Habitat assessment of planted, naturally regenerated and primary tropical cloud forest

A research study on the difference in forest structure between planted and naturally regenerated forest compared to primary tropical montane cloud forest within Cloudbridge Nature Reserve, Costa Rica

Mathijs van der Sanden
August 3, 2017

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Technical report commissioned by Van Hall Larenstein University of Applied Sciences and Cloudbridge Nature Reserve on the habitat assessment conducted at Cloudbridge Nature Reserve by Mathijs van der Sanden during the internship period of the 3rd year of the BSc Tropical Forestry

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Summary

In the 1960s, the Costa Rican government started a land colonization program that encouraged prospective homesteaders to improve virgin farm land by clearing the property they wanted to claim and work, mainly for the beef export market to supply the fast food industry in North America. This resulted in farmers clearing even the steeply sloped mountainous areas of Costa Rica due to the lack of flat land in the country. These steep, deforested areas were used as pastureland and subsequently abandoned after several years which left the forests fragmented and the cleared patches vulnerable to erosion. One of the montane forest systems affected by this deforestation frenzy are known as cloud forests.

Fifteen years ago, Cloudbridge Nature Reserve started a reforestation project in such an area. Adjacent to Chirripó National Park and another private nature reserve, it links different forested areas which makes it possible for flora and fauna to migrate through the landscape. However, reforestation is a costly occupation and very time-consuming. Cloudbridge would greatly benefit from knowing how effective its efforts have been so far. The objective of this research is thus to assess if planted areas are recovering in a faster successional process than the naturally regenerated areas compared to the unaffected primary forest. This can be assessed by monitoring and comparing the forest structure and the growth over the years of selected trees within planted, naturally regenerated and primary cloud forest. This leads to the research question: *Is there a difference in forest structure between planted, naturally regenerated and primary areas of tropical cloud forest within Cloudbridge Nature Reserve?*

The planted areas are represented by 7 plots, the naturally regenerated areas by 10 plots and the primary by 3 plots. In every plot, all trees with a DBH of 10 or higher are tagged with a number. For each tagged tree, the DBH was measured, the tree height and volume calculated, crown class determined, and whether the tree was alive or dead recorded. On top of that, the canopy closure per plot was measured.

For this assessment three different statistical tests were used; One-Way and Two-Way ANOVA, and Kruskal-Wallis. All data first went through a normality test to analyse whether or not the data was normal distributed. The collected data for the number of trees per hectare and the crown class per habitat type appeared to have a normal distribution ($P>0.05$). Based on this, the parametrical tests One-Way and Two-Way ANOVA were used to analyse significance in the number of trees and crown class respectively. To analyse whether there was a significant difference in DBH, height, volume and canopy closure the non-parametrical Kruskal-Wallis test was used since this data was not normal distributed.

Difference in DBH increment: Planted areas had a median increase in DBH of 5.7% between 2016 and 2017, with naturally regenerated areas at 3.4%, and primary areas the lowest at 1.3%. *Difference in DBH:* Trees within the naturally regenerated plots had a median DBH of 20.0 cm compared to a median of 16.7 cm for planted and 19.0 cm for primary forest. *Difference in tree height:* Trees within primary forest plots had a median height of 14.4 m, with an extreme value of 64.5 m, compared to a median of 10.5 m for planted and 12.4 m for naturally regenerated forest. *Difference in tree volume:* Trees within primary forest plots had a median volume of 0.44 m^3 compared to a median of 0.25 m^3 for planted and 0.38 m^3 for naturally regenerated forest. *Difference in crown class:* Planted forest plots contain the highest number of crown class 1 trees with a mean of 8.714 trees compared to a mean of 5.1111 for naturally regenerated and 5.667 trees for primary forest. Crown class 2 trees are most present in naturally regenerated forest with an average of 6.4, and trees with crown classes 3 and 4 occur most in primary forest plots with an average of 11 and 10.667 respectively. *Difference in canopy closure:* Naturally regenerated forest habitats generally have a denser canopy than planted and primary habitats with a median canopy closure of 97.2 % compared to a median of 88.7 % for planted and a median of 93.9 % for primary forest. *Difference in number of trees:* The mean number of trees within the primary forest plots was 31.0, compared to 16.714 trees in planted, and 21.1 in naturally regenerated plots. Per hectare this would be: 631 trees per hectare for primary forest, 409 trees per hectare for natural, and 340 trees for planted areas. All results except the number of trees were significant ($P<0.05$).

Overall, it can be concluded that either way both planting and natural regeneration are good ways to let the forest recover to its former state. However, although naturally regenerated areas resemble the primary forest structure more closely at this moment, planted areas are recovering faster. The effort Cloudbridge put in replanting the area is clearly showing its results.

1. Introduction

According to the United Nations Environment Programme (UNEP, 2011) nearly 1.6 billion people rely on forests and two-thirds of all terrestrial plants and animals make their homes within these ecosystems. Furthermore, forests store more than 650 billion tons of carbon and offer lots of environmental goods and services (FAO, 2010). Yet, rampant deforestation is happening all over the world. Every year around 13 million hectares of forests are cleared, mainly because of the growing demand for agricultural land (FAO, 2010).

Even in Costa Rica, one of the most sought-after eco destinations in the world, deforestation is still a problem (LePree, 2008; Lehmann, 2011). Here forests have to make way for the cultivation of bananas, pineapple, beef and coffee (DeLyser, 2015). In the 1960s, the Costa Rican government started a land colonization program that encouraged prospective homesteaders to improve virgin farm land by clearing the property they wanted to claim and work, mainly for the beef export market to supply the fast food industry in North America (Evans, 1999). This resulted in a 'race' just to obtain some suitable land (Spooner, 2017), and resulted with farmers clearing even the steeply sloped mountainous areas of Costa Rica due to the lack of flat land in the country (Evans, 1999). These steep deforested areas were used as pastureland and subsequently abandoned after several years which left the forests fragmented and the cleared patches vulnerable to erosion (Buschbacher, 1986).

1.1 Cloud forests

One of the montane forest systems affected by this deforestation frenzy are known as cloud forests. Tropical cloud forests are by itself already a rare and fragile ecosystem and only make up 2.5% of the total area of the world's tropical forests (Bubb, et al., 2004). Unfortunately, besides the pressure of direct human interference like deforestation, these rich mountainous forests are also under increasing threat due to climate change (Bubb, et al., 2004).

Cloud forests occur between an elevation of 1500 to 3500 meters above sea level on large inland mountain systems, whereas in coastal mountainous regions this zone may descend to a 1000 meters (Bubb, et al., 2004). Annual and seasonal rainfall patterns in cloud forests range from 500 to 6000 mm per year. They are found wherever clouds and mist are frequently in contact with mountain slopes.

This makes cloud forests an important water source. They have the important role of stabilizing water quality and maintaining the natural flow patterns of the streams and rivers originating and passing through them. Since tropical clouds forests can capture the water from the condensation of clouds and fog, this makes this forest type an important and relatively reliable water source during dry seasons (Bubb, et al., 2004).

Besides being a vital water source, tropical cloud forests are of exceptional ecological importance due to their high level of species diversity and endemism (Challenger, 1998). One of the characteristics of a cloud forest is the quantity and diversity of ferns, mosses, orchids, and other plants growing on every rock, tree and branch surface. This is the reason why so much water can be obtained from clouds and fog only. In addition to that, they prevent erosion on the mountain slopes and act as essential carbon sinks (DeLyser, 2015).

1.2 Problem statement

Cloudbridge Nature Reserve is located in a cloud forest area in Costa Rica that was largely deforested in the 1960s. This privately-owned reserve covers around 280 hectares and was founded back in 2002 (Spooner, 2017). One of the goals of Cloudbridge is to return this unique and important cloud forest ecosystem to its former glory. Since it is adjacent to Chirripó National Park and surrounded by other nature reserves, it also links different forested zones which makes it possible for flora and fauna to migrate through bigger areas (an ecological bridge in the clouds). To enhance and accelerate the process of recovery of the deforested areas, Cloudbridge started actively reforesting areas of the reserve.

However, reforestation is a costly occupation and very time-consuming. Cloudbridge would greatly benefit from knowing how effective its efforts have been so far. The objective of this research is thus to assess if planted areas are recovering in a faster successional process than the naturally regenerated areas, and how similar these areas are compared to the 70+ years unaffected primary forest. This can be assessed by monitoring and comparing the forest structure and the growth over the years of selected trees within planted, naturally regenerated and primary cloud forest (Spies, 1998). Because of this, this research builds upon earlier obtained data. This leads to the research question: *Is there a difference in forest structure between planted, naturally regenerated and primary areas of tropical cloud forest within Cloudbridge Nature Reserve?*

To be able to answer this question it is divided into the following sub questions:

- *Is there a significant difference in tree DBH between planted, naturally regenerated and primary forest?*
- *Is there a significant difference in tree height between planted, naturally regenerated and primary forest?*
- *Is there a significant difference in tree volume between planted, naturally regenerated and primary forest?*
- *Is there a significant difference in canopy closure between planted, naturally regenerated and primary forest?*
- *Is there a significant difference in the number of trees per hectare between planted, naturally regenerated and primary forest?*
- *Is there a significant difference in crown classes between planted, naturally regenerated and primary forest?*

2. Methods

2.1 Study area

Cloudbridge Nature Reserve is located in the south-central region of Costa Rica, on the southern slopes of the Talamanca mountain range and adjacent to Chirripó National Park in the east and to Talamanca Nature Reserve in the northwest (see figure 1). It covers almost 300 hectares with an elevation range from 1500 to 2600 meters above sea level and with a precipitation of around 4300 mm a year (Spek, 2011). This is without taking into account the water obtained directly by the trees, mosses and ferns from clouds and fog.

Only a small part of the reserve contains primary forest (around 50 ha). The majority is planted and naturally regenerated forest of former pasture or farmland. The planted areas are 15 years at the oldest and are maintained regularly. The naturally regenerated areas vary widely in age from around 9 up to 50 years. Everything older than 70 years, and which has never been touched, is considered primary forest. The naturally regenerated areas between 30 and 50 years old are considered secondary forest and were excluded from this analysis. This is because they are too far in their successional stage compared with the relatively young planted areas to make good comparisons.

Throughout the reserve there are 24 plots (see figure 1), however, only 20 of them were used for this assessment. The planted areas are represented by 7 plots, the naturally regenerated areas by 10 plots and the primary by 3 plots. Four plots were left out of the assessment since they do not completely represent the three forest types. That is, plot 14 contains naturally regenerated forest of more than 30 years old which is considered secondary forest. Plot 18 and 20 contain naturally regenerated as well as planted habitats, and plot 33 includes two different ages of regeneration.

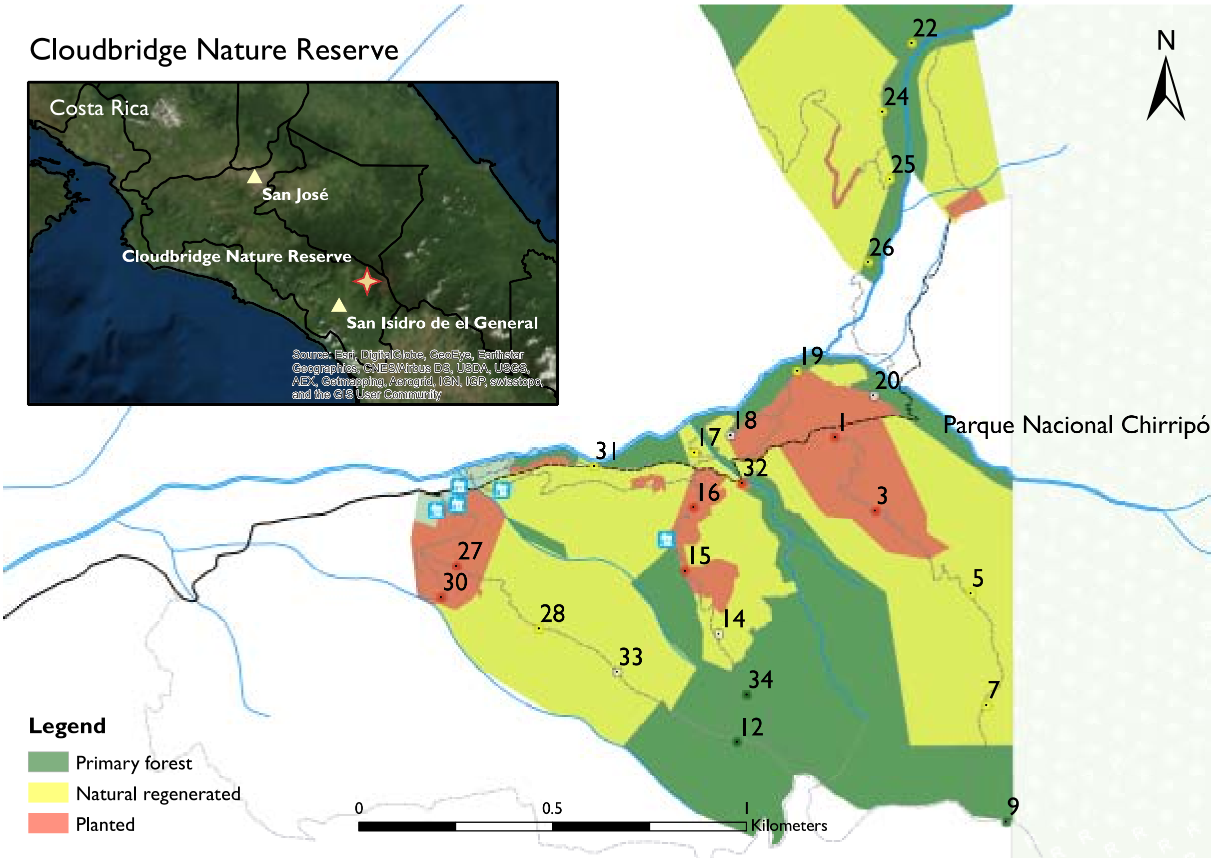

Figure 1 *Map of Cloudbridge Nature Reserve showing forest types and locations of the 24 plots.*

2.2 Data collection

Hence, for the assessment, 20 instead of the 24 available plots have been used. Every plot has a 12.5-meter radius (which gives an area of 490.87 m^2) around a fixed central marker. The borders of the plots are marked with flagging tape. In every plot, all trees with a DBH of 10 cm or higher are tagged with a number. For each tagged tree, the DBH was measured (diameter at breast height), the tree height and volume calculated, crown class determined, and whether the tree was alive or dead recorded. On top of that, the canopy closure per plot was measured. All data was collected in the period of February to July in 2016 and 2017. However, the tree height of 2016 was calculated with a different formula than the tree height of 2017. The way the tree height was calculated in 2016 was updated for the 2017 assessment due to the fact that the former formula was less accurate. For this reason, the height and volume data of 2016 is not used for this research.

DBH (Diameter at Breast Height) measurements

Tree size is classified by measuring the diameter at 1.37 meters from the ground (breast height of an average man). To measure the DBH, a bamboo pole was marked at this specific height. Using the marked pole as a reference, the diameters of the trees were measured with a diameter tape. When a tree was too big for the diameter tape to get around the tree, a normal measuring tape was used to measure the circumference which was later converted to diameter. Trees growing on a slope were measured on the upslope side of the tree. When a trunk of a tree separated into two or more stems (multi-stem) below the 1.37 meter mark all stems were measured at the DBH height. Trees that were partly in a plot were considered inside of the plot when half or more of the trunk was within the plot.

Tree height measurements and calculations

To measure tree height, the Pythagorean theorem was used. First the eye height of the observer (x) was measured. This eye height was then marked on a bamboo pole. Using the marked pole, the observer's eye height was marked on the tree trunk. Whereupon the observer walked away from the tree till both the top of the tree and the eye height on the trunk were clearly visible. Next the distance from the observer's eye height on the tree to the eye height of where the observer was standing was measured (d). Using a clinometer, the angle to the observer's eye height on the tree (a) and the angle to the top of the tree (b) were determined. To avoid measurement errors, the angle to the top of the tree was never larger than 80 degrees. The actual tree height was calculated using the formula as shown in figure 2.

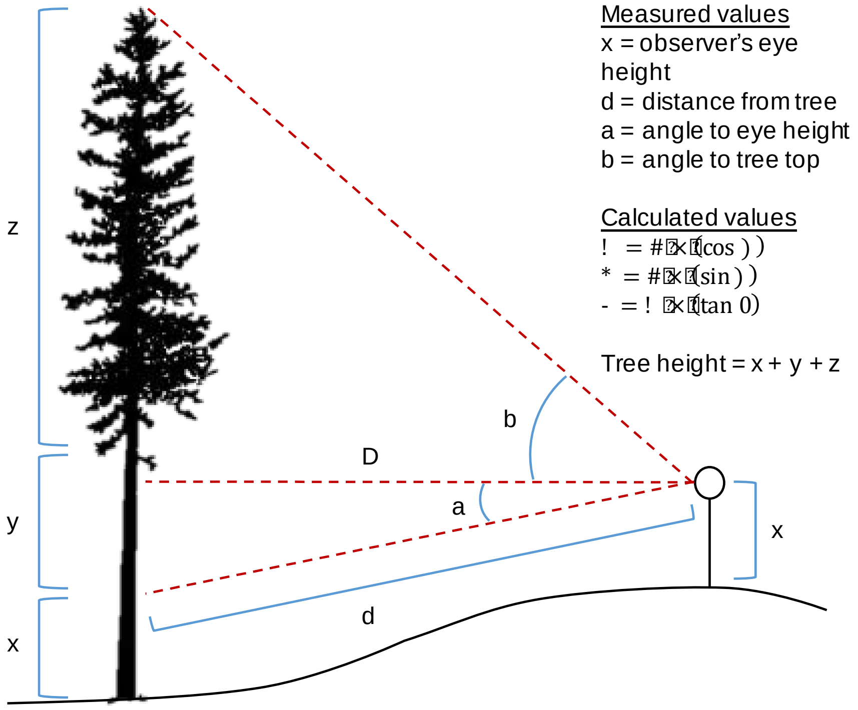

Figure 2 *Measured values and calculations based the Pythagorean theorem to calculate tree height*

Volume calculation

The volume of a tree was calculated according to the simple formula: $V = \pi * (\frac{DBH/100}{2})^2 * height$. When a tree had more than one stem and thus more than one DBH measured, the square root of these diameters was used to calculate the volume of the tree. Because of this, the outcomes of the volume calculations are rough estimates.

Crown class measurement

To determine the dominance of a tree, the crown of each tree was placed within a class based on their canopy.

1. Dominant trees; their crowns are above the canopies of neighbouring trees, standing out a bit from the rest. 80% or more of its canopy is fully exposed to the full sun.
2. Codominant trees; their crowns intermingle with many others, with 50-80% of its canopy fully exposed to the full sun.
3. Intermediate trees; their crowns are mostly below the height of others in the stand, receiving 20-50% of the full sun.
4. Suppressed trees; their canopies are completely below the height of all stand mates, they receive almost no direct sunlight.

Canopy closure measurements

Canopy closure of all 20 plots throughout the reserve was measured in June 2017. To measure canopy closure per plot a densiometer was used. How to read a densiometer is shown in figure 3. Within every plot, five survey points were set out. The centre point is exactly in the middle of the plot where the plot marker is located. The other four points are set out 8 meters away from the centre in a north, east, south and west direction (see figure 4). At each survey point using the densiometer, four measurements were done, also in a north, east, south and west direction. Next those four measurements were averaged giving the closure in percentage per survey point.

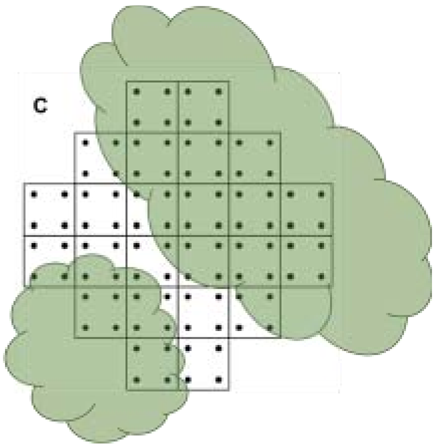

Figure 3 *To measure canopy closure imagine a dot in every corner of the 24 squares. Count all dots that are covered in shade. Times this number with 1.04 giving the percentage canopy closure.*

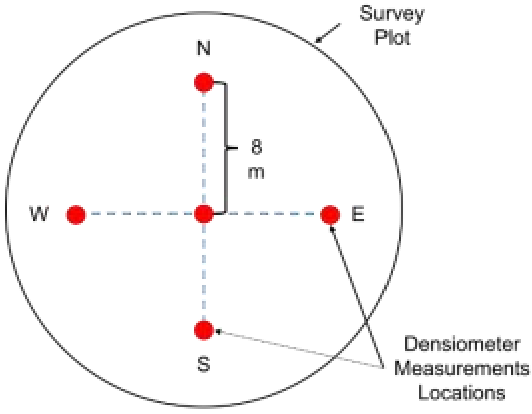

Figure 4 *The five measurements points within a survey plot set out in a north, east, south, west direction and one point in the centre of the plot.*

2.3 Data analysis

To analyse the DBH increment per individual tree from 2016 to 2017, the percentage increase was used. This was calculated according to the formula:

$$DBH2017 - DBH2016 / _{DBH2017} * 100.$$

The percentage increase was then used for the statistical analysis instead of working with the actual growth in centimetres. This was done to point out the relative DBH increment per tree.

For this assessment three different statistical tests were used: One-Way and Two-Way ANOVA, and Kruskal-Wallis. All data first went through a normality test to analyse whether or not the data was normally distributed. The collected data for the number of trees per hectare and the crown class per habitat type appeared to have a normal distribution ($P>0.05$). Based on this, the parametrical tests One-Way and Two-Way ANOVA were used to analyse significance in the number of trees and crown class, respectively. To analyse whether there was a significant difference in DBH, height, volume and canopy closure the non-parametric, Kruskal-Wallis test was used since this data was not normally distributed.

When comparing the DBH data of 2016 and 2017, some measurement errors where found - that is, several trees had shrunk or grown so much it most likely was a measurement error. All those trees were left out of the analysis. To determine whether a tree had grown too much to be realistic, the theoretical possible growth per tree was calculated. Based on a mean annual increment of 1.5 cm for tropical trees (Clark & Clark, 1999; Karyati, Jusoh, & Wasli, 2017; Kueh Jui Heng, et al., 2011; Schneider, et al., 2013; Singh, 2015), the formula used to calculate the possible growth per tree was:

$$DBH2017 - (DBH2016 * 1.5).$$

All trees with an increase in DBH larger than the calculated theoretical limit were excluded from the analysis.

3. Results

Difference in DBH Increment

Planted areas had a median increase in DBH of 5.7% between 2016 and 2017, with naturally regenerated areas at 3.4%, and primary areas the lowest at 1.3%. The growth ranges from 0% DBH increment to 20% for both planted and naturally regenerated areas (see figure 5). The maximum increment in centimetres in the planted plots was 3.0 cm, 6.9 cm for naturally regenerated, and 8.5 cm for primary forest (see appendix 1).

The Kruskal-Wallis test gives a P-value of P=<0.0001 which indicates a significant difference between the DBH increment of the measured trees of planted, naturally regenerated and primary forest plots within the year 2016 to 2017. Based on this it can be stated that planted forest habitats generally had a 1.7 times higher DBH increment over the year 2016-2017 (see table 1), compared to naturally regenerated habitats.

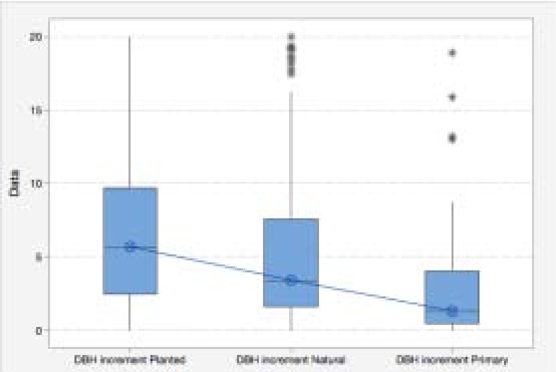

Figure 5 *Boxplot of the difference in DBH increment per forest type*

Table 1 *Descriptive statistics of the difference in DBH increment per forest type*

Descriptive Statistics

Sample	N	Median	Mean Rank	Z-Value
DBH increment Planted	61	5,7	144,2	3,01
DBH increment Natural	137	3,4	122,3	0,33
DBH increment Primary	43	1,3	83,9	-3,85
Overall	241		121,0	

Difference in DBH

Trees within the naturally regenerated plots had a median DBH of 20.0 cm compared to a median of 16.7 cm for planted, and 19.0 cm for primary forest (see table 2). While the DBH range in the primary areas was much higher than the other two habitat types (up to 167.1 cm as can be seen in figure 6), overall, there were more trees with a larger DBH in the natural regeneration areas.

The Kruskal-Wallis test gives a P-value of P=0.0205 which indicates a significant difference between the DBH of the measured trees of planted, naturally regenerated, and primary forest plots. Based on this it can be stated that naturally regenerated forest habitats generally have trees with a larger DBH than trees within primary habitats, with planted habitats having the smallest DBHs.

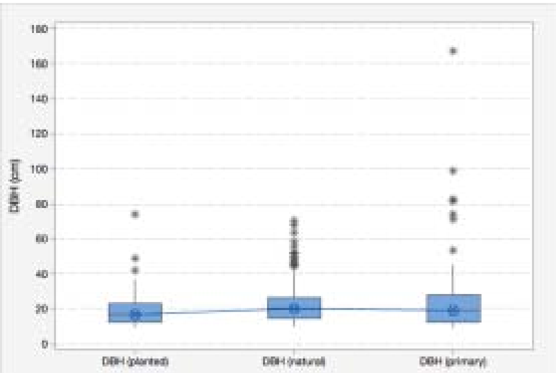

Figure 6 *Boxplot of the difference in DBH per forest type*

Table 2 *Descriptive statistics of the difference in DBH per forest type*

Descriptive Statistics

Sample	N	Median	Mean Rank	Z-Value
DBH (planted)	117	16,7	184,4	-2,78
DBH (natural)	211	20,0	224,2	2,23
DBH (primary)	93	19,0	214,5	0,32
Overall	421		211,0	

Difference in Tree Height

Trees within primary forest plots had a median height of 14.4 m and a wider range in height than planted and naturally regenerated plots, with an extreme value of 64.5 m (see figure 7), compared to a median of 10.5 m for planted and 12.4 m for naturally regenerated forest (see table 3).

The Kruskal-Wallis test gives a P-value of P=0.0170 which indicates a significant difference between the height of the measured trees of planted, naturally regenerated, and primary forest plots. Based on this, it can be stated that primary forest habitats generally contain taller trees than naturally regenerated habitats, which have taller trees than planted habitats.

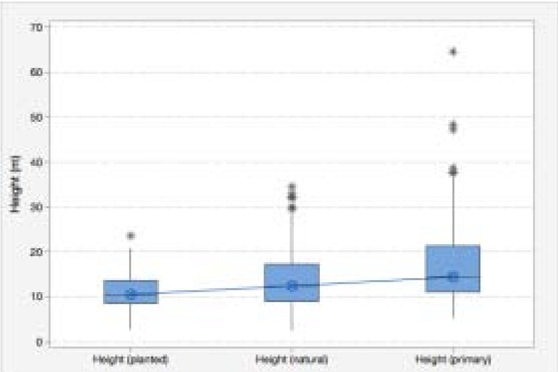

Figure 7 *Boxplot of the difference in tree height per forest type*

Table 3 *Descriptive statistics of the difference in tree height per forest type*

Descriptive Statistics

Sample	N	Median	Mean Rank	Z-Value
Height (planted)	116	10,5	163,2	-4,89
Height (natural)	210	12,4	213,9	0,66
Height (primary)	93	14,4	259,5	4,47
Overall	419		210,0	

Difference in Volume

Trees within primary forest plots had a median volume of 0.44 m^3 compared to a median of 0.25 m^3 for planted and 0.38 m^3 for naturally regenerated forest. Again, the primary forest areas have an extreme value, up to 141.34 m^3, due to the fact that these primary forest plots contained several tall and wide trees (see figure 8). In this case though, the 141.34 m^3 is not realistic since the volume calculations are not accurate enough.

The Kruskal-Wallis test gives a P-value of P=0.0011 which indicates a significant difference between the volume of the measured trees of planted, naturally regenerated and primary forest plots. Based on this it can be stated that primary forest habitats generally contain trees with a larger volume than naturally regenerated habitats, which have trees of larger volume than planted habitats. The boxplot of the volume per habitat type does not show the two outlier volumes (36.14 m^3 and 141.34 m^3) since the boxplot was not readable otherwise (see table 4).

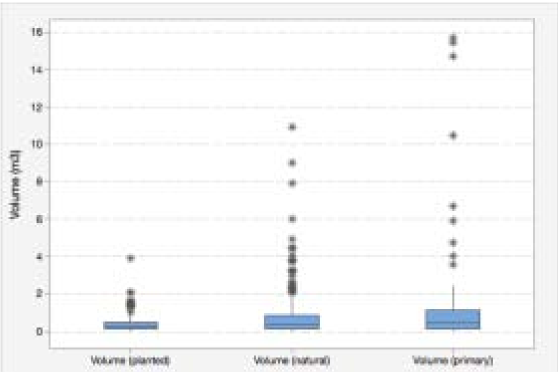

Figure 8 *Boxplot of the difference in volume per forest type*

Table 4 *Descriptive statistics of the difference in volume per forest type*

Descriptive Statistics

Sample	N	Median	Mean Rank	Z-Value
Volume (planted)	116	0,25	175,5	-3,61
Volume (natural)	210	0,38	219,7	1,64
Volume (primary)	93	0,44	231,1	1,90
Overall	419		210,0	

Difference in Crown class

The Two-Way ANOVA test gives a P-value of P=0.0120 which indicates a significant difference between the crown classes of the measured trees of planted, naturally regenerated and primary forest plots. Based on this, it can be stated that planted forest plots contain the highest number of crown class 1 trees with a mean of 8.7 trees compared to a mean of 5.1 for naturally regenerated and 5.7 trees for primary forest. Crown class 2 trees are most present in naturally regenerated forest with an average of 6.4, and trees with crown classes 3 and 4 occur most in primary forest plots with an average of 11.0 and 10.7 respectively (see figure 9).

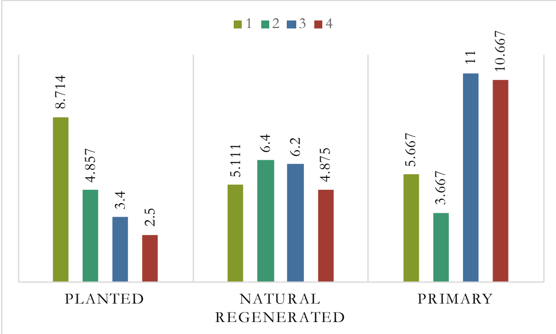

Figure 9 *Graph showing the means of number of trees per crown class per forest type*

Difference in Canopy closure

The Kruskal-Wallis test gives a P-value of P<0.0001 which indicates a significant difference between the canopy closure of the planted, naturally regenerated and primary forest plots. Based on this, it can be stated that naturally regenerated forest habitats generally have a denser canopy than planted and primary habitats with a median canopy closure of 97.2 % compared to a median of 88.7 % for planted and a median of 93.9 % for primary forest (see table 5). Although it should be noted that the canopy closure for naturally regenerated forest has a big range in contrast to a relatively small and consistent range for primary forest (see figure 10).

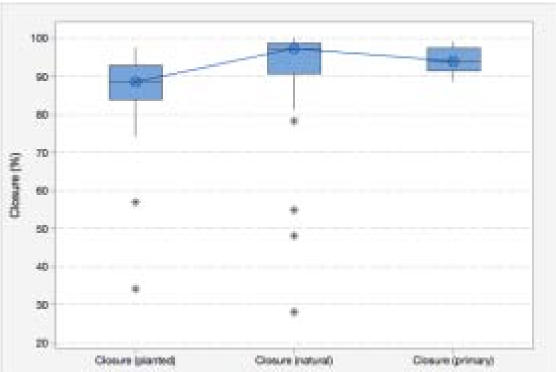

Figure 10 *Boxplot of the difference in canopy closure per forest type*

Table 5 *Descriptive statistics of the difference in canopy closure per forest type*

Descriptive Statistics

Sample	N	Median	Mean Rank	Z-Value
Closure (planted)	35	88,7	30,7	-5,00
Closure (natural)	50	97,2	62,4	4,10
Closure (primary)	15	93,9	57,0	0,94
Overall	100		50,5	

Difference in Number of trees

The mean number of trees within the primary forest plots was 31.0, compared to 16.7 trees in planted, and 21.1 in naturally regenerated plots (see table 6). Per hectare this would be: 631 trees per hectare for primary forest, 409 trees per hectare for naturally regenerated, and 340 trees for planted areas.

The One-Way ANOVA test gives a P-value of P=0.1381 which indicates there is no significant difference between the number of trees per plot in the planted, naturally regenerated, and primary forest habitat types. Although the primary forest plots typically had more trees, the variances are too big for the results to be significant due to the fact there were not enough sample plots (see figure 11).

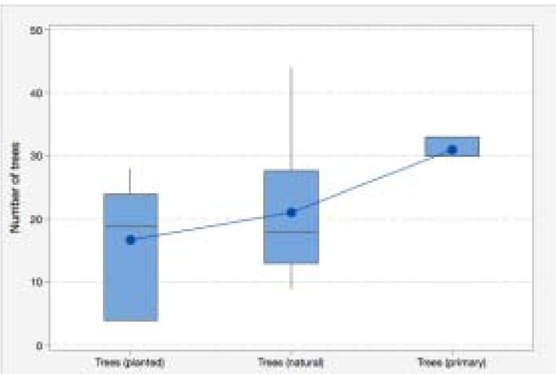

Figure 11 Boxplot of the difference in number of trees per forest type

Table 6 *Means of number of trees per forest type*

Means

Factor	N	Mean	StDev	95% CI
Trees (planted)	7	16,714	9,464	(8,895; 24,533)
Trees (natural)	10	21,100	11,010	(14,558; 27,642)
Trees (primary)	3	31,000	1,732	(19,057; 42,943)

Pooled StDev = 9,80495

4. Conclusion and discussion

The results of the data analyses indicate a difference in recovery based on forest structure between planted and naturally regenerated forest when compared to primary tropical cloud forest. Looking at the data of 2017, naturally regenerated areas are in a further successional stage towards primary forest than the planted areas. DBH, as well as height, volume and canopy closure have higher medians in naturally regenerated plots compared to planted plots. However, this difference could be explained due to the fact that the plots within the naturally regenerated areas are older on average than the planted areas (15 and 10 years on average, respectively). So, the fact that naturally regenerated forest has a further developed forest structure at this moment does not necessarily say it is recovering faster.

A number of planted areas were planted because the forest was struggling to come back on its own. For some reason, these areas were less suitable for the forest to recover by itself. However, when taking the DBH increment into account, planted plots are recovering faster. With a median of 5.4% the increment over the year 2016-2017 is 1.7 times higher than the DBH increment within naturally regenerated plots. This is probably due to the spacing in which the trees are planted and the clearing and maintenance of undergrowth that is carried out several times per year. Because the planted trees have more space, they have less competition from neighbouring trees in both nutrient uptake and sunlight availability. Clearing of undergrowth like ferns, climbers and shrubs also enhances nutrient uptake and sunlight availability in the early stages of the planted trees. Another factor that can be of influence on the higher DBH increment could be the fact that the planted areas are on the more accessible parts of the reserve. In most situations, the naturally regenerated areas have not been planted because they are too steep to safely plant trees or even inaccessible. The steepness has also an effect on how suitable it is for trees to grow. That is, the steeper a slope, the more soil and nutrients run off.

To be able to say more about the effect of the steepness bias and to get a better understanding on the overall recovery speed, there are some improvements that can be made for further research. Firstly, the annual height increment should be included next to the DBH to get a better idea of the growth speed. Secondly, including the trees with a DBH from 5 to 10 cm to the assessment. This would likely double the number of trees in each plot and thus provides a more reliable dataset. Thirdly, an inventory of the slope percentages within the plots could help to assess whether or not there is a link between the type of forest and the steepness, and thus if there is a slope bias. Finally, it could also be useful to identify more tree species and compare species composition to get a better understanding in how similar planted and naturally regenerated plots are to primary forest plots.

Overall, it can be concluded that either way, both planting and natural regeneration are good ways to let the forest recover to its former state. However, although naturally regenerated areas resemble the primary forest structure more closely at this moment, planted areas are recovering faster. The effort Cloudbridge put in replanting the area is clearly showing its results.

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Appendices

Appendix 1A: DBH increment in centimetres for planted plots

DBH increment per tree in Planted plots			
Tree nr.	DBH 2016 (cm)	DBH 2017 (cm)	Increment
17	12.0	12.0	0.0
216	14.5	14.5	0.0
40	16.3	16.4	0.1
217	36.0	36.1	0.1
487	26.9	27.0	0.1
477	18.1	18.3	0.2
450	11.7	11.9	0.2
474	23.2	23.5	0.3
475	16.5	16.8	0.3
486	15.1	15.4	0.3
61	13.0	13.3	0.3
396	10.0	10.3	0.3
231	21.0	21.4	0.4
57	19.7	20.1	0.4
558	24.0	24.5	0.5
30	18.4	18.9	0.5
480	17.2	17.7	0.5
232	14.0	14.5	0.5
34	21.7	22.3	0.6
22	16.0	16.6	0.6
234	48.3	48.9	0.6
488	13.8	14.5	0.7
222	15.0	15.8	0.8
473	12.3	13.2	0.9
483	21.7	22.6	0.9
464	28.4	29.4	1.0
305	19.0	20.0	1.0
29	18.3	19.4	1.1
463	19.4	20.5	1.1
229	28.5	29.7	1.2
38	11.0	12.2	1.2
456	15.4	16.7	1.3
226	27.0	28.3	1.3
482	14.1	15.4	1.3
66	22.8	24.2	1.4
5	20.5	21.9	1.4
409	23.0	24.5	1.5
393	14.5	16.0	1.5
453	10.3	11.8	1.5
42	16.7	18.3	1.6
484	15.0	16.7	1.7
470	10.0	11.9	1.9
304	19.0	21.0	2.0
209	21.1	23.2	2.0
302	32.5	34.5	2.0
43	16.0	18.2	2.2
227	28.0	30.2	2.2
8	17.0	19.2	2.2
543	10.0	12.2	2.2
306	31.0	33.2	2.2
56	12.5	14.7	2.2
210	10.5	12.8	2.3
303	17.5	19.9	2.4
407	13.5	15.9	2.4
59	71.6	74.1	2.5
406	17.5	20.0	2.5
211	10.5	13.1	2.6
223	26.0	28.7	2.7
471	12.4	15.1	2.7
476	28.4	31.4	3.0
408	12.0	15.0	3.0

Appendix 1B: DBH increment in centimetres for naturally regenerated plots

DBH increment per tree in Naturally Regenerated plots			
Tree nr.	DBH 2016 (cm)	DBH 2017 (cm)	Increment
2	14.8	14.8	0.0
97	13.0	13.0	0.0
110	15.5	15.5	0.0
126	34.5	34.5	0.0
150	21.0	21.0	0.0
187	29.0	29.0	0.0
253	26.5	26.5	0.0
256	25.0	25.0	0.0
363	12.9	12.9	0.0
381	25.8	25.8	0.0
428	18.7	18.7	0.0
506	36.9	36.9	0.0
509	20.4	20.4	0.0
540	13.8	13.8	0.0
119	12.0	12.1	0.1
541	20.8	20.9	0.1
21	10.9	11.0	0.1
107	10.5	10.6	0.1
367	10.3	10.4	0.1
368	20.0	20.1	0.1
154	27.0	27.2	0.2
436	19.5	19.7	0.2
513	16.6	16.8	0.2
135	15.5	15.7	0.2
353	11.5	11.7	0.2
87	11.0	11.2	0.2
273	11.0	11.2	0.2
116	10.0	10.2	0.2
437	11.2	11.4	0.2
248	47.0	47.2	0.2
279	17.5	17.8	0.3
512	28.4	28.7	0.3
361	25.3	25.6	0.3
537	17.9	18.2	0.3
101	13.0	13.3	0.3
297	13.0	13.3	0.3
128	13.6	14.0	0.3
295	22.0	22.4	0.4
430	31.6	32.0	0.4
432	22.0	22.4	0.4
538	21.3	21.7	0.4
143	18.5	18.9	0.4
369	14.6	15.0	0.4
206	10.5	10.9	0.4
192	10.0	10.4	0.4
269	10.0	10.4	0.4
252	33.2	33.7	0.5
82	36.5	37.0	0.5
92	31.0	31.5	0.5
444	24.0	24.5	0.5
201	23.0	23.5	0.5
88	22.0	22.5	0.5
365	21.2	21.7	0.5
497	20.0	20.5	0.5
246	16.0	16.5	0.5
245	10.0	10.5	0.5
185	14.6	15.1	0.5
121	17.5	18.0	0.5
370	11.6	12.2	0.6
448	26.9	27.5	0.6
280	19.2	19.8	0.6
189	18.5	19.1	0.6
239	23.0	23.7	0.7
539	23.0	23.7	0.7
147	11.0	11.7	0.7
357	66.8	67.6	0.8
96	47.0	47.8	0.8
360	27.0	27.8	0.8

259	17.0	17.8	0.8
429	12.5	13.3	0.8
11	32.8	33.6	0.8
426	36.6	37.5	0.9
545	35.5	36.4	0.9
366	12.6	13.5	0.9
98	12.0	12.9	0.9
289	26.7	27.7	0.9
286	11.2	12.2	0.9
508	29.7	30.7	1.0
195	29.0	30.0	1.0
137	23.5	24.5	1.0
103	10.0	11.0	1.0
354	30.3	31.4	1.1
114	14.0	15.1	1.1
362	31.0	32.1	1.1
199	11.5	12.7	1.2
144	33.5	34.7	1.2
140	24.0	25.3	1.3
94	13.0	14.4	1.4
358	12.9	14.3	1.4
418	29.5	31.0	1.5
158	23.5	25.0	1.5
439	22.3	23.8	1.5
445	20.2	21.7	1.5
145	17.5	19.0	1.5
129	23.1	24.6	1.6
505	22.1	23.7	1.6
120	31.0	32.6	1.6
359	22.2	23.8	1.6
191	11.0	12.6	1.6
442	18.0	19.7	1.7
148	35.0	36.8	1.8
449	26.8	28.6	1.8
109	22.0	23.8	1.8
3	30.4	32.2	1.8
35	37.7	39.6	1.9
443	34.6	36.5	1.9
111	20.0	21.9	1.9
420	14.1	16.0	1.9
197	13.0	14.9	1.9
130	22.0	24.0	2.0
415	35.8	38.0	2.2
440	32.0	34.2	2.2
173	18.0	20.3	2.3
152	10.0	12.3	2.3
155	33.0	35.5	2.4
168	26.4	28.9	2.4
174	42.5	45.0	2.5
490	11.0	13.5	2.5
115	13.5	16.1	2.6
546	19.5	22.1	2.6
151	18.5	21.2	2.7
166	15.0	17.7	2.7
423	21.4	24.4	3.0
180	13.5	16.7	3.2
169	14.5	17.7	3.2
494	16.8	20.0	3.3
134	24.3	28.0	3.7
131	18.3	22.2	3.9
108	66.5	70.5	4.0
424	31.8	36.1	4.3
547	18.0	22.3	4.3
417	18.6	23.0	4.4
299	28.5	33.3	4.8
146	20.0	25.0	5.0
33	31.7	36.7	5.0
291	36.7	42.7	6.0
205	32.7	39.6	6.9

Appendix 1C: DBH increment in centimetres for primary forest plots

DBH increment per tree in Primary forest plots			
Tree nr.	DBH 2016 (cm)	DBH 2017 (cm)	Increment
333	23.5	23.5	0.0
338	11.0	11.0	0.0
347	12.2	12.2	0.0
375	10.0	10.0	0.0
516	19.0	19.0	0.0
525	18.5	18.5	0.0
531	10.2	10.2	0.0
527	24.8	24.9	0.1
383	12.5	12.6	0.1
388	12.0	12.1	0.1
553	29.0	29.1	0.1
554	14.7	14.8	0.1
378	10.2	10.3	0.1
514	28.5	28.7	0.1
325	19.0	19.2	0.2
321	16.5	16.7	0.2
518	15.3	15.5	0.2
389	15.9	16.1	0.2
310	44.5	44.7	0.2
552	33.0	33.2	0.2
524	22.8	23.1	0.3
551	10.5	10.8	0.3
337	16.0	16.4	0.4
330	38.0	38.5	0.5
350	30.5	31.0	0.5
343	21.0	21.5	0.5
328	19.5	20.0	0.5
323	14.5	15.1	0.6
530	26.3	27.0	0.7
386	31.0	31.7	0.7
517	25.3	26.2	0.9
329	10.5	11.5	1.0
326	42.0	43.1	1.1
314	25.2	26.6	1.3
534	43.0	44.8	1.8
385	28.4	30.4	2.0
315	69.0	71.3	2.3
324	13.0	16.0	3.0
331	20.0	23.0	3.0
523	23.1	26.5	3.4
379	77.4	81.5	4.1
313	94.0	98.7	4.7
340	45.0	53.5	8.5