the case the largest of the stems (i.e. the main stem) was measured. Furthermore when a liana showed growth abnormalities the researcher measured just below dbh at a place where the abnormality no longer influenced the measurements. Abnormalities could be large growths, knots, fissures, or wounds. Dead lianas were also included in the data set because these also contributed to the total above ground biomass. In bundles of lianas (like in picture 1) the stems were measured individually unless impossible to do so because of converging growth, in that case they were classified and measured as one individual.

Picture 1: Bundle of lianas

Literature

Adrien N. Djomo, A. K. (2011). *Estimations of total ecosystem carbon pools distribution and carbon biomass current annual increment of a moist tropical forest.* Elsevier.

Andrew R. Marshall, P. J. (2020). *Conceptualising the Global Forest Response to Liana Proliferation.* Frontiers in Forests and Global Change.

Baldassarre, D. T. (2020). *What's the Deal with Birds?* Oswego: Iris publishers.

Blanco, F. M. (1880). *Flora de Filipinas.*

C. Gehring, S. P. (2004). *Liana allometric biomass equations for Amazonian primary and secondary forest.* Forest Ecology and Management.

Campanello, P. I., Garibaldi, J. F., Genoveva Gatti, M., & Goldstein, G. (2007). *Lianas in a subtropical Atlantic Forest: Host preference and tree growth.* Buenos Aires: Elsevier.

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W.B.C., Duque, A., Eid, T., Fearnside, F. M., Goodman, R.C., Henry, M., Martínez-Yrízar, A., Mugasha, W.A., Muller-Landau, H.C., Mencuccini, M., Nelson, B.W., Ngomanda, A., Nogueira, E. M., Ortiz-Malavassi, E., Pélissier, R., Ploton, P., Ryan, C. M., Saldarriaga, J. G., Vieilledent G.,(2014). *Improved allometric models to estimate the aboveground biomass of tropical trees.* Global Change Biology.

Cloudbridge Reserva. (n.d.). *REPORTS*. Retrieved from cloudbridge: http://www.cloudbridge.org/publications/reports/

databasin. (n.d.). Retrieved from databasin: https://databasin.org/maps/new/#datasets=92cd21cec56a48289ebaeccaa75d6ada

Diego R. Pérez-Salicrup, A. C. (2006). *Cost and Efficiency of Cutting Lianas in a Lowland Liana Forest of Bolivia.* Biotropica.

Garguillo, M. B., Magnuson, B., & Kimball, L. (2008). *A field guide to the plants of Costa Rica.* A zona tropical publication.

Gerwing, J. J., & Farias, D. L. (2000). *Integrating Liana Abundance and Forest Stature into an Estimate of Total Aboveground Biomass for an Eastern Amazonian Forest.* Journal of Tropical Ecology.

Gerwing, J. J., Schnitzer, S. A., Burnham, R, J,. Bongers, F,. Chave, J,. DeWalt, D. J., Ewango, C. E. N,. Foster, R,. Kenfack, D,. Martínez-Ramos, M,. Parren, M., Parthasarathy, N., Pérez-Salicrup, D. R., Putz, F.E., Thomas, D. W.,(2006). *A Standard Protocol for Liana Censuses*

Harwardcommunications. (2012, January 23). *The difference between "ton" and "tonne"*. Retrieved from blog.harwardcommunications: https://blog.harwardcommunications.com/2012/01/23/the-difference-between-ton-and-tonne/#:~:text=Both%20%E2%80%9Cton%E2%80%9D%20and%20%E2%80%9Ctonne,as%20a%20%E2%80%9Cmetric%20ton%E2%80%9D.

J. Castellanos, M. M. (1991). *Root biomass of a dry deciduous tropical forest in Mexico.* Springer.

Jérôme Chave, R. C. (2003). *Spatial and temporal variation of biomass in a tropical forest: results from a large census plot in Panama.* British Ecological ociety.

JOSEPH S. VITELLI, B. A. (2009). *Control of the invasive liana, Hiptage benghalensis.* Weed Biology and Management.

Lai, H., Hall, J. S., Turner, B. L., & Van Breugel, M. (2017). *Liana effects on biomass dynamics strengthen during secondary forest succession.* Ecology.

Mascaro, J., Schnitzer, S., & Carson, W. P. (2004). *Liana Diversity, Abundance, and Mortality in a Tropical Wet Forest in Costa Rica.* ResearchGate.

Perez-Salicrup, D. R., Schnitzer, S. A., & Putz, F. E. (2004). *Community ecology and management of lianas.* Marquette: Biological Sciences Faculty Research and Publications.

Pérez-Salicrup, D. R., Sork, V. L., & Putz, F. E. (1999). *Lianas and Trees in a Liana Forest of Amazonian Bolivia.* Biotropica.

plantsoftheworldonline. (n.d.). *Uncaria Schreb.* Retrieved from plantsoftheworldonline: http://plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:327895-2

Putz, F. E. (1983). *Liana Biomass and Leaf Area of a "Tierra Firme" Forest in the Rio Negro Basin, Venezuela.* Biotropica.

RainforestPlants. (2012, March 30). *Plant Family List*. Retrieved from wheatoncollege: http://wikis.wheatoncollege.edu/rainforest/index.php?title=Dilleniaceae

Reserva Cloudbridge. (2017). *REFORESTATION*. Retrieved from cloudbridge: http://www.cloudbridge.org/the-project/reforestation/

R-L WANG, R.-S. Z.-L.-M.-T.-W. (2011). *Elevated temperature may accelerate invasive expansion of the liana plant Ipomoea cairica.* Guangdong: Wiley Online Library.

Schnitzer, S. A., & Bongers, F. (2002). *The ecology of lianas and their role in forests.* Trends in Ecology & Evolution.

Schnitzer, S. A., DeWalt, S. J., & Chave, J. (2005). *Censusing and Measuring Lianas: A Quantitative Comparison of the Common Methods.* Biotropica.

Schnitzer, S. A., Kuzee, M. E., & Bongers, F. (2005). *Disentangling above- and below-ground competition between lianas and trees in a tropical forest.* Journal of Ecology.

Suzanne R. Yorke, S. A. (2013). *Increasing Liana Abundance and Basal Area in a Tropical Forest: The Contribution of Long-distance Clonal Colonization.* Wiley online library.

The Cloudbridge Reserve. (n.d.). *CLOUDBRIDGE NATURE RESERVE*. Retrieved from cloudbridge: http://www.cloudbridge.org/

Useful Tropical Plants. (2019, 6 13). *Randia aculeata*. Retrieved from Useful Tropical Plants: http://tropical.theferns.info/viewtropical.php?id=Randia+aculeata

weather-atlas. (n.d.). *Monthly weather forecast and climate*. Retrieved from weather-atlas: https://www.weather-atlas.com/en/costa-rica/puerto-viejo-de-talamanca-climate#rainfall

William F. Laurance, D. P.-S. (2001). *RAIN FOREST FRAGMENTATION AND THE STRUCTURE OF AMAZONIAN LIANA COMMUNITIES.* Ecology.

Yuan, C.-m., Liu, W.-y., Tang, C. Q., & Li, X.-s. (2009). *Species composition, diversity, and abundance of lianas in different secondary and primary forests in a subtropical mountainous area, SW China.* Ecological research.