Reforestation practices at Cloudbridge Nature Reserve, Costa Rica

A study on the differences in forest structure between primary cloud forest, natural regeneration and replanted areas

Fleer, Michon

CLOUDBRIDGE NATURE RESERVE

van hall larenstein university of applied sciences

Reforestation practices
at Cloudbridge Nature Reserve, Costa Rica

A study on the differences in forest structure between primary cloud forest, natural regeneration, and planted areas

Bachelor thesis at
Van Hall Larenstein University of Applied Sciences, Velp, The Netherlands

Course:	Forest and Nature Management
Specialization:	Tropical Forestry

Author:	Michon Fleer
Internal Supervisor:	Peter van der Meer Van Hall Larenstein University of Applied Sciences (VHL), The Netherlands
External Supervisor:	Jennifer Powell, Scientific Coordinator, Cloudbridge Nature Reserve, Costa Rica

Place:	Velp, The Netherlands
Date:	8-31-2017

Abstract

In this study, the forest structure of primary cloud forest in Costa Rica was compared with the forest structure of natural regeneration and replanted areas. This was done to inform Cloudbridge Nature Reserve on which reforestation practice i.e. natural regeneration or replanting is most useful to carry out in the succession towards primary cloud forest. The study was conducted in 9 circle plots, spaced throughout the habitat types in the Reserve, by measuring the DBH and height of the trees, the canopy cover of the plots, and determining the crown class of each tree. Furthermore, the amount of standing dead trees, tree density and basal area was determined for each habitat type. Data analysis resulted in a significant difference in DBH, height, canopy cover and basal area between primary cloud forest, natural regeneration and replanted areas. These differences were especially caused by a significant variation in forest structure between primary forest and replanted areas. This indicates more similarity between primary forest and natural regeneration. In the current developmental phase of forest restoration, replanted areas and naturally regenerated areas were close to similar. Therefore, replanting does not yet seem to influence forest succession. This shows that, currently, natural regeneration and replanting are equally effective as reforestation method to carry out. This realization will help Cloudbridge Nature Reserve in making informed decisions on which reforestation method to pursue in the future.

Key words: Cloud forest, Cloudbridge Nature Reserve, Costa Rica, forest structure, natural regeneration, primary forest, replanting

Acknowledgements

First of all, I would like thank my supervisor at Cloudbridge Nature Reserve, Jennifer Powell, for guiding me during the first phases of establishing myself and throughout the rest of the study. I want to thank Mathijs van der Sanden for enthusiastically working with me on the study from the beginning and consistently updating the fieldwork schedule according to consultations between him and myself. I want to thank my supervisor at Van Hall Larenstein, Peter van der Meer, for his overall guidance, critical review on concept versions of the report and his suggestions about what possibly to include in the study. I would also like to thank Cloudbridge director Tom Gode and his wife Linda Moskalyk for the opportunity to conduct my thesis research at the organisation, with special thanks to Tom for his guidance with species identification on one of the first days and explaining about Cloudbridge and their activities. Furthermore, I want to thank the general manager, Frank Spooner, for challenging Mathijs and me with a tough hike on the first day we went into the reserve. Finally, I want to thank Laura Cannon, a volunteer from the UK, for assisting me with the tree measurements in the last plots.

List of Abbreviations

Abbreviation	**Full name/ description**		
CNR	Cloudbridge Nature Reserve		
GIS	Geographic Information System		
VHL	Van Hall Larenstein University of Applied Sciences		
ANOVA Test	Analysis Of Variance Test		
DBH	Diameter at breast height		
N/ha	Number per hectare		
Post-Hoc Test	A test with which to determine between which of three or more variables there is a significant difference.		
P-value	Probability value. This indicates the probability that two or more means have been drawn from the same set of samples.		
cm	Centimeter	=	0.01 meter
cm^2	Square centimeter		
cos	Cosine		
km^2	Square kilometer		
m	Meter		
m^2	Square meter		
ha	Hectare	=	10.000 square meter
sin	Sinus		
%	Per cent		
tan	Tangent		

Table of Contents

1 Introduction and context of the study

Currently the area of forest in Costa Rica accounts for 51.5% of the land area that approximates 51060 km^2 (Central Intelligence Agency). With a water surface area of 40 km^2, the total area of forest and nature in Costa Rica is 26335,9 km^2. However, the forests of Costa Rica are threatened by deforestation, which is largely a result of land clearance for cattle ranching and agriculture, which nowadays account for 37.1% of the land use of Costa Rica. From 1980 deforestation rates declined and Costa Rica has seen stabilization of forest cover and even an increase in reforestation ever since (Vallet, et al., 2016; Allen & Padgett Vásquez, 2017). Drivers of such a forest transition are thought to be result of the three land use processes (1) land use displacement through international trade of land-based products, (2) land use intensification in agriculture and forestry, allowing for land sparing, and (3) this intensification may in part result from a geographical redistribution of land use at the sub-national level to better match land use with land suitability (Jadin, Meyfroidt, & Lambin, 2016).

Tropical forests are used for ecosystem goods and services like timber, non-timber forest products, soil stabilization or enhancement of water catchments (Alamgir, Turton, Macgregor, & Pert, 2016). Other uses include biodiversity conservation, ecotourism and carbon storage to mitigate climate change (Sasaki, et al., 2016). Reforestation in degraded and deforested areas is supposed to contribute significantly to the abovementioned topics. This is important for the use of forests by future generations and for conservation of unique biodiversity. Equally, reforestation is important for mitigating climate change, research in the fields of environment and ecology, and education (Cloudbridge Nature Reserve).

Cloud forests account for 2,5 per cent of the total area of tropical forests globally, making them a rare and fragile ecosystem (Bubb et al. 2004). These are characterized by a high level of biodiversity and are home to many endemic species, making cloud forests important as these moisture-reliant species use cloud forests to survive, even in the dry season (Cloudbridge Nature Reserve). In turn, some species have important functional roles for ecosystem processes within cloud forests, for example epiphytes regulating water flow (Gotsch, Nadkarni, & Amici, 2016). Cuni-Sanchez et al. (2017), state that cloud forests (also known as tropical montane forests) make up 8% of the world's tropical forests. Cloud forests are further important for ecosystem services like carbon storage, freshwater production and landscapes of scenic beauty (Toledo-Aceves, Meave, González-Espinosa, & Ramírez-Marcial, 2010). Because cloud forests have the capacity to intercept moisture from clouds and thus depend on clouds for moisture, they are very vulnerable to climatic changes that negatively impact weather conditions (DeLyser, 2015). Furthermore, being of small proportion globally, they are highly susceptible to fragmentation as a result of land clearance for agriculture and forestry (Martínez, et al., 2009).

Cloudbridge Nature Reserve (CNR) in Costa Rica is a privately-owned reserve covering 280 hectares of previous (pre-) montane tropical cloud forest. Most of the land had been cleared for cattle ranches and small subsistence farms from 1950 onwards. The Reserve was founded by an ex- South African couple, Ian and Genevive Giddy, that came back one day from climbing Mount Chirripó and were astonished by the pace of deforestation in the area in those days. They decided to come back one day, buy some land, and just let the trees grow. In addition, they started a tree planting program. Founded in 2002, CNR functions as a reforestation project, environmental education center and research station, which is dedicated to creating a biological corridor to link the Talamanca Reserve and other remnant patches of forest in the area to Chirripó National Park, and to helping the forest return to its natural mature state (DeLyser, 2015; J. Powell, personal communication, April 26, 2017). Additional aims of the Reserve are to conduct research on a permanent base and to visualize the forest development in the area.

Various reforestation or forest restoration techniques are known and can be implemented to reforest an area. Reforestation is defined as changing previously deforested land back to forest land (Introduction, 2004).
According to the article *Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Lands* of Chazdon (2008), outcomes of particular reforestation methods are:

1. Restoration of soil fertility for agricultural or forestry use
2. Production of timber and non-timber forest products, or
3. Recovery of biodiversity and ecosystem services

The different reforestation methods found are (Chazdon, 2008):

1. Reclamation
2. Rehabilitation
3. Commercial reforestation/agroforestry
4. Reforestation with native trees
5. Assisted natural regeneration
6. Natural regeneration

To determine reforestation success, generally three ecosystem attributes are assessed. These are: diversity, vegetation structure, and ecological processes (Ruiz-Jaen & Aide, 2005). In their study, Ruiz-Jaén & Aide (2005) defined replanted areas as reforested sites. According to their study, reforestation or forest restoration succes is achieved when a reforested site can be left without further management assistance.
In this study the focus will be on the ecosystem attribute of vegetation structure, from now on referred to by forest structure. In general, forest structure is determined by measuring tree DBH, height (Ruiz-Jaén & Aide, 2005) and canopy structure.

At CNR, the two reforestation methods that are applied as of 2002 are natural regeneration and replanting.
This study is part of the habitat assessment project that was established at CNR in 2016 to monitor reforestation development and determines which of the two reforestation techniques carried out (natural regeneration or active (re)planting) is most effective (J. Powell, personal communication, January 23, 2017).
The importance of the study for CNR is to assess whether its publicly promoted strategy towards reforestation (replanting) does carry any significant effect and to be able to inform visitors on why CNR is pursuing this strategy and how it is carried out. This way, visitors get a better understanding of the purpose of the reforestation project, which in turn enables CNR to attract more donations to finance its activities.
Additionally, this study is relevant as a methodological reference for future research.

1.1 Problem definition

The goal of CNR is to bring back natural cloud forest to link the Talamanca Reserve and other forest patches to Chirripó National Park by reforesting the area.
However, there is a lack of knowledge about the most effective method of reforestation in CNR i.e. natural regeneration vs replanting. Natural regeneration is the process of letting vegetation grow back naturally whereas planted areas have been planted from 2002 onwards.
The lack of knowledge about the effectiveness of the prevailing reforestation methods is problematic for both CNR and Costa Rica.
As for CNR, the organization is dedicated to conserve old growth cloud forest and the biodiversity of this unique tropical forest ecosystem and wants to pursue this goal in the most effective way.
As for Costa Rica, CNR is a contributer to Costa Rica's national carbon neutrality goal (Cloudbridge Nature Reserve).
The intention of the study is to determine which reforestation technique is best producing a forest structure most resembling the remnant old growth forest in the reserve, so that informed choices can be made on the best reforestation practices for the reserve.

1.2 Objective

The objective of the study is to determine which reforestation method used by CNR is most effective.

1.3 Hypothesis

1. *There is a significant difference in forest structure between natural regenerated areas, replanted areas and old growth forest. It is expected that the replanted areas resemble old growth forest the most, especially with respect to DBH –and height class distribution, and canopy cover.*

1.4 Research questions

The research questions to attain the objective and to test this hypothesis are:

1. Is there a significant difference in the forest structure between the natural regenerated areas, replanted areas and old growth forest in terms of:
    a. DBH class distribution
    b. Tree height
    c. Canopy cover
    d. Crown classes
    e. Standing dead trees
    f. Tree density
    g. Basal area

2. What are the consequences of replanting as a reforestation method?

The report will first focus on the methodology used in the study to answer the research questions. Secondly, the data collected in the methodology will be represented in the results, after having performed statistical analysis on the data. Third, the results will be discussed in relation with findings of other studies in the discussion. Furthermore, the limitations of this study will be highlighted in the same section. In the conclusion that follows, the most relevant findings will shortly be summarized.

In the recommendations, hereafter, will then propose subjects and activities for focus of future research. The final part of the report will consist of references and the appendix.

2 Methodology

The methodology describes where, when, and how the study was conducted to get the results for answering the research questions. First, the study area will be described, during which period the study was carried out and in what plot design. The procedure of measurements will describe how the data was collected. The section on how the data was analysed statistically to obtain the results will close the methodology.

2.1 Study area

The study was conducted at CNR, which is located on southern slope of the Talamanca mountain range in the south-central region of Costa Rica. CNR borders the western edge of Chirripó National Park (Fig.14), which is a UNESCO World Heritage Site. Elevation at CNR ranges from 1500 m to 2650 m.

In the reserve 3 forest types can be found, which were studied in this research: Old growth forest, natural regenerated forest and planted forest.
Data was collected from 9 circle plots with a diameter of 25 meters that are spaced throughout these forest types. This was done during the months February until May 2017. All the plots in the reserve were established in 2013 as part of a bird survey at CNR, which is indicated by a draft document of a bird monitoring study data report made by the scientific coordinator of CNR (Powell, 2017). In 2016, CNR began to use these same plots for the habitat assessment to compare the habitats with the bird survey data.

Below, the plots in the various forest types at CNR are described. In addition, the information is given in short in table 1. The reserve and forest types can also be found in figure 1. For a reference map, see figure 14 in appendix 9.6.

1. Old growth forest (Fig.10):
- A current minimum age of 71 years (exact age unknown)
- Elevation of the plots ranges between 1950-2140 m
- Previous habitat type (from beginning of CNR) was old growth forest

2. Natural Regeneration as a reforestation method (Fig.12):
- An age of 15 years currently (regeneration started in 2002)
- Elevation of the plots ranges from 1660-1970 m
- Previous habitat type was pasture

3. Planted areas as a reforestation method (Fig.11):
- An age of 15 years currently (replanting started in 2002)
- Elevation of the plots ranges from 1640-1730 m
- Previous habitat type was pasture
- Of the three plots, two new plots were established in 2017 to accurately compare with even aged natural regeneration.

Table 1. Habitat type information

Use of area	Current Habitat type	Current age	Elevation (m)	Previous Habitat type
Forest	Old Growth	71	1950-2140	Old Growth
Reforestation	1. Nat. Regen.	15	1660-1970	Pasture
	2. Planted	15	1640-1730	Pasture

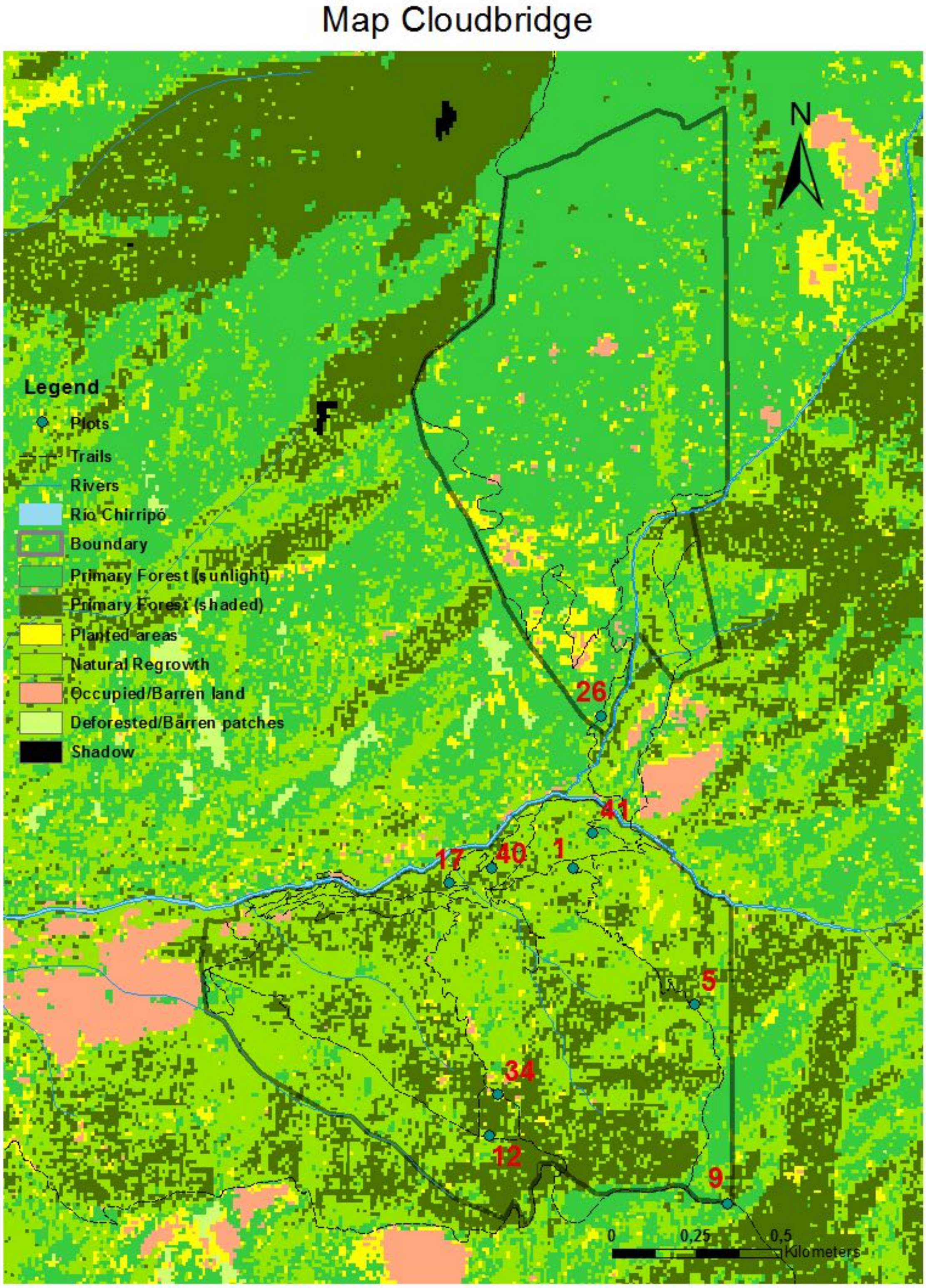


Figure 1. A with GIS generated map of Cloudbridge, surroundings, and sample plot numbers within the reserve (Cloudbridge Nature Reserve; Mathijs van der Sanden, student at Van Hall Larenstein University, 2017)

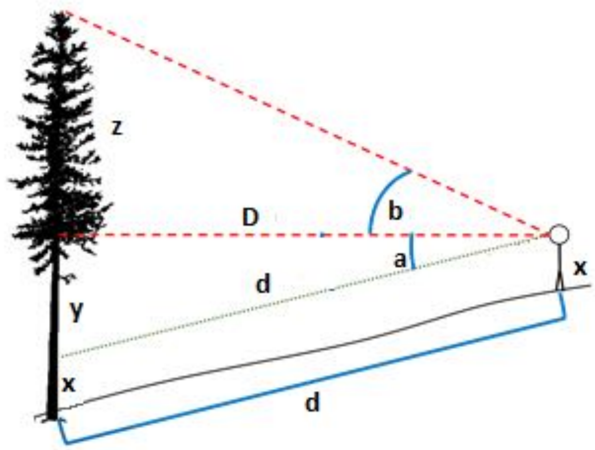
2.2 Procedure of measurements

In this study, **canopy structure**, **DBH** (diameter at breast height), **height** and **crown class** of trees are compared between locations in CNR with different forms of reforestation (natural regeneration, replanted areas and old growth cloud forest).
Furthermore, the **tree density** and the amount of **standing dead trees** per habitat type are determined. Information about DBH and tree density is important because it gives an overview of how large the trees are and how many are present, which together is relevant for determining a forest's rate of seedling establishment.
Canopy structure is assessed as this is important for determining the current development phase of the forest. The amount of standing dead trees is determined because there are of importance for all kinds of fungi, plants and animals and therefore enhancing biodiversity.
Subsequently, the **basal area** for all the trees per habitat type was determined. Basal area is of importance for knowing how much area a tree claims and is useful for managing interactions between individual trees.

DBH
The diameter at breast height (DBH) is an aspect used in forestry to easily measure the diameter of a tree and use this information in possible tree volume and basal area calculations. The universal standard for measuring DBH is at 1,35-1,37 m from the ground. In this study, the standard of 1,37 m was used.
In each plot, trees with a DBH of 10 cm and more were already tagged in 2016 with a unique number (Fig.16). During this study, the trees with a DBH of 5 cm and above were also tagged with a unique number. The tags are used to monitor differences in the future growth of individual trees in the succession towards a vegetation in old growth state. DBH and tree height of each tagged tree in the plot were measured and the average height and DBH calculated for the plot and forest type. In the case of multiple stems per tree (Fig.15), a multi-stem calculation was used to determine the eventual DBH of the tree. In these cases, the square root of the sum of the squared DBHs was taken (Swiecki & Bernhardt, sd). DBH class distributions were determined per forest type. The height of the trees was measured using a clinometer and measuring tape, while DBH was measured using a DBH tape.

Tree height
The tree height was measured by at least two persons using a measuring tape and clinometer. The aspects measured in the field are described below:
- Observers eye height (x)
- Distance to eye height indicated on the tree (d)
- Angle to the eye height indicated on tree (a)
- Angle to treetop (b)

With these measurements, the following was calculated:
- Horizontal distance to the tree (D)
- Height between eye height on tree and horizontal distance (y)
- Remaining height until treetop (z)



Measured Values
x = Observer eye-height
d = Distance to observer eye/ distance from tree along ground to observer
a = Angle to eye-height (degree scale)
b = Angle to treetop (degree scale)

Calculated Values
y = **d** x (sin(**a**))
D = **d** x (cos(**a**))
z = **D** x (tan(**b**))
Tree height = **x** + **y** + **z**

Figure 2. Tree height measurement

The observer chose a location a certain distance from the tree, from which the treetop was comfortably visible. The person standing near the tree indicated the eye height (x) on the tree and held one end of the measuring tape at this height. To measure ‘d’, the observer held the measuring tape at his eye and determined the distance from the ‘x’ indicated on the tree. Since most plots included slopes, the observer chose a location up the hill to take the measurements. After measuring ‘d’, with the clinometer ‘a’ and ‘b’ were measured. With these measurements, the ‘D’, ‘y’ and ‘z’ were determined to calculate the total height of the tree.

Canopy cover
Canopy cover (Fig.18) was measured using a densiometer (Fig.17) at five locations within the plot: the center of the plot, and 8 m North, East, South and West of the center. At each location, four measurements were taken facing respectively the compass directions North, East, South and West, as the canopy cover can differ significantly with small movements of the densiometer. These measurements were pooled together to calculate one average canopy cover per plot. Hereafter, these were calculated per habitat type for statistical analysis.

Crown class
For each tagged tree, the crown class was determined. This determination is done in accordance with *Protocol: Measuring tree diameter, class size, and average species,* Procedure B: Determine the crown class for the tree (Ecoplexity, 2010). The 4 crown classes are:

1. Dominant trees: crowns are above the canopies of neighboring trees, standing out a bit from the rest. With 80% or more of the canopy fully exposed to the full sun.
2. Codominant trees: crowns intermingle with many others, with 50-80% of canopy fully exposed to the full sun.
3. Intermediate trees: crowns are mostly below the heights of others in the stand, receiving 20-50% of the full sun.
4. Suppressed trees: canopies are completely below the heights of others in the stand, receiving almost no direct sunlight.

The measurements were based on two protocols established by CNR, which are mainly developed using the following sources:

- Estimation of forest canopy cover: a comparison of field measurement techniques (Korhonen, Korhonen, Rautiainen, & Stenberg, 2006).
- Forest canopy cover and canopy closure: Comparison of assessment techniques (Paletto & Tosi, 2009).

- Private Native Forestry Code of Practice Guideline No. 4: Techniques for Measuring Stand Height (New South Wales Environmental Protection Authority, 2013).
- Protocol: Measuring tree diameter, class size, and average species diameter (Ecoplexity, 2010).

Dead trees
In addition to the measurements of live stems, dead trees were included in the data collection. Including these individuals is important for possible total tree volume calculations for each habitat type. However, they are also relevant due to their ecological value for animals. A certain amount of standing dead wood is typical for healthy forest ecosystems, providing habitat for a wide variety of animals such as insects, woodpeckers, owls, hawks, and mammals (Grotta, 2013).

Tree density
Besides all the other aspects, the tree density (in trees/ha) per habitat type was measured to determine the differences between old growth forest, areas with natural regeneration and planted areas. Tree density is important to determine a forest's rate of seedling establishment.

Basal Area
The basal area of the trees is calculated with the measured tree DBH. Basal area is important for monitoring and managing interactions between individual trees in a stand.

2.3 Data Analysis

For data collection, the following materials were used: DBH tape, measuring tape, clinometer, densiometer and flagging tape. Data were recorded on field forms and later transferred to computer. As for data analysis, a Shapiro-Wilk Normality Test was used to assess if the frequency distributions significantly differ from a Normal Distribution. The test indicates that the DBH frequency distributions per habitat type are all significantly different than a Normal Distribution, and therefore they do not follow a Normal Distribution. This analysis was also undertaken for the aspect of tree height per Habitat type. The same for the aspects of canopy cover and basal area. For the Normality Test tables per aspect see appendix 9.3.
For comparing the means of the scores on the aspects per habitat type, the data were statistically analysed with a One-Way ANOVA Test (Analysis of Variance) and a Post hoc Test using the Bonferroni Test to assess which two habitat types per aspect account for this difference.

3 Results

In this chapter, the findings of the study are represented by statistically analysed data, having used the procedure of data analysis described in the methodology.

3.1 Findings related to forest structure differences

DBH

In figure 3, a clear difference can be observed in the DBH categories 10-15 cm and 25-30 cm between planted areas and the other two habitat types. Most trees per ha in each habitat type were found in DBH class 5-10 cm. With increasing DBH, the figure shows less trees per ha in naturally regenerated and planted areas, and more in old growth forest.

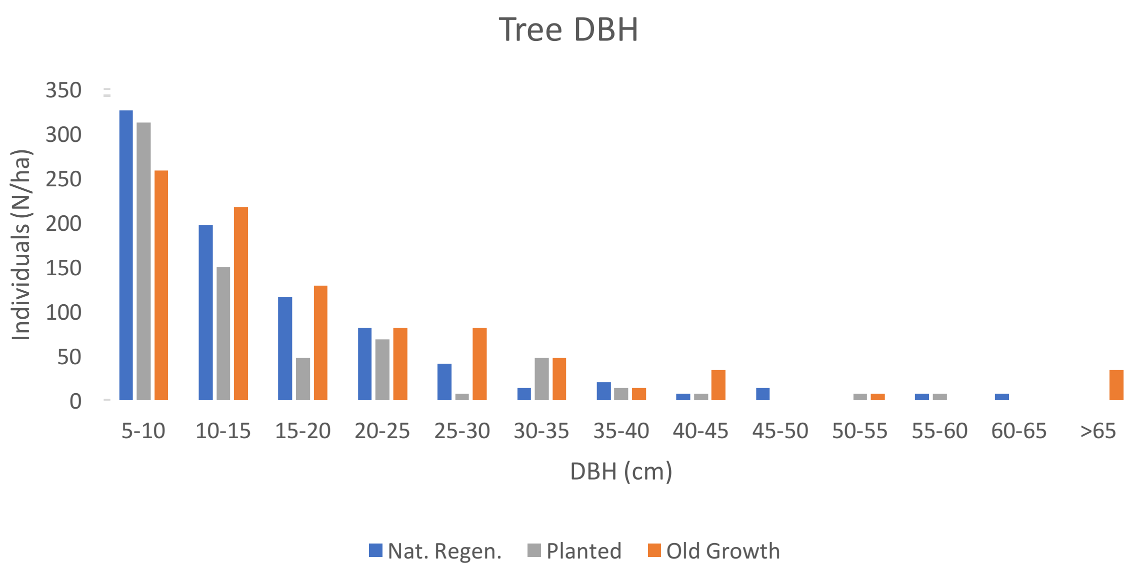


Figure 3. DBH class distribution per Habitat type

Table 2. Means of DBH per Habitat type for trees >=5 and <10 cm DBH

Aspect	Nat. Regen.	Planted	Old Growth
DBH (cm)	7,2	7,5	7,0

Table 3. Means of DBH per Habitat type for trees >=10 cm DBH

Aspect	Nat. Regen.	Planted	Old Growth
DBH (cm)	20,3	21,1	23,8

Analysis with a One-way ANOVA Test (Analysis of Variance), results in a P-value of 0,018, indicating a high statistically significant difference between the means of the DBH observations per habitat type.

With a Post hoc Test using the Bonferroni Test, it becomes clear that this variation is caused by a significant difference in DBH between both old growth and natural regeneration, and old growth and planted areas.

Height

Looking at figure 4, it becomes clear that with increasing height, more trees per ha are found in old growth forest and a lower number per ha in the other habitat types. In the old growth forest, most trees per ha have a height of 10-15 m. For the two other habitat types, most trees per ha have a height of 5-10 m.

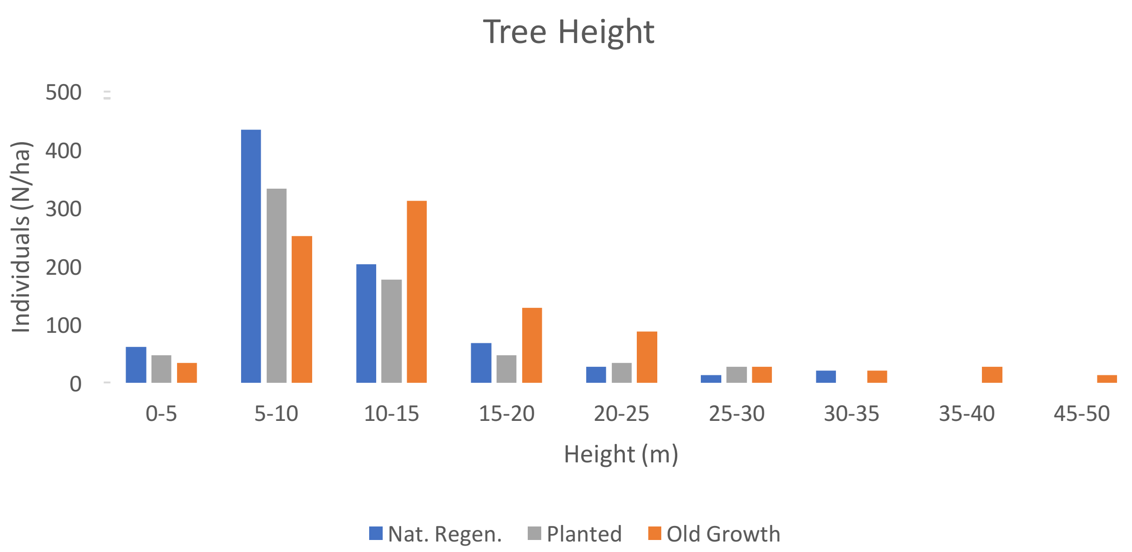


Figure 4. Height class distribution per Habitat type

Table 4. Means of height per Habitat type

Aspect	Nat. Regen.	Planted	Old Growth
Height (m)	10,55	10,33	14,76

Analysed with a One-way ANOVA Test, the result is a statistically significant difference (Table 27). This value indicates that there is a very high statistically significant difference between the means of the tree heights in the habitat types.

A Bonferroni Post Hoc Test results in a statistically significant difference in height between both old growth forest and natural regeneration, and old growth forest and planted areas.

Canopy cover

Taking table 5 into account, it can be concluded that the plots located in old growth forest have a denser canopy than the other two habitat types. In addition, the plots located in planted areas have the most open canopy. Analysis with a One-way ANOVA Test results in a P-value of 0,001.
A Bonferroni Test reveals a statistically significant difference in canopy cover between old growth forest and planted areas.

Table 5. Means of canopy cover per Habitat type

Aspect	Nat. Regen.	Planted	Old Growth
Canopy cover (%)	91,79	86,07	97,98

Crown class

From figure 5 below and table 12 in Appendix 9.1, showing the crown class, it can be concluded that old growth forest contains most trees with a crown class of 4, indicating the abundance of smaller trees that are over shaded by others in the stand.

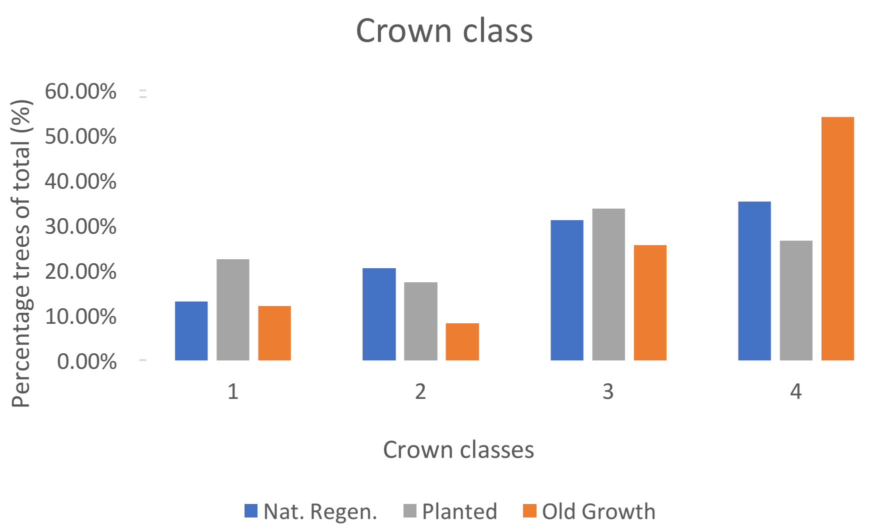


Figure 5. Percentages of total trees per Habitat type in different crown classes

Standing dead trees

The dead trees found in old growth forest fall in the DBH classes 10-15 cm and 30-35 cm. The dead trees in naturally regenerated areas fall in all DBH classes shown (Fig.6).

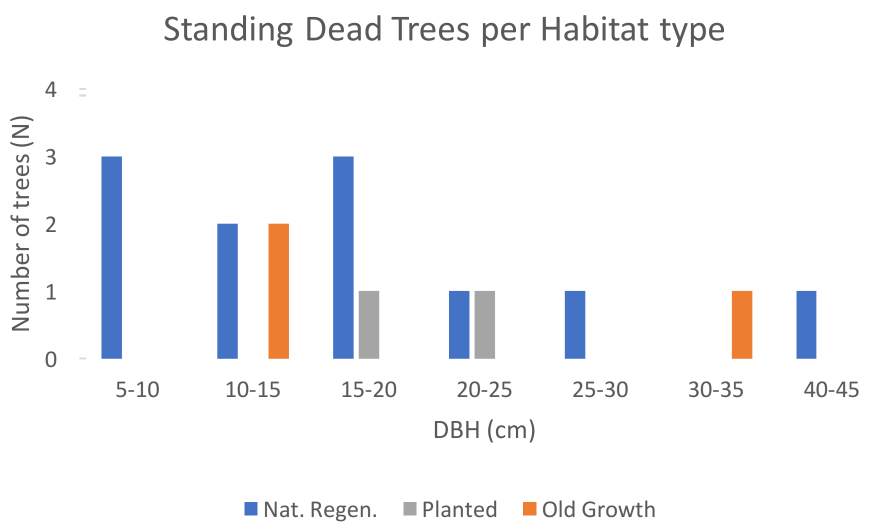


Figure 6. DBH classes for the number of standing dead trees per Habitat type

Tree density

As shown in table 6 and 7, more trees per ha with a DBH of 5 cm and above are found in natural regeneration areas than in the other two habitat types, with old growth forest containing the lowest number of trees per ha in this DBH class. For DBH class of 10 cm and above, most trees per ha were found in old growth forest (Table 7).

Table 6. Tree density per Habitat type for trees >=5 and <10 cm DBH

Aspect	Nat. Regen.	Planted	Old Growth
Trees/ha	326	312	258

Table 7. Tree density for trees >=10 cm DBH

Aspect	Nat. Regen.	Planted	Old Growth
Trees/ha	503	353	645

Basal Area

As indicated in figure 7, most trees per ha in each habitat type fall in the basal area class of 0-200 cm^2, showing a clear difference with the number of trees per ha in the other basal area classes. Table 8 shows a clear difference in total basal area between planted areas and old growth forest.

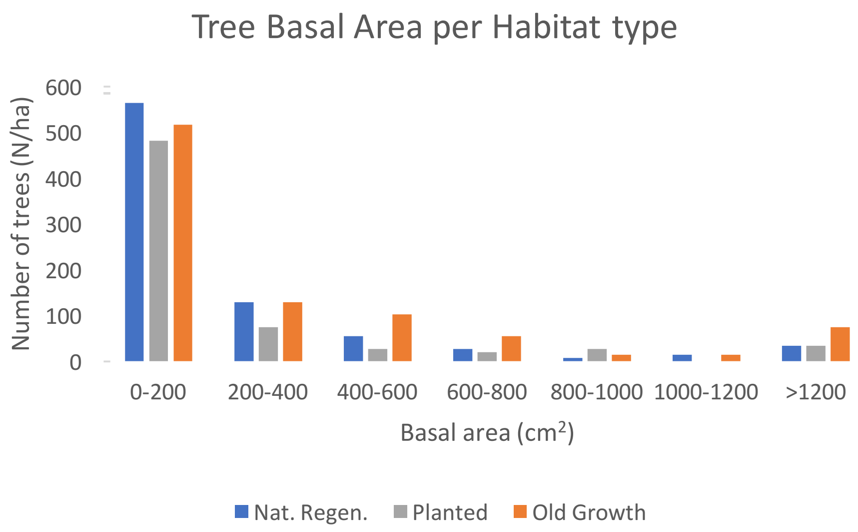


Figure 7. Tree basal area in cm^2 per Habitat type

Table 8. Total tree basal area per Habitat type

Aspect	Nat. Regen.	Planted	Old Growth
Basal Area (m^2)	3,3	2,5	6,5

A One-way ANOVA Test results in a P-value of 0,025, indicating that there is a significant difference between the habitat types. The Bonferroni Post Hoc Test shows no significant difference between either of the three habitat types (Appendix 9.5).

3.2 Advantages and limitations of the two reforestation methods

Table 9. Pros and cons for each reforestation method per point to consider

Considerations	Nat. Regen.	Planted
Costs	Low	Slightly high
Labor intensity	Little	Relatively intensive
Time	Less	More
Awareness	Less	More

In table 9, the advantages and limitations of the two reforestation methods are shown.
The establishment costs are low for natural regeneration for applying this method basically means just letting the vegetation grow without further management. Therefore, also labor will be less intensive than when choosing to plant. In addition, planting will bring about slightly higher costs (Barnett & Baker, 1991). This study found that natural regeneration took less time to grow towards primary cloud forest, although slightly less than planted areas. The awareness will, however, be more when applying planting as reforestation method (Cloudbridge Nature Reserve).

4 Discussion of the results

In the discussion, the obtained results will be discussed based on comparisons with other literature. In addition, the limitations of the study, organization of future studies and the broader context of the study will be described.

Earlier data at CNR
In comparison with the findings of this study, 2016 data at the same study plots showed a lower mean DBH in natural regenerated areas, and the mean DBH in old growth forest was higher. Mean tree height in natural regeneration was higher, and lower in old growth forest. Furthermore, at least 2 trees measured in 2016 have died between the data collection in 2016 and 2017. These 2 trees were standing in one natural regeneration plot each. Tree densities in naturally regenerated sites and old growth forest were lower.
However, some points need to be considered:

- The study done in 2017 included corrected and updated procedures for collecting data. This was especially the case for the multistem DBH calculation and height measurements. In 2016, no multistem DBH calculation was considered. In 2017, height was measured using degrees instead of percentages, for working with degrees was more accurate.
- Only data from naturally regenerated areas and old growth forest are compared between 2016 and 2017. The reason for this is that two of the three plots located in planted areas, were newly established in 2017. These three plots therefore were of even age i.e. 15 years old, which was necessary to compare them with plots in naturally regenerated areas, which were also at age 15. The two new plots could not be compared with 2016 data so the already existing plot was excluded from this comparison as well.

Data from similar studies elsewhere
A study on structural characteristics and floristic composition in a cloud forest in Monteverde Cloud Forest Reserve measured a higher total number of trees and found more trees in DBH category >10 cm. Tree density was lower for stems >10 cm DBH (Nadkarni, Matelson, & Haber, 1995).
Another study, which was conducted in an upper montane cloud forest in Brazil, measured more trees having a DBH of >=5 cm and found a lower mean for DBH and height and a higher tree density (Pompeu, et al., 2014). However, in that study, the plots were all located at an elevation of 1900 m and soil texture and chemical properties of the soil were analysed.
A study at La Selva Biological Station in Costa Rica found more individuals with a DBH of >=10 cm (Lieberman, Lieberman, Peralta, & Hartshorn, 1996).
A study in the tropical montane rain forests on Mount Kinabalu, Borneo, measured a higher number of tree stems, but from a DBH of >=4,8 cm, and found that the mean and maximum DBH on ultramafic soils tends to decrease with increase in elevation, while on non-ultramafic soils the mean and maximum DBH differed less with altitude. The maximum tree height decreased with elevation on ultramafic as well as on non-ultramafic soils (Aiba, et al., 2015).

In conclusion to the comparison with other studies carried out on forest structure, one can say that the findings vary significantly. This could be explained by the fact that other researches did not make any distinction in naturally regenerated forest, planted areas, and old growth cloud forest. Furthermore, the study conducted at La Selva Biological Station focused partially on tropical lowland rain forest instead of only cloud forest.

Means of forest structure aspects
Considering the means of the tree DBH in the current study, more variation is found between old growth forest and planted areas than between natural regeneration and planted areas. The means of the tree height in natural regeneration and planted areas are close to similar, while the mean tree height in old growth forest differs more from the means in natural regeneration and planted areas. Regarding the canopy cover, the old growth forest had the densest canopy while the canopy of the planted areas was most open. The mean canopy cover in natural regeneration is more similar to that of planted areas, while the mean of old growth forest is higher than in the other habitat types. When considering the crown class, planted areas have the highest number of individuals that are classified as dominant, having most of the crown above the canopy. The old growth forest has the lowest number of trees with dominant crowns. Most of the trees in the old growth forest are classified as suppressed trees having a crown that is completely over shaded by the crowns of other trees in the stand.

Factors in DBH class distribution and tree height
The differences in DBH class distributions can be explained by variation in elevation, slope or other geographical factors per plot, like not facing the same compass direction. This could also explain variation in tree height per plot per forest type. Clark and Clark (2000) found that variation in forest structure of an old growth lowland rain forest at La Selva was affected, among other factors, by difference in topographic position and slope angle.

Factors in canopy cover
A denser canopy in naturally regenerated areas compared to planted areas could be explained by the fact that planted areas were first planted with pioneer tree species, which are fast growers, to eventually provide enough shade for climax tree species, which are characterized by slower growth (Cloudbridge Nature Reserve). Furthermore, differences could be explained by variation in geographical factors, which are also possible causes for variation in crown class between the habitat types.

Factors in standing dead trees
The differences in standing dead trees between the habitat types, particularly in naturally regenerated areas, can be explained by the fact that these areas are located at a lower elevation than the old growth forests in the reserve. These areas receive less wind and therefore contain more standing dead trees (The everchanging forest: disturbance and dynamics, 2010).

Factors in tree density
The variation in tree density per habitat type can be explained by the amount of large tree stems. In montane and young regrowth forest, the absence of very large tree stems results in a high tree density whereas in old growth forest, the presence of such large tree stems leads to a lower tree density (Many rainforests: formations and ecotones, 2010).

Factors in basal area
As with DBH –and height class distributions, differences in elevation, slope or other geographical factors can explain the variation in tree basal area between the habitat types.

Limitations of this study
Taking into consideration the results of the measurements and data collected in this study, one of the main limitations of the study is that the observations per aspect were compared between the three habitat types without considering factors like elevation of the plots, slope, or any other geographical factor. The results per aspect show a clear difference between habitat types, but, without having made a distinction in geographical factors, it cannot be concluded with certainty that the difference is solely a result of the various forest types only.

Furthermore, **a** comprehensive study of reforestation would have required collection of data that have not been collected in the current study.
A complete tree species inventory to determine and compare diversity was not conducted due to non-availablity of required indigenous expertise as well as because of a timeframe too short to accurately identify the species.
Trees with a DBH of >=5 and <10 cm have not been identified as smaller trees are difficult to identify due to absence of typical characteristics seen in older, bigger trees.
As a consequence, data collected on tree species, calculations for volume, biomass and carbon stock were not conducted as these aspects require species specific data for the calculations.

Organization of further studies
The way in which the study was carried out could be organized more effectively. In the case of tree monitoring, this can be done by tagging the trees in plots 40 and 41 for monitoring future growth of the trees. Also, when deciding to identify the tree species, this can be done by looking for an expert in this area who can assist research for multiple days in the field.

Similar studies at other locations took different approaches to tree species identification: For the study on Mount Kinabalu, Aiba et al. (2015) made use of work done earlier by other researchers for species identification. Pompeu et al. (2014) made use of various herbaria when considering identification of tree species. In the study of DeLyser (2015), species were identified with the help of books and websites. In a study on the structure and floristics of secondary and old growth lowland forest at La Selva Biological Station, species identification in the field was conducted by a local expert (Guariguata, Chazdon, Denslow, Dupuy, & Anderson, 1997). In a study on forest structure and aboveground biomass variation in an Atlantic moist forest in Brazil, the forest composition was determined by consulting previous studies that distinguished each forest type by diversity and composition (Alves, et al., 2010). In a study on above ground biomass and forest attributes in tropical montane forests on three mountains in Northern Kenya, samples of unidentified tree species were collected for identification by the Herbarium of the University of Nairobi (Cuni-Sanchez, et al., 2017).

Broader context
When looking at the bigger picture of forest restoration, knowledge of topics like reforestation methods and their advantages and constraints can be of importance for strategies of other countries or regions on restoration of forests. In this phase of development, Costa Rica, with its drivers of forest restoration after a long period of deforestation, can act as a good example for other countries to implement similar policies and strategies regarding reforestation. With knowledge about drivers of reforestation, forest restoration practices, their strengths and weaknesses and knowing when restoration is successful, other countries can critically review points for improvement to halt deforestation and begin building towards clear and concrete objectives for reforestation.

5 Conclusion

There is a statistically significant difference in forest structure between the habitat types natural regeneration, planted areas and old growth forest at Cloudbridge Nature Reserve. Results indicate that the DBH- and height class distribution of the naturally regenerated areas resemble the old growth situation the most. This is also the case for crown class. Looking at the results, it becomes evident that the means of natural regeneration are closer to the means of old growth forest than are those of planted areas. Since CNR is still replanting, one can conclude that in these areas forest restoration is not yet successful. Considering only the plots measured in this study and the current developmental phase of the reforested areas, it seems that replanting and natural regeneration are similarly effective, i.e. per aspect there is no significant difference between the means found in these habitat types. The method of replanting does not yet seem to have an effect on forest succession. This is important information for CNR, as it can be used to decide on which reforestation method the focus will be in the future to work towards old growth cloud forest. This study can contribute to reforestation of cloud forests globally in aiming to manage and conserve a rapidly declining unique forest ecosystem under pressure of today's climate change events.

6 Recommendations

1. To monitor future growth of the trees in plots 40 and 41 and compare these data with the data collected in this study, these trees should be tagged with a number like the trees in the other plots measured.
2. When deciding to identify tree species, an expert in this field of expertise should be looked for to assist researchers in the field for multiple days.
3. To make better comparisons in the future, it is highly recommended to take geographical factors into account when analyzing the data collected.
4. It is recommended to use this initial study as a reference for future studies on the same subject.
5. In preparation of future data collection, it is recommended to get as much information of the site as possible and to study relevant considerations, including previous reports on similar topics in advance.
6. Future multi-year recurrent data collection is highly recommended as, in this case, only one research is far less valuable than multiple studies on the same topic, spread over an interval period of around 3-5 years.
7. In case of a multi-year reforestation monitoring program, attention should be paid to deciding on once in how many years data collection should take place of professional quality (e.g. by well-prepared students of VHL), and on having data collected in between these moments by volunteers. If so, procedures and training material should be prepared for instructing these volunteers on how to collect the data
8. Sample sets of follow-up studies could be adapted or extended by having more sites as to enhance the comparability of the existing data collection sites in terms of comparable geographical factors. Finally, procedures and means of making data available and accessible should also be considered when undertaking efforts to effectively organize the approach of future data collection.
9. Conducting a stepwise multiple regression analysis is recommended to determine with certainty if the variation per aspect in each forest type is a result of different elevations.
10. Regarding the forest restoration techniques found by Chazdon (2008), CNR could start adopting the method of assisted natural regeneration, whereby carrying out enrichment planting in naturally regenerated plots.
11. Future research could take into account an article (Bustamante et al., 2015) on a monitoring framework for forest dynamics that found that the combination of ecosystem models, multiscale remote sensing and networks of field plots can be relevant for the evaluation of forest degradation and recovery and their interactions with biodiversity and carbon recycling.
12. Special attention in future research should be paid to topics like tree species diversity, tree volume, biomass and carbon storage to gain more insight in important animal-tree interactions, decomposition rates and forest health, and means of improving carbon stock of the forest to help mitigate climate change.

8 References

Aiba, S.-i., Sawada, Y., Takyu, M., Seino, T., Kitayama, K., & Repin, R. (2015). Structure, floristics and diversity of tropical montane rain forests over ultramafic soils on Mount Kinabalu (Borneo) compared with those on non-ultramafic soils. *Australian Journal of Botany*, 191-203.

Alamgir, M., Turton, S. M., Macgregor, C. J., & Pert, P. L. (2016). Assessing regulating and provisioning ecosystem services in a contrasting tropical forest landscape. *Ecological Indicators*, 319-334.

Allen, K., & Padgett Vásquez, S. (2017). Forest cover, development and sustainability in Costa Rica: Can one policy fit all? *Land Use Policy*, 212-221.

Alves, L., Vieira, S., Scaranello, M., Camargo, P., Santos, F., Joly, C., & Martinelli, L. (2010). Forest structure and live aboveground biomass variation along an elevational gradient of tropical Atlantic moist forest (Brazil). *Forest Ecology and Management*, 679-691.

Bubb, P., May, I., Miles, L., & Sayer, J. (2004). *Cloud Forest Agenda.* Cambridge, UK.

Bustamante, M., Roitman, I., Aide, T., Alencar, A., Anderson, L., Aragão, L., . . . Vieira, I. (2015). Toward an integrated monitoring framework to assess the effects of tropical forest degradation and recovery on carbon stocks and biodiversity. *Global Change Biology*, 92-109.

Central Intelligence Agency. (n.d.). *The World Factbook*. Retrieved January 24, 2017, from Central Intelligence Agency: https://www.cia.gov/library/publications/the-world-factbook/geos/cs.html

Chazdon, R. L. (2008). Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Lands. *Science*, 1458-1460.

Clark, D., & Clark, D. (2000). Landscape-scale variation in forest structure and biomass in a tropical rain forest. *Forest Ecology and Management*, 185-198.

Cloudbridge Nature Reserve. (n.d.). *Conservation*. Retrieved August 26, 2017, from Cloudbridge Nature Reserve: http://cloudbridge.org/the-project/conservation/

Cloudbridge Nature Reserve. (n.d.). *Reforestation*. Retrieved August 27, 2017, from Cloudbridge Nature Reserve: http://cloudbridge.org/the-project/reforestation/

Cloudbridge Nature Reserve. (n.d.). *The Project*. Retrieved August 26, 2017, from Cloudbridge Nature Reserve: http://cloudbridge.org/the-project/

Cuni-Sanchez, A., Pfeifer, M., Marchant, R., Calders, K., Sørensen, C., Pompeu, P., . . . Burgess, N. (2017). New insights on above ground biomass and forest attributes in tropical montane forests. *Forest Ecology and Management*, 235-246.

DeLyser, K. (2015). *Assessing the effectiveness of reforestation efforts in the tropical montane cloud forest of Costa Rica.*

Ecoplexity. (2010). Retrieved from Ecoplexity: http://www.ecoplexity.org/?q=node/236

Gotsch, S. G., Nadkarni, N., & Amici, A. (2016). The functional roles of epiphytes and aboreal soils in tropical montane cloud forests. *Journal of Tropical Ecology*, 1-14.

Grotta, A. (2013, 7 23). *The Blog*. Retrieved from Oregon Forests: http://oregonforests.org/blog/value-dead-wood

Guariguata, M., Chazdon, R., Denslow, J., Dupuy, J., & Anderson, L. (1997). Structure and floristics of secondary and old-growth forest stands in lowland Costa Rica. *Plant Ecology*, 107-120.

Introduction. (2004). In J. Evans, & J. Turnbull, *Plantation Forestry in the Tropics* (pp. 3-13). Oxford: Oxford University Press.

Jadin, I., Meyfroidt, P., & Lambin, E. (2016). International trade, and land use intensification and spatial reorganization explain Costa Rica's forest transition. *Environmental Research Letters*, 1-14.

Korhonen, L., Korhonen, K., Rautiainen, M., & Stenberg, P. (2006). Estimation of Forest Canopy Cover: a Comparison of Field Measurement Techniques. *Silva Fennica*, 577-588.

Lieberman, D., Lieberman, M., Peralta, R., & Hartshorn, G. (1996). Tropical Forest Structure and Composition on a Large-Scale Altitudinal Gradient in Costa Rica. *Journal of Ecology*, 137-152.

Many rainforests: formations and ecotones. (2010). In J. Ghazoul, & D. Sheil, *Tropical Rain Forest Ecology, Diversity, and Conservation* (pp. 129-153). Oxford: Oxford University Press.

Martínez, M., Pérez-Maqueo, O., Vázquez, G., Castillo-Campos, G., García-Franco, J., Mehltreter, K., . . . Landgrave, R. (2009). Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. *Forest Ecology and Management*, 1856-1863.

Nadkarni, N. M., Matelson, T. J., & Haber, W. A. (1995). Structural Characteristics and Floristic Composition of a Neotropical Cloud Forest, Monteverde, Costa Rica. *Journal of Tropical Ecology*, 481-495.

New South Wales Environmental Protection Authority. (2013). Retrieved from New South Wales Environmental Protection Authority: http://www.epa.nsw.gov.au/resources/pnf/130027standheight.pdf

Paletto, A., & Tosi, V. (2009). Forest canopy cover and canopy closure: Comparison of assessment techniques. *European Journal of Forest Research*, 265-272.

Pompeu, P., Leite Fontes, M., dos Santos, R., Garcia, P., Batista, T., Caldas Carvalho, W., & de Oliveira Filho, A. (2014). Floristic composition and structure of an upper montane cloud forest in the Serra da Mantiqueira Mountain Range of Brazil. *Acta Botanica Brasilica*, 456-464.

Powell, J. (2017). *Bird Monitoring Study Data Report Jan 2013-Dec 2016.*

Ruiz-Jaen, M. C., & Aide, T. (2005). Restoration Success: How Is It Being Measured? *Restoration Ecology*, 569-577.

Ruiz-Jaén, M. C., & Aide, T. (2005). Vegetation structure, species diversity, and ecosystem processes as measures of restoration success. *Forest Ecology and Management*, 159-173.

Sasaki, N., Asner, G. P., Pan, Y., Knorr, W., Durst, P. B., Ma, H. O., . . . Putz, F. E. (2016). Sustainable Management of Tropical Forests Can Reduce Carbon Emissions and Stabilize Timber Production. *Frontiers in Environmental Science*, 1-13.

Swiecki, T., & Bernhardt, E. (n.d.). *Guidelines for Developing and Evaluating Tree Ordinances*. Retrieved May 28, 2017, from Phytosphere Research: http://phytosphere.com/treeord/measuringdbh.htm

The everchanging forest: disturbance and dynamics. (2010). In J. Ghazoul, & D. Sheil, *Tropical Rain Forest Ecology, Diversity, and Conservation* (pp. 229-246). Oxford: Oxford University Press.

Toledo-Aceves, T., Meave, J., González-Espinosa, M., & Ramírez-Marcial, N. (2010). Tropical montane cloud forests: Current threats and opportunities for their conservation and sustainable management in Mexico. *Journal of Environmental Management*, 974-981.

Vallet, A., Locatelli, B., Levrel, H., Brenes Pérez, C., Imbach, P., Estrada Carmona, N., . . . Oszwald, J. (2016). Dynamics of Ecosystem Services during Forest Transitions in Reventazón, Costa Rica. *PLOS ONE*, 1-18.

9 Appendices

9.1 Tables of forest structure aspects

DBH

Table 10. DBH classes (cm) per Habitat type

DBH classes	Nat. Regen.	Planted	Old Growth	Grand Total
5-10	48	46	38	132
10-15	29	22	32	83
15-20	17	7	19	43
20-25	12	10	12	34
25-30	6	1	12	19
30-35	2	7	7	16
35-40	3	2	2	7
40-45	1	1	5	7
45-50	2			2
50-55		1	1	2
55-60	1	1		2
60-65	1			1
65-70				
70-75			2	2
75-80				
80-85			2	2
85-90				
90-95				
95-100			1	1
Grand Total	**122**	**98**	**133**	**353**

Height

Table 11. Height classes (m) per Habitat type

Height classes	Nat. Regen.	Planted	Old Growth	Grand Total
0-5	9	7	5	21
5-10	64	49	37	150
10-15	30	26	46	102
15-20	10	7	19	36
20-25	4	5	13	22
25-30	2	4	4	10
30-35	3		3	6
35-40			4	4
45-50			2	2
Grand Total	**122**	**98**	**133**	**353**

Canopy cover

Table 12. Canopy cover per Habitat type

Nat. Regen. (%)	Planted (%)	Old Growth (%)
95,16	66,56	98,28
92,04	96,2	97,5
97,24	76,7	96,98
97,76	94,38	98,28
94,12	92,04	95,94
94,9	89,18	98,28
95,68	92,3	98,02
70,98	94,9	99,84
88,92	93,08	99,06
93,6	95,16	97,5
91,78	81,64	96,2
95,94	55,64	98,8
74,36	90,48	99,84
97,24	91,52	96,46
97,24	81,38	98,8

Crown class

Table 13. Percentage of total trees in crown class per Habitat type

Crown class	Nat. Regen.	Planted	Old Growth
Dominant: 1	13,11%	22,45%	12,03%
Codominant: 2	20,49%	17,35%	8,27%
Intermediate: 3	31,15%	33,67%	25,56%
Suppressed: 4	35,25%	26,53%	54,14%

9.2 Tables of forest structure data measured in 2016

Table 14. Tree density per Habitat type in 2016

Aspect	Nat. Regen.	Old Growth
Trees/ha	1080	1813

Table 15. Means of comparable aspects from 2016 data

Aspect	Natural Regeneration	Old Growth
DBH (cm)	19,68	25,69
Height (m)	11,25	11,24

Table 16. DBH classes per Habitat type from 2016 data

DBH classes (cm)	Natural Regeneration	Old Growth	Grand Total
5-10	2		2
10-15	20	25	45
15-20	13	21	34
20-25	8	12	20
25-30	3	11	14
30-35	2	4	6
35-40	1	2	3
40-45	1	5	6
45-50	2	2	4
65-70	1	2	3
75-80		2	2
80-85		1	1
85-90		1	1
90-95		1	1
Grand Total	**53**	**89**	**142**

Table 17. Height classes per Habitat type from 2016 data

Height classes (m)	Natural Regeneration	Old Growth	Grand Total
0-5	3	4	7
5-10	19	35	54
10-15	21	30	51
15-20	7	11	18
20-25	3	4	7
25-30		1	1
Grand Total	**53**	**85**	**138**

9.3 Normality Tests

DBH

Table 18. Normality Test result for the DBH aspect

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DBH Old Growth	,192	98	,000	,713	98	,000
DBH Nat. Regen.	,166	98	,000	,800	98	,000
DBH Planted	,193	98	,000	,783	98	,000

a. Lilliefors Significance Correction

DBH of >=5 cm

Table 19. Normality Test result for DBH >=5 cm

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DBH Old Growth	,125	38	,139	,942	38	,048
DBH Nat. Regen.	,127	38	,128	,934	38	,026
DBH Planted	,187	38	,002	,888	38	,001

a. Lilliefors Significance Correction

DBH of >=10 cm

Table 20. Normality Test result for DBH >=10 cm

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DBH Old Growth	,196	52	,000	,759	52	,000
DBH Nat. Regen.	,186	52	,000	,788	52	,000
DBH Planted	,175	52	,000	,839	52	,000

a. Lilliefors Significance Correction

Height

Table 21. Normality Test result for the height aspect

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Height Old Growth (m)	,142	98	,000	,898	98	,000
Height Nat. Regen. (m)	,138	98	,000	,868	98	,000
Height Planted (m)	,135	98	,000	,873	98	,000

a. Lilliefors Significance Correction

Canopy cover

Table 22. Normality Test result for the canopy cover aspect

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Nat. Regen.	,299	15	,001	,682	15	,000
Planted	,270	15	,004	,788	15	,003
Old Growth	,129	15	,200*	,956	15	,615

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Basal Area

Table 23. Normality Test result for the Basal area aspect

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
BA Old Growth	,334	98	,000	,443	98	,000
BA Nat. Regen.	,292	98	,000	,533	98	,000
BA Planted	,289	98	,000	,565	98	,000

a. Lilliefors Significance Correction

9.4 Tables of One-way ANOVA results

DBH

Table 24. ANOVA Test result for the DBH aspect

Tests of Between-Subjects Effects

Dependent Variable: DBH

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1384,862[a]	2	692,431	4,090	,018
Intercept	92010,703	1	92010,703	543,485	,000
Habitat_Type	1384,862	2	692,431	4,090	,018
Error	59254,209	350	169,298		
Total	156411,678	353			
Corrected Total	60639,071	352			

a. R Squared = ,023 (Adjusted R Squared = ,017)

DBH of >=5 cm

Table 25. ANOVA Test result for DBH >=5 cm

Tests of Between-Subjects Effects

Dependent Variable: DBH

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5,661[a]	2	2,831	1,343	,265
Intercept	6795,453	1	6795,453	3224,615	,000
Habitat_Type	5,661	2	2,831	1,343	,265
Error	271,851	129	2,107		
Total	7169,450	132			
Corrected Total	277,512	131			

a. R Squared = ,020 (Adjusted R Squared = ,005)

DBH of >=10 cm

Table 26. ANOVA Test result for DBH >=10 cm

Tests of Between-Subjects Effects

Dependent Variable: DBH

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	574,446[a]	2	287,223	1,499	,226
Intercept	98199,093	1	98199,093	512,585	,000
Habitat_Type	574,446	2	287,223	1,499	,226
Error	41763,578	218	191,576		
Total	149242,228	221			
Corrected Total	42338,024	220			

a. R Squared = ,014 (Adjusted R Squared = ,005)

Height

Table 27. ANOVA Test result for the height aspect

Tests of Between-Subjects Effects

Dependent Variable: Height (m)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1289,034[a]	2	644,517	13,254	,000
Intercept	48037,357	1	48037,357	987,822	,000
Habitat_Type	1289,034	2	644,517	13,254	,000
Error	17020,349	350	48,630		
Total	68644,746	353			
Corrected Total	18309,383	352			

a. R Squared = ,070 (Adjusted R Squared = ,065)

Canopy cover

Table 28. ANOVA Test result for the canopy cover aspect

Tests of Between-Subjects Effects

Dependent Variable: Average Canopy Cover (%)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1064,051[a]	2	532,026	7,696	,001
Intercept	380493,698	1	380493,698	5503,902	,000
Habitat_Type	1064,051	2	532,026	7,696	,001
Error	2903,528	42	69,132		
Total	384461,277	45			
Corrected Total	3967,579	44			

a. R Squared = ,268 (Adjusted R Squared = ,233)

Basal Area

Table 29. ANOVA Test result for the canopy cover aspect

Tests of Between-Subjects Effects

Dependent Variable: Basal Area

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4114295,001[a]	2	2057147,501	3,748	,025
Intercept	39640273,090	1	39640273,090	72,221	,000
Habitat_Type	4114295,001	2	2057147,501	3,748	,025
Error	192107174,783	350	548877,642		
Total	238972186,983	353			
Corrected Total	196221469,784	352			

a. R Squared = ,021 (Adjusted R Squared = ,015)

9.5 Post Hoc Test Bonferroni

DBH

Table 30. Post Hoc Bonferroni Test result for the DBH aspect

Multiple Comparisons

Dependent Variable: DBH

Bonferroni

(I) Habitat Type	(J) Habitat Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Old Growth	Nat. Regen.	3,8725	1,63114	,054	-,0513	7,7962
	Planted	4,3191*	1,73218	,039	,1523	8,4859
Nat. Regen.	Old Growth	-3,8725	1,63114	,054	-7,7962	,0513
	Planted	,4466	1,76500	1,000	-3,7991	4,6924
Planted	Old Growth	-4,3191*	1,73218	,039	-8,4859	-,1523
	Nat. Regen.	-,4466	1,76500	1,000	-4,6924	3,7991

Based on observed means.

The error term is Mean Square(Error) = 169,298.

*. The mean difference is significant at the ,05 level.

DBH >=5 cm

Table 31. Post Hoc Bonferroni Test result for DBH >=5 cm

Multiple Comparisons

Dependent Variable: DBH

Bonferroni

(I) Habitat Type	(J) Habitat Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Old Growth	Nat. Regen.	-,1958	,31522	1,000	-,9604	,5688
	Planted	-,5115	,31823	,331	-1,2834	,2604
Nat. Regen.	Old Growth	,1958	,31522	1,000	-,5688	,9604
	Planted	-,3157	,29953	,882	-1,0422	,4108
Planted	Old Growth	,5115	,31823	,331	-,2604	1,2834
	Nat. Regen.	,3157	,29953	,882	-,4108	1,0422

Based on observed means.

The error term is Mean Square(Error) = 2,107.

DBH >=10 cm

Table 32. Post Hoc Bonferroni Test result for DBH >=10 cm

Multiple Comparisons

Dependent Variable: DBH

Bonferroni

(I) Habitat Type	(J) Habitat Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Old Growth	Nat. Regen.	3,5195	2,14603	,307	-1,6580	8,6970
	Planted	2,7611	2,38762	,746	-2,9992	8,5215
Nat. Regen.	Old Growth	-3,5195	2,14603	,307	-8,6970	1,6580
	Planted	-,7583	2,50460	1,000	-6,8009	5,2842
Planted	Old Growth	-2,7611	2,38762	,746	-8,5215	2,9992
	Nat. Regen.	,7583	2,50460	1,000	-5,2842	6,8009

Based on observed means.

The error term is Mean Square(Error) = 191,576.

Height

Table 33. Post Hoc Bonferroni Test result for the height aspect

Multiple Comparisons

Dependent Variable: Height (m)

Bonferroni

(I) Habitat Type	(J) Habitat Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Old Growth	Nat. Regen.	3,8404*	,87421	,000	1,7374	5,9433
	Planted	4,0627*	,92836	,000	1,8295	6,2959
Nat. Regen.	Old Growth	-3,8404*	,87421	,000	-5,9433	-1,7374
	Planted	,2223	,94595	1,000	-2,0532	2,4978
Planted	Old Growth	-4,0627*	,92836	,000	-6,2959	-1,8295
	Nat. Regen.	-,2223	,94595	1,000	-2,4978	2,0532

Based on observed means.

The error term is Mean Square(Error) = 48,630.

*. The mean difference is significant at the ,05 level.

Canopy Cover

Table 34. Post Hoc Bonferroni Test result for the canopy cover aspect

Multiple Comparisons

Dependent Variable: Average Canopy Cover (%)

Bonferroni

(I) Habitat Type	(J) Habitat Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Old Growth	Nat. Regen.	6,1880	3,03604	,144	-1,3829	13,7589
	Planted	11,9080*	3,03604	,001	4,3371	19,4789
Nat. Regen.	Old Growth	-6,1880	3,03604	,144	-13,7589	1,3829
	Planted	5,7200	3,03604	,199	-1,8509	13,2909
Planted	Old Growth	-11,9080*	3,03604	,001	-19,4789	-4,3371
	Nat. Regen.	-5,7200	3,03604	,199	-13,2909	1,8509

Based on observed means.

The error term is Mean Square(Error) = 69,132.

*. The mean difference is significant at the ,05 level.

Basal Area

Table 35. Post Hoc Bonferroni Test result for the Basal area aspect

Multiple Comparisons

Dependent Variable: Basal Area

Bonferroni

(I) Habitat Type	(J) Habitat Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Old Growth	Nat. Regen.	216,9498	92,87571	,060	-6,4667	440,3663
	Planted	229,5392	98,62906	,062	-7,7173	466,7956
Nat. Regen.	Old Growth	-216,9498	92,87571	,060	-440,3663	6,4667
	Planted	12,5893	100,49771	1,000	-229,1622	254,3409
Planted	Old Growth	-229,5392	98,62906	,062	-466,7956	7,7173
	Nat. Regen.	-12,5893	100,49771	1,000	-254,3409	229,1622

Based on observed means.

The error term is Mean Square(Error) = 548877,642.

9.6 Relevant images

Figure 8. Map of the Perez Zeledon region, with San Isidro De El General and Chirripo National Park (Kaarten, Apple Inc. 2012-2014)

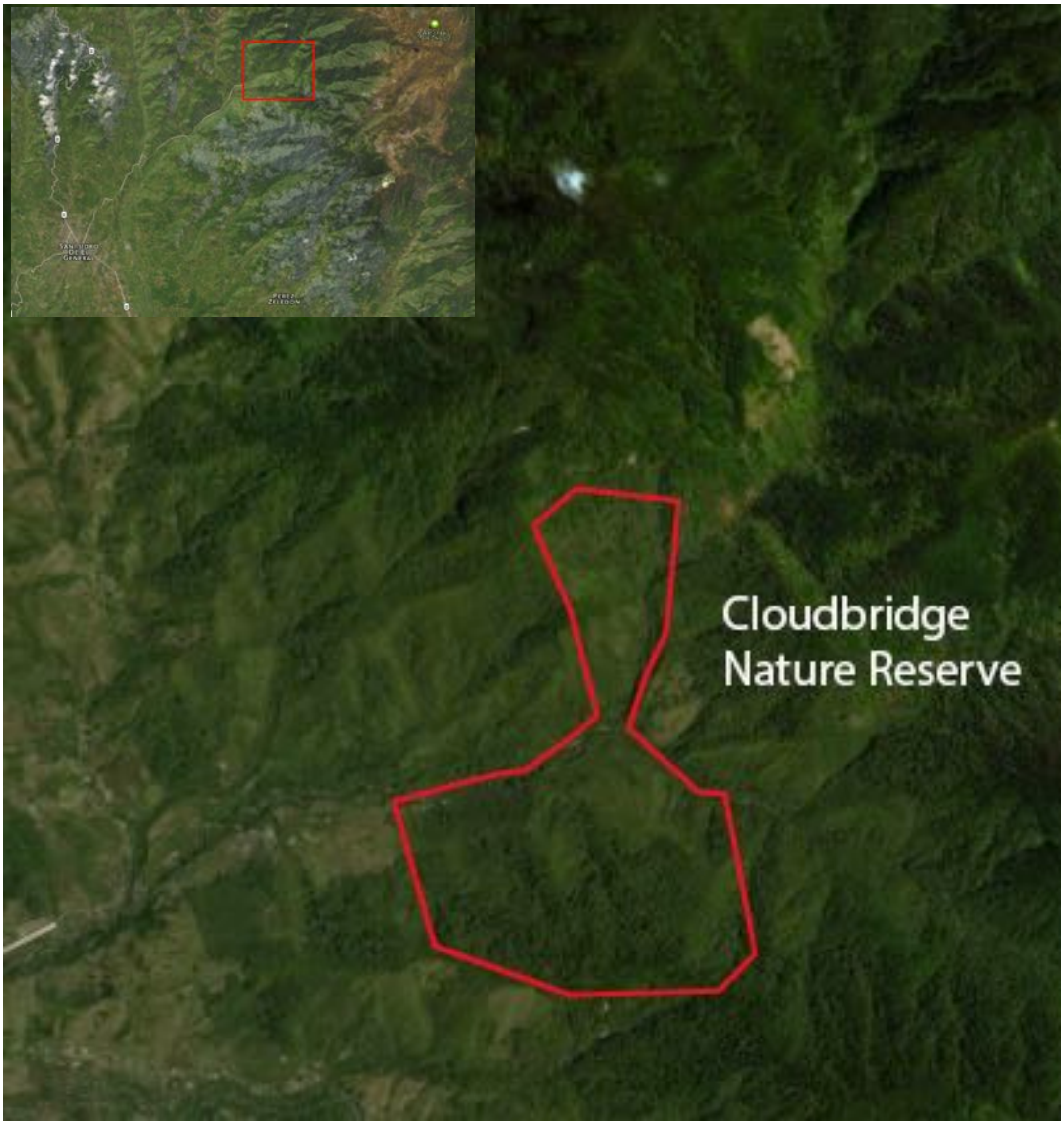


Figure 9. Map of Cloudbridge and surroundings (Kaarten, Apple Inc. 2012-2014)


Figure 10. An old growth cloud forest site


Figure 11. Site with replanted trees


Figure 12. A naturally regenerated site

Figure 13. A bird survey point, also used as the center for the Habitat Assessment plots

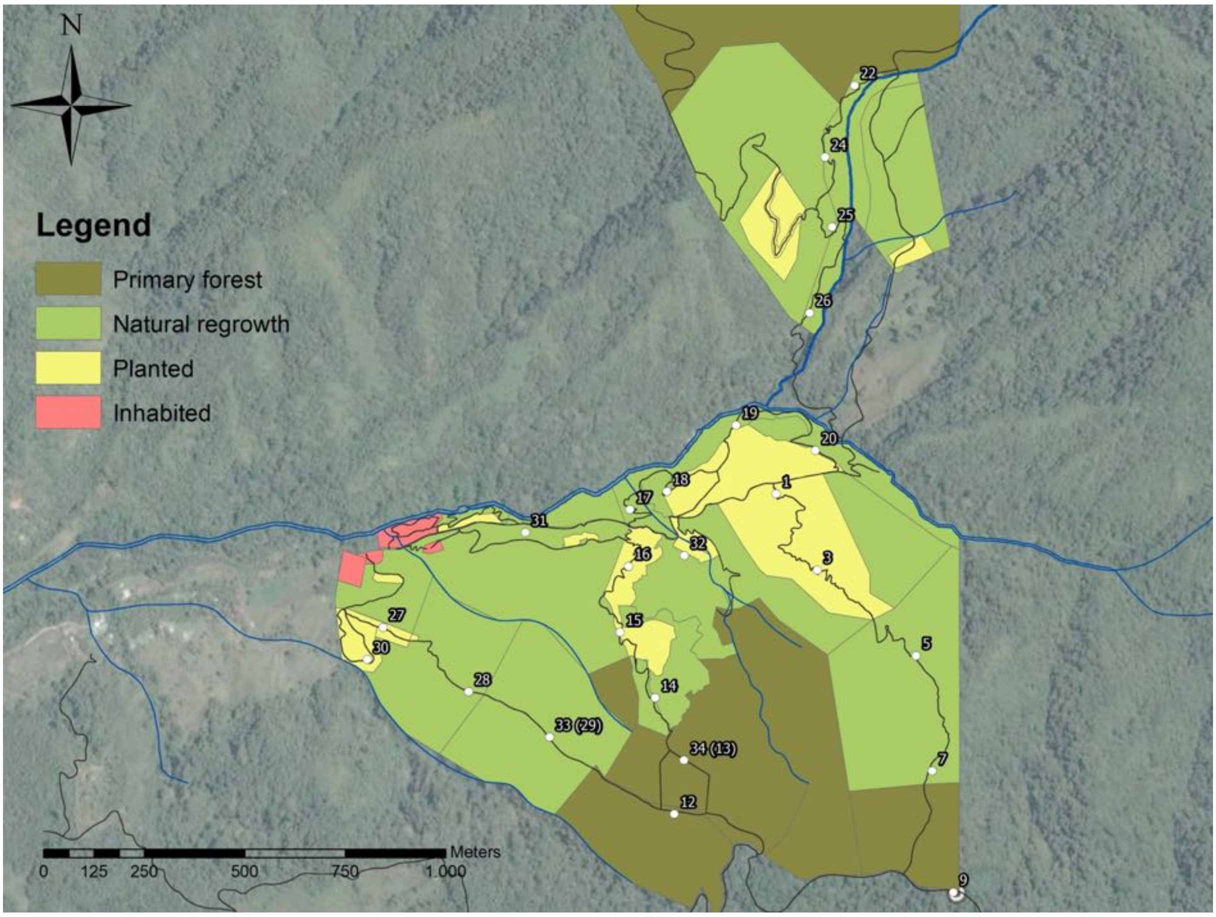


Figure 14. Reference map of Cloudbridge (Cloudbridge Nature Reserve)


Figure 15. A tree with multiple stems

Figure 16. A tree tag containing a unique number

Figure 17. Densiometer for measuring the canopy cover


Figure 18. An emergent tree in an old growth forest site