A forest recovery evaluation at the Cloudbridge nature reserve

A research on the differences of forest structure in the succession towards original cloud forest between natural regenerated and manually replanted areas in the Cloudbridge nature reserve.

Technical report on the research conducted at the Cloudbridge nature reserve by Michiel Spek and Tijmen Hoogendijk during the internship period in the 2nd and 3rd semester of the 3rd year of the BSc Tropical Forestry and Nature Management at the Van Hall Larenstein University of Applied Sciences.
Written by: Michiel Spek, May 2011

Field work carried out by: Michiel Spek
Tijmen Hoogendijk

Supervisors: Tom Gode, Cloudbridge nature reserve
Judith Jobse, Van Hall Larenstein
University of Applied Sciences
FOREWORD

For my study Tropical Forestry and Nature Management at the Van Hall Larenstein University of Applied Sciences, Tijmen Hoogendijk and I carried out a research for the Cloudbridge Private Nature Reserve in Costa Rica. The Cloudbridge nature reserve is situated in the southern central part of Costa Rica along the Cordillera Talamanca mountain chain.

This study investigates if there is a significant difference in the succession stages of forest structure from abandoned pasture land towards a cloud forest climax ecosystem between manually replanted areas and areas that are left for natural regeneration. And when this is the case, how this can be explained. With the results of this research I hope to find out in which way the forest structure succession towards a cloud forest ecosystem can be accelerated and so help the owners of the Cloudbridge Nature Reserve with making efficient choices regarding their future reforestation efforts.

I would like to thank Tom Gode and Linda Moskalyk for their advice, support and supervision during the research and I would like to thank Genevieve Giddy for giving me the opportunity to carry out this research at the Cloudbridge nature reserve.
SUMMARY

In the last years more and more nature conservationists become aware that it is important to link fragmented ecological areas to conserve the different species habitats in the tropics. When different ecological zones are linked, it will become easier for animal to migrate through bigger areas and so spread their gene pool and thus sustain healthy populations. For this reason a reforestation project is started in the Cloudbridge Nature Reserve to link the mountain regions of Chirípó with the Cordillera Talamanca mountain chain.

There is still a lack of knowledge on how to reforest former pasture farm land and how restoration of the original vegetation can be accelerated. To initiate this slow recovery process back to cloud forest, researchers try to come up with good technical approaches to reforest abandoned pasture lands.

Specific problems encountered at the Cloudbridge nature reserve during reforestation efforts are high mortality rates of planted seedlings and very slow developing tree seedlings in the replanted areas. As well, many planted seedlings are being overgrown by exotic grasses which remained in pastures after the abandoning of farmers and in this way are being terminated in their development towards becoming actual trees.

The Cloudbridge nature reserve was established in 2001, large areas still consisting of former pastureland. Tree replanting was first started in 2002 and since then development of a selection of the planted trees was monitored over the years for their survival rates, vitality and canopy closure. The regenerated trees in areas that were left to recover naturally are never monitored on these parameters. This research will monitor forest recovery in these naturally regenerated areas for the first time.

This research is specifically initiated to compare whether tree planting has established a more advanced successional stage of forest structure with those areas that are left for natural recovery on sites with comparable environmental circumstances. This to find out which tree species have developed most successfully and thus are most suitable for planting during future reforestation efforts. Furthermore a literature study has been carried out to find out which factors might have an influence on the acceleration of succession stages in forest structure under natural circumstances and how they could be influenced in order to accelerate this process.

To answer these questions, several steps had to be taken. To find out if there is a difference in successional forest structure development between the two compared reforestation strategies, a monitoring was conducted on tree establishment, individual tree development and seedling regeneration between the natural regenerated and planted areas. After all the measured data was entered in a database and averages were calculated, it became clear that there is a significant difference in developed forest structure and seedling regeneration between the natural regenerated and planted areas.

Overall, the replanted areas are proceeded in a further stage of forest recovery development compared to the naturally regenerated areas. Though this is due to only a small selection of the actually replanted tree species. Most of the initially planted tree species were not even found back in the field during our monitoring. Along the planted trees, also a considerable
amount of tree species has naturally regenerated within the replanted areas and only due to this fact the overall forest structure development is more advanced in the replanted areas. Though the finding of this difference in forest structure development between replanted and naturally regenerated areas is a sign that the manually planting of specific tree species can accelerate recovery of the forest structure on abandoned pasture lands considerably.

The replanted areas score higher on all parameters which have been measured during our field work. Though this is only partly due to the tree species that have actually been replanted, also on the replanted areas a significant amount of trees has regenerated naturally.

Concluding from the interpreted data from the field and further literature research, the next list of fifteen tree species shows to be most promising planting mix in order to accelerate the recovery of the forest structure on abandoned pasture lands in Cloudbridge nature reserve:

- Güštite (Acnistus arborescens)
- Alder (Alnus acuminate)
- Cedro dulce (Cedrela tomdulzii)
- Guarumo (Cecropia polyphlebia)
- Poro (Erythrina poepigiana)
- Maicillo (Gonzalagunia rosea)
- Burio (Heliocarpus americanus)
- Guayaba de Montana (Inga sierrae/ oerstediana)
- Guaba (Inga punctata)
- Ratoncillo (Myrsine coriacea)
- Wild avocado (Persea caerulea)
- Calagra (Psychiotra sylvivaga)
- Roble (Quercus copeyensis)
- Solanum (Solanum storkii)
- Mexican Elm (Ulmus Mexicana)
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1. INTRODUCTION

The cloud forests of the southern region of Costa Rica are of exceptional conservation importance, due to their high species diversity and endemism (Challenger, 1998). In the last decades these important cloud forest areas have been degraded and fragmented. (Fearnside, 1993). A key role in the vanishing and degrading of cloud forests is the establishment of pasture land in these former forest areas. (Tabarelli et al., 1999). After abandoning of these pasture lands by the farmers, the recovery back to forest will take many years (Uhl Buschbacher, 1988). To accelerate this slow recovery process back to cloud forest, researchers try to come up with good technical approaches to reforest abandoned pasture lands and counter the fragmentation of the original cloud forest.

In recent years, several studies have shown that once pastureland is abandoned, native species seedling recruitment is poor (Cubina & Aide 2001). Major factors causing this fact are the lack of remaining soil seed bank and seed rain input (Zimmerman, Pascarella and Aide, 2000)

A variety of studies point out that several site factors are also slowing down forest recovery, including lack of soil nutrients, soil compaction, competition with aggressive non native pasture grasses, seasonal drought, low rates of seedling colonization and predation (Buschbacher, 1986) Remnant trees can increase seed dispersal, increase soil nutrients and reduce soil temperatures (Rhoades et al., 1998). Another study recorded lower growth rates of some species of native tropical forest, between seedlings planted in open pasture compared with those under remnant trees (Holl & Quiros-Nietzen, 1999).

The goal of this research will be to investigate whether the planting of trees in abandoned pastures can accelerate the successional process in vegetation structure towards a climax cloud forest ecosystem. And when this is the case, which tree species are the most effective to achieve this goal and thus recommended for planting during future reforestation efforts in the Cloudbridge nature reserve.
2. PROBLEM STATEMENT

In the last years more and more nature conservationists become aware that it is important to link fragmented ecological areas to conserve the different species habitats in the tropics. When different ecological zones are linked, it will become easier for animal to migrate through bigger areas and so spread their gene pool and thus sustain healthy populations. For this reason a reforestation project is started in the Cloudbridge Nature Reserve to link the mountain regions of Chiripó with the Cordillera Talamanca mountain chain.

There is still a lack of knowledge on how to reforest former pasture farm land and how restoration of the original vegetation can be accelerated. To initiate this slow recovery process back to cloud forest, researchers try to come up with good technical approaches to reforest abandoned pasture lands. Specific problems encountered at the Cloudbridge nature reserve during reforestation efforts are high mortality rates of planted seedlings and very slow developing tree seedlings in the replanted areas. As well, many planted seedlings are being overgrown by exotic grasses which remained in pastures after abandoning by farmers and in this way are being terminated in their development towards becoming actual trees.

This research is initiated to compare whether tree planting has established a more advanced successional stage of forest structure with those areas that are left for natural recovery on sites with comparable environmental circumstances. This to find out which tree species have developed most successfully and thus are most suitable for planting during future reforestation efforts. Furthermore a literature study has been carried out to find out which factors might have an influence on the acceleration of succession stages in forest structure and how they could be influenced in order to accelerate this process.
The goal of this research will be to investigate whether the planting of trees in abandoned pastures can accelerate the successional process in vegetation structure towards a climax cloud forest ecosystem and which factors might have an influence on this. And when this is the case, which tree species are the most effective to achieve this goal and thus recommended for planting during future reforestation efforts in the Cloudbridge nature reserve.

This research is about to compare whether tree planting has established a more advanced successional stage of forest structure recovery after five and ten years in comparison with those areas that are left for natural recovery on sites with comparable environmental circumstances.

Main question: *Is there a significant difference in the successional stage of forest structure recovery towards a cloud forest climax ecosystem between the replanted areas and the areas that are left for natural regeneration on sites with comparable environmental circumstances within the Cloudbridge nature reserve?*

Sub-question 1: What average amount of remnant trees and regenerated tree seedlings can be found in the replanted and naturally regenerated plots?

Sub-question 2: Is there a significant difference in the amount of counted trees and tree seedlings within the different plots of replanted areas?

Sub-question 3: Which light level conditions are provided by the different tree species found in the replanted and naturally regenerated areas?

Sub-question 4: Is there a significant difference in the light level conditions and tree seedlings within the different plots of replanted areas and what is the cause?

Sub-question 5: What is the average overall canopy cover on the plots left for natural regeneration and those left to regenerate naturally?

Sub-question 6: Which tree species in both the replanted and naturally recovering areas provided the highest amount of average shade cover and thus are the most suitable tree species to plant according to this aspect?
4. RESEARCH METHODS

STUDY AREA DESCRIPTION

This research was conducted in a variety of plantation sites and in areas left to recover naturally within the Cloudbridge nature reserve. This private reserve is situated in the southern central part of Costa Rica along the Cordillera Talamanca mountain chain on an elevation between 1.500 and 2.600 meters above sea level. It covers roughly three hundred hectares of primary and secondary forest and is part of an important bio-region, surrounded by cloud forest and high elevation shrub lands, with a high diversity of species. Cloudbridge nature reserve borders the Chiripo national park, which has the status of an UNESCO World Heritage Site due to its high biodiversity and endemism. The average rainfall is approximately 4300 mm per year and the mean low and high temperature are 13,4 and 23,1 degrees Celsius.

RESEARCH PLOTS

For this research, eight study sites within the reserve were selected. Four of the selected sites have been replanted and another four were left for natural regeneration after establishment. Both in the natural regenerated as replanted areas two areas where established in 2001-2002 (ten years old) and two where established in 2006-2007 (five years old). The sites within the same age classes are selected on similar environmental circumstances to give a unbiased comparison of regeneration between replanted and naturally regenerated areas. All the research areas used to be former pasture lands which have been grazed on for approximately 25 up to 30 years.

Because of the large size of the area, it was impossible to investigate ecosystem recovery at individual tree scale. Due to that, specific plots of natural regeneration as well as planted areas were selected to carry out the research. Inside each plot, a transect with a total length of 100 meters was selected.

TRANSECT SELECTION

Inside each plot, a transect with a total length of 100 meters and a width of 8 meters was selected. Sometimes it was necessary to select a few shorter transect within a plot, due to the fact that a part of the slope was impassable because of the steepness, or the length or the width of the plot was less than 100 meters, so in this case more shorter transect in one plot were needed. Plots of natural regenerated areas and planted areas with the same age where compared, so plots where selected on age by using information provided by our principle T. Gode. Furthermore GIS data of Cloudbridge reserve developed by J. Tingerthal was used to select the plots and transects. In appendix I is a map enclosed which shows where the different plots and transects are located. In appendix II are maps enclosed for every plot.

The transects were created by using a machete to clear the lines. The coordinates and altitude for the beginning and the end of each transect were measured by using a GPS. Furthermore the distance of the transect was measured.
SAMPLING METHOD

After the transect were created all trees and parameters within a 4 meter range on both sides of the transect were measured. Several parameters per tree were measured, these parameters are:

- Species of tree
- Number of seedlings
- Species seedlings
- Coordinates tree
- Crown coverage (%)

The parameters DBH, height, crown diameter and crown cover were estimated. An empty example of the field form can be found in appendix III.

- After all the data was gathered, it was entered in Excel sheets.
- All the data gathered per transect was entered in different sheets to create a good overview of all the data gathered per transect.
- All the data of the different transects within a plot were combined to get a good overview of all the information per plot.
- All the data that was gathered in the plantation areas was combined, this also applies for the natural regenerated areas.

Many sheets were necessary to process all the data. These sheets are not attached in this report. To give you an idea how the data is processed, examples of different kind of sheets are attached in appendix IV. The detailed data is available on request or can be found on the external hard drive of Cloudbridge.

LITERATURE STUDY

A literature study has been carried out to find out which factors might have an influence on the acceleration of succession stages in forest structure under natural circumstances and how they could be influenced in order to accelerate this process. Furthermore, various books on the cloud forest trees of Costa Rica where consulted to select the most suitable species to be planted under the environmental circumstances present in the Cloudbridge nature reserve in order to help the reserve staff to make efficient choices according to their future reforestation efforts.

LIMITATIONS OF THE RESULTS

As said above, because of the large size of the area, it was impossible to investigate ecosystem recovery at individual tree scale. Due to that, areas of natural regeneration as well as planted areas were selected to carry out the research. Inside each plot, a transect with a total length of 100 meters and a width of 8 meters was selected.

By using samples, not all the trees and seedlings in the different areas were measured, but only a part of it. After that it was possible to make and estimation per hectare by extrapolating the gathered data. These data doesn’t display the actual values, but it gives us a realistic estimation. After all the data was processed, it was possible to compare the data and to answer the research questions.
5. RESULTS LITERATURE STUDY

1. REGENERATION PROCESSES IN VIRGIN CLOUD FORESTS

Before anything can be said about forest recovery on abandoned pastures, the natural regeneration in an undisturbed forest has to be examined. In this part of the report the main colonization systems used by different groups of tree species are explained.

1.1 GAPS

The most important event in the tree regeneration process within a virgin cloud forest is when an opening of the canopy occurs. A big part of tropical tree species are depending on canopy opening for seed germination or growth beyond sapling stage. The term gap or canopy gap is generally uses to refer to such empty areas within forest canopy. Gaps are normally caused by wind throw of one or more canopy dominants and become areas of the forest that have greater light levels and available nutrients. Gaps are the sites of the greatest understory regeneration and seedling growth. As canopy gap dynamics affect seedling establishment, it determines the future of the canopy composition.

The most important factor affecting the regeneration within these canopy gaps is the microclimate. Gaps have a different micro-climate varying with their size in contrast with the overall forest climate (Brown, 1993). The larger the gap, the more extreme the micro-climate will be, as the amount of direct sunlight heavily affects the microclimate. Within a canopy gap, the environmental circumstances are varying as well, the micro-climate is most extreme in the center and changes outwards to the gap edge and beyond.

In terms of forest recovery dynamics, (abandoned) pastures are nothing more than very large canopy gaps, although this is a simplification since most abandoned pastures lack a tree seed bank which is present in big naturally occurring forest gaps due to major disturbances such as tornados or forest fires.

In relation to their size, abandoned pastures have an highly extreme canopy gap micro-climate due to their continuous direct exposure to sunlight.

1.2 MICRO-CLIMATE

Differences in moisture availability can partly cause the difference in seedling survival and growth rates in open gaps or inside an established forest. Water deficit has been reported as a major cause of seedling death of tropical trees in large gaps (Turner, 2001). Outside a forest structure, the lower air humidity may increase the rate of water loss from the seedlings. Studies have shown that human intervention may facilitate and accelerate the re-colonization of tropical rainforest species. A study suggested that that establishment of tree plantations are a way to accelerate natural regeneration of native species on abandoned pasture lands (Chapman and Chapman, 1996). Though it is widely accepted that one cannot simply introduce primary forest species (in the form of seeds or seedlings) into abandoned pasture lands. Mainly because primary forest species may not survive under full sunlight and in high soil temperatures during their juvenile stage (Whithmore, 1991)
Another study suggested that manually planted pioneer trees can accelerate the recovery of a forest microclimate (Lugo, 1992). As also in natural rainforest succession, colonization of pioneer species create a suitable condition for climax species to germinate and grow. Pioneer species grow fast and will produce a canopy as quick as possible due to the competitive environment in canopy gaps. This will reduce the weed cover, increase available soil nutrients, improve soil water holding capacity and thus create a microclimate for climax species in which they are able to germinate. Another research highlighted the role of remnant tree shade in providing a favorable environment for climax tree species seedling growth by reducing light intensity and soil temperature (Harvey and Haber, 1999).

1.3 GAP CLOSURE

Canopy closure occurs in two ways. Individual trees below the top of the canopy can grow taller, expanding their canopy in all dimensions while gaining height. Neighbouring canopy tree individuals can also increase horizontal branch growth, filling up the existing gap. Research has shown that most gaps close from below as individuals grow up in the gap. This vertical recruitment is a dominant succession process in many forest ecosystems (Whitmore, 1998). Because of the competitive environment in the forest understory, individual trees have a high probability of dying when they are small. The probability of mortality then decreases for a time when the individuals reach a dominant canopy position. Finally, as trees age, the chances of dying increase again, and the recruitment process will start all over again.

1.3.1 AVAILABILITY OF LIGHT

At any particular location, the amount of light entering the gap depends on the size and topographic position of the gap, position within the gap, the height of the surrounding canopy, the sun angle and the sky conditions (Messier, 1996). Forest respond to canopy openings in two major ways: by responding through reorganization of vegetation established prior to disturbance or by responding as vegetation that becomes established following disturbance (Marks, 1974). The size of gaps in closed forests has shown to determine the type of trees recruited in the gaps. The smaller gaps are being regenerated by shade-tolerant species and the large gaps by (seed colonizing) shade-intolerant species. Though a continuum of regeneration strategies exists, with this observation researchers have tried to divide gap colonization by trees into two contrasting ecologic groups: those termed ‘climax’ or primary forest species (non-pioneer) and those classified as pioneer species (Whitmore, 1978).

1.3.2 PIONEER SPECIES

Pioneer species germinate and establish in big gaps after their creation. Their basic strategy is to become a dominant canopy tree as fast as possible. To do this, pioneer species have evolved similar characteristics to quickly and efficiently attain a dominant canopy position in the forest. Typically they produce a large volume of low density wood by fast growth and are characterized by open-branched crowns that fill as much space as possible to reduce
competition. They start to reproduce early in life and produce large quantities of small seeds that disperse easily and that stay viable in the seed banks for a long period of time. In this way they can colonize new gaps efficiently as they occur shattered through the forest. Their leaves are short-lived and their nutrients are rapidly recycled for new flushes. This strategy makes it inefficient to invest in mechanical or chemical protection against herbivores. Because of the continuum of regeneration strategies amongst trees and the ongoing debate if two distinct groups can even be classified, the true pioneer species are defined as those trees that can only germinate and establish in full light conditions. All other species that have the ability to germinate and/or establish in shaded conditions are considered climax species.

1.3.3 CLIMAX SPECIES

Climax species or shade-tolerant species are able to establish themselves under a canopy cover as advance regeneration and will respond to small gaps with a low sunlight intensity. It is a very diverse group of species. Some of these species are able to germinate in full shade, but need full light within a year to survive, while other tree species can wait several years in the canopy’s understory and use several small canopy openings and closures to grow before reaching a dominant canopy position. In contrast with the pioneer specie, climax species are slower growing species that produce high density wood and crowns. Because of the low energy availability under the canopy, shade tolerant species have developed numerous of adaptations to become as efficient as possible. They have adaptations to lower grazing pressure by herbivores, multiple layers of leaves to collect as much as possible of the available sunlight and specialized seeds in order to establish successfully under the canopy. These have to contain sufficient reserves to grow a root system and the first photosynthetic organs to survive. The negative effect of this is that they are more susceptible to seed predation, which makes it necessary for them to germinate within a few days. For these reasons climax species need to put a lot of energy in their seeds, thus limiting their seed quantities and extending the maturity time of the tree.

1.4 MICRO-SITE

Of particular importance in determining seed germination and early tree establishment in gaps is the nature and abundance of forest floor substrates found in open gap positions (Greene et al., 1999). Tree recruitment is often more dependent on this micro-site quality, which may override the effect of standing the surrounding forests, gap size and resource gradients in the gap. (Gray and Spies, 1997). Micro-site variability may be a factor of forest floor disturbance and the presence of exposed mineral soil, amount and type of coarse wood debris and degree of competing vegetation. The amount, type and, and degree of decomposition of coarse woody debris on the forest floor significantly determine seed germination and survival and growth of tree seedlings in many forest ecosystems (Harmon et al, 1986). Fallen logs, upon suitable decay, act as nurse logs or preferred sites of germination. Fallen wood, though making up only a small percentage of the micro-sites, accounts for a disproportional percentage of established seedlings. This differentiation in density and species composition on rotten wood has been attributed to the reduced competition from herbs on the raised surfaces of the coarse woody debris and retention of favorable moisture supplies (Harmon and Franklin, 1989). Whether a tree dies and remains standing for a significant of time, breaks off above the ground, or uproots to create forest
floor and soil disturbance will determine the type of micro-site available for upcoming colonization.

Non-tree vegetation may often respond to the increased resources fluxes in gaps and act as an important factor militating against successful response of tree species. Trees may therefore not respond to gap openings because of above- and below-ground competition effected by flourishing ground vegetation. Response of competing vegetation may depend on the occurred gap size. In some cases, single tree gaps result in regeneration of canopy dominants, while gaps of multiple trees enhance successful shrub regeneration, thereby suppressing the regeneration of present tree dominant seedlings (Huenneke, 1983).
6. RESULTS FIELD STUDY

To most important parameter to compare the developed forest structure is the total amount of closed canopy over the area to be reforested. In table 1 and 2 is the total shade cover calculated in the naturally regenerated areas and the replanted areas.

Table 1: Total shade cover in the areas left for natural regeneration.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Average crown diameter (m)</th>
<th>Average crown cover (%)</th>
<th>Average crown cover (m²)</th>
<th>Number of found trees in natural regeneration</th>
<th>Total shade cover in all plantation plots in m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band</td>
<td>3.9</td>
<td>65</td>
<td>3.1</td>
<td>23</td>
<td>189</td>
</tr>
<tr>
<td>Soreo</td>
<td>3.5</td>
<td>65</td>
<td>4.2</td>
<td>24</td>
<td>42</td>
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<td>65</td>
<td>3.1</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Geraalia gonazalugia</td>
<td>3.6</td>
<td>65</td>
<td>3.1</td>
<td>5</td>
<td>15</td>
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<tr>
<td>Soreo</td>
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<td>65</td>
<td>4.2</td>
<td>23</td>
<td>42</td>
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<tr>
<td>Psychotria sylvegena</td>
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<td>53</td>
<td>2.6</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
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<td>53</td>
<td>2.6</td>
<td>4</td>
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<td>2.8</td>
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<td>4.2</td>
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<td>0.7</td>
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<td>4</td>
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<td>Total shade cover plantation per ha</td>
<td>212</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Table 2: Total shade cover in replanted areas.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Average crown diameter (m)</th>
<th>Average crown cover (%)</th>
<th>Average crown cover (m²)</th>
<th>Number of found trees in plantation</th>
<th>Total shade cover in all plantation plots in m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band</td>
<td>3.5</td>
<td>65</td>
<td>3.1</td>
<td>23</td>
<td>189</td>
</tr>
<tr>
<td>Quercus</td>
<td>2.7</td>
<td>65</td>
<td>3.8</td>
<td>23</td>
<td>38</td>
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<td>11.2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Ceder dulce</td>
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<td>3.1</td>
<td>4</td>
<td>12</td>
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The overall shade cover in the replanted areas shows to be almost twice as high compared to the areas that were left to recover naturally. Although naturally regenerated species in the replanted areas are providing an essential part of the shade cover as well. Table 3 and 4 also show the average developed amount of provided shade per hectare per tree species. This data is used to select the tree species to be recommended for planting in the future on Cloudbridge nature reserve.
Table 3 and 4 show the different seedling species that were found in the natural regenerated areas and the different seedling species that were found in the replanted areas. When you look at both tables, you can see that more seedling species were found in the natural regenerated areas, but that more seedlings were found in the replanted areas.

A reason that more seedlings were found in the replanted area could be that there is more shadow because of the larger amount of trees that were found. As you can see in appendix V are most seedlings found under Burio, Ulmus mexicana and Psychotria sylvivaga. Only the Ulmus mexicana was planted and only 165 of the 1013 seedlings that were found, were found under the Ulmus mexicana. This is 16 percent of the total amount of species that were found. Because of that, it is not possible to say that more seedlings were found because most of them established under planted species.
In table 5 the averages of the diameter breast height (DBH) and total height of all the found tree species both in the replanted as naturally regenerated areas are calculated. In this way we can see which species are most successful in developing towards a mature tree stage within the given period of time after initiation of forest recovery. This data is used to make the selection of tree species which are most recommended for planting in Cloudbridge nature reserve during future reforestation efforts.
7. CONCLUSIONS

Literature studies on natural regeneration in a virgin cloud forest shows that the most important event in the tree regeneration process within a virgin cloud forest is when an opening of the canopy occurs. Further came forward that the size of gaps in closed forests determines the type of trees recruited in the gaps. Small gaps coupled with advance regeneration of shade-tolerant species (climax species) ignites the ‘reorganization’ response while seed colonization of large gaps by shade-intolerant (pioneer species) would define the other extreme. From this observation researchers have tried to divide gap colonization by trees into two contrasting ecologic groups: those named primary of climax species (non-pioneer) and pioneer species. Tree recruitment is sometimes more dependent on micro-site quality, which may override the effect of the gap size, resource gradients and height of the surrounding canopy. Also micro-climate related factors as soil humidity, sunlight intensity and soil temperature may suppress the regeneration and development of present tree seedlings. Overall can be concluded that pioneer species are the most recommended type of trees to be planted in large open areas as they are adapted to the extreme micro-climate present in these places.

To test if there is a significant difference in forest structure development and amount of regenerated seedlings between the natural regenerated area and the replanted areas, a monitoring was conducted. After the results were compared it became clear that there is a significant difference in forest structure development and amount of regenerated seedlings.

Overall, the replanted areas are proceeded in a further stage of forest recovery development compared to the naturally regenerated areas. Though this is due to only a small selection of the actually replanted tree species. Most of the initially planted tree species were not even found back in the field during our monitoring. Along the planted trees, also a considerable amount of tree species has naturally regenerated within the replanted areas and only due to this fact the overall forest structure development is more advanced in the replanted areas. The replanted areas score higher on all parameters which have been measured during our field work. Though this is only partly due to the tree species that have actually been replanted, also on the replanted areas a significant amount of trees has regenerated naturally.

Though the finding of this difference in forest structure development between replanted and naturally regenerated areas is a sign that the manually planting of specific tree species can accelerate recovery of the forest structure on abandoned pasture lands considerably.

The overall crown cover in the parts that are left for natural regeneration is lower due to the fact that there are places where not even pioneer trees couldn’t manage to establish naturally after 5 to 10 years. Big parts of these areas are still dominated by exotic grasses. In these areas human intervention is required to bring in the pioneer species manually in order to accelerate the colonizing of a forest structure.

It’s of significant importance that these open areas are converted into forest structures in the shortest possible time as most migrating animals avoid open areas. Hence the open areas left in the reserve are barriers for many species. Pioneer species are capable to convert open lands into forest structures in a considerable short amount of time and thus are the most logical choice to plant for this purpose.

Remnant trees create a microclimate by evening out extremes such as long exposure to sunlight and related high soil temperatures, reducing impact of wind and raindrop erosion and preventing droughts by sustaining the soil humidity. Most climax species are not built to survive any of these
potential extremes in a juvenile stage and thus are only able to survive within the relative smooth circumstances of a established forest climate.

In all rainforest ecosystems, colonization of pioneer species after disturbance creates a suitable for climax species to germinate and grow. Pioneer species grow very fast and must produce canopy as quickly as possible as an effect of the highly competitive environment in canopy gaps. This canopy cover will reduce the weed cover and create a favorable microhabitat an microclimate for climax species to germinate and often increase soil nutrients.

Planting of climax species should be postponed until pioneer species have established a microclimate without environmental extremes in which climax species seedlings can survive.

RECOMMENDED TREE SPECIES

After interpretation of the data gained during our observations in the field and according to our literature research, we can conclude that the following planting mix of tree species will be most successful for future reforestation efforts on abandoned pasture lands in order to accelerate the recovery of the forest structure in the Cloudbridge nature reserve:

SOIL IMPROVING NITROGEN FIXATORS

- Alder (*Alnus acuminate*)

A fast growing, nitrogen fixating tree which can reach great heights in a short amount of time. It produces a wide crown with half open foliage. This species is used in plantations for pulp and lower quality construction material production due to its low density.

- Poro (*Erythrina poeppigiana*)

A fast growing, shade intolerant and nitrogen fixing tree which is used for the purpose of living fence widely by farmers in the surrounding area and throughout whole Costa Rica for a variety of purposes. This due to the fact that this tree is easily propagated by branch cuttings which makes it a promising candidate for reforestation of abandoned pastures as well. The tree can reach a big size in a considerable short amount of time.

- Guayaba de Montana (*Inga sierra e/oerstediana*)

Medium to large nitrogen fixating tree with dense foliage. The flowers attract moths and hummingbirds while the seeds are dispersed by a wide variety of animals. This tree is not particularly shade tolerant nor shade-intolerant and represents a group of tree in the middle of pioneer and climax species.

- Guaba (*Inga punctata*)

This nitrogen fixating tree is one of the faster growing but smaller trees within the Inga family. This species was historically frequently planted as a shade tree in coffee plantations.
Their flowers are visited by as well bats, birds and insects. Seeds are dispersed by animals such as monkeys and squirrels. Present reforestation experiments with this species under similar environmental circumstances as on Cloudbridge nature reserve shows promising results due to their ability of diminishing exotic grass species in a short period of time. A nursery of approximately 500 planted guaba seeds is being set up right now within the Cloudbridge nature reserve.

**FRUIT BEARING SEED DISPERSER ATTRACTORS**

- **Solanum** (*Solanum storkii*)

  This small, but fast growing flowering and fruit bearing pioneer tree which attracts a wide variety of seed dispersing and pollinating animals. Easily propagated by branch cuttings makes is at ideal tree for reforestation efforts.

- **Maicillo** (*Gonzalagunia rosea*)

  This small, flowering and fruit bearing pioneer tree attracts a wide variety of birds and pollinators. Though this is not a potential canopy species, it’s likely one of the most promising species to attract seed dispersing animals into the to be reforested areas.

- **Güitite / Gallinero / Wild tobacco** (*Acnistus arborescens*)

  This is a small but fast growing tree which is likely to be a promising species to accelerate forest structure recovery on abandoned pastures. It’s a flowering species and produces large amount of small fruit all along its branches which attracts a large variety of birds. It produces a soft wrinkly bark which give this species the ideal properties to cultivate orchids on. This species is widely used for purposes such as fences and land marking due to its capability to be able to be propagated by branch cuttings. The tree has a short live-span and is likely to be overgrown after passing of time by more shade tolerant species.

- **Wild avocado** (*Persea caerulea*)

  This fruiting climax species tree occurs widely through the primary cloud forest and is a main food source for the pride of the cloud forest: the Resplendent Quetzal. The tree is shade tolerant and likely to develop optimally after planting in a further proceeded stage of forest succession.

**FAST GROWING GRASSLAND COLONIZERS**

- **Calagra** (*Psychotria sylvivaga*)

  We couldn’t find this tree back during our literature studies (the scientific name mentioned above is used throughout this report but most likely to be incorrect) though it proved to be a promising tree in the naturally regenerated parts of Cloudbridge nature reserve. The local
workers call this tree ‘Calagra’. It is fast growing pioneer tree with an average crown diameter with dense foliage.

- Guarumo (*Cecropia polyphlebia*)

Guarumo is a fast growing, shade-intolerant tree which in natural conditions could be found in relatively light conditions and such as canopy edges. Guarumo is an important tree for many animals in the tropical forest. It is one of the main food sources of Howler monkeys and the tree is a home base for sloths. Mature trees are found often on edges of secondary forest and forest gaps.

- Burio (*Heliocarpus americanus*)

The Burio is one of the fastest growing trees in this region, and likely one of the few tree species able of competing with the present grass species left in the abandoned pastures without human interference. It is a typical pioneer species with a wide open crown which produces low density wood. The tree is able to regenerate under a variety of extreme conditions and capable of forming a forest structure in a considerable short time span. It drops a lot of foliage and the so formed litter layer existing out of leaves and coarse wood debris competes with exotic grasses and forms a substrate on which seedlings of other tree species can develop. The tree has a short live-span and is likely to be overgrown after passing of time by more shade tolerant species.

- Ratoncillo (*Myrsine coriacea*)

Ratoncillo is a very fast growing tree with an average crown diameter and low to average density foliage. It produces high amounts of seeds which attracts birds and other seed dispersers like squirrels.

HIGHLY VITAL CLOUD FOREST CANOPY TREES:

- Mexican Elm (*Ulmus Mexicana*)

The mexican elm is a shade tolerant species and one of the largest trees found in the cloud forest. This species produces a wide, deep crown with very dense foliage. After maturing almost no light passes through the dense foliage and creates large areas of low light level conditions under the tree crowns. The tree is shade tolerant and likely to develop optimally after planting in a further proceeded stage of forest succession.

- Cedro dulce (*Cedrela tonduzii*)

This tree is native to the cloudforest and is a half shade tolerant species which can reach great heights in maturity. From literature studies and from our observations in the field can be concluded that this species creates a wide crown with an open foliage. Also during dry periods, this tree loses its foliage which makes is a less suitable species to compete with exotic grass species in the initial stage of replanting efforts. For this reason this tree is recommended to be planted in a further proceeded stage of forest succession.
• **Oak (Quercus copeyensis)**

This oak is an abundant tree in the primary cloud forest, it is this a shade tolerant species which produces a average to wide crown with very dense foliage. This seems to be the only quercus species with a higher survival rate under less shaded conditions though planting in a further developed stage of forest recovery is recommended. After maturing almost no light passes through the dense foliage and creates large areas of low light level conditions under the tree’s crown. The tree is shade tolerant and likely to develop optimally after planting in a further proceeded stage of forest succession.
DISCUSSION

Overall, the measured forest structure in the replanted areas was higher than in the areas that were left for natural regeneration. Also the average amount of seedlings found under the individual trees was higher in the planted areas. This sounds logical, but in the replanted areas, most regenerated seedlings were found under naturally regenerated trees. Also the further proceeded stage of forest succession is mainly due to naturally regenerated trees while most planted tree species were not found back at all.

To determine whether that this observation is a coincidence or might have an explainable underlying cause more research has to be conducted. More transects in the areas have to be made and more factors like the distance to primary forest edge should be taken into account in order to explain these observations.
8. REFERENCES


APPENDIX I: MAP CLOUDBRIDGE RESERVE
APPENDIX II: MAPS SAMPLE PLOTS

Map plot 1: Transect A01-A02

A01 — A02 Transect A01-A02

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APPENDIX IV: EVALUATION FIELD FORM

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</tr>
<tr>
<td>Species</td>
<td>Date (mm)</td>
<td>Height (m)</td>
<td>Dir. Diam (mm)</td>
<td>Under grass cover</td>
<td>Incl. Cover</td>
<td>Incl. St.</td>
<td>Canopy</td>
<td>Coor. Lat.</td>
<td>Coor. Lon.</td>
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<td>20</td>
<td>20</td>
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</tr>
</tbody>
</table>

**Date of inventory:** 23-5-2011

**Conducted by:** Michel Saeke and Timen Hoogendoorn

**Coordinates:**
- North: 50 80 98
- West: 69 3 43
Example of sheet were all the trees of one species of all different plots are compiled.

<table>
<thead>
<tr>
<th>nr</th>
<th>species</th>
<th>DBH (cm)</th>
<th>Height (m)</th>
<th>cr. Diam (m)</th>
<th>cr. cover (%)</th>
<th>and. Cover</th>
<th>nr. seedlings</th>
<th>Sp. Seedlings</th>
<th>coordinate N</th>
<th>coordinate W</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bino</td>
<td>15</td>
<td>8</td>
<td>3</td>
<td>30</td>
<td></td>
<td>3</td>
<td>Micana spec. 1x</td>
<td>09 28 413</td>
<td>003 34 240</td>
</tr>
<tr>
<td>2</td>
<td>Bino</td>
<td>15</td>
<td>8</td>
<td>2</td>
<td>30</td>
<td>4</td>
<td>5</td>
<td>Quercus ? 1x</td>
<td>09 28 413</td>
<td>003 34 240</td>
</tr>
<tr>
<td>3</td>
<td>Bino</td>
<td>16</td>
<td>10</td>
<td>3</td>
<td>25</td>
<td>4</td>
<td>7</td>
<td>Ulmus martiana 1x</td>
<td>09 28 229</td>
<td>003 34 651</td>
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<tr>
<td>4</td>
<td>Bono</td>
<td>26</td>
<td>12</td>
<td>6</td>
<td>30</td>
<td>4</td>
<td>5</td>
<td>Solanum 2x</td>
<td>09 29 229</td>
<td>003 34 665</td>
</tr>
<tr>
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<td>Bino</td>
<td>10</td>
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<td>5</td>
<td>40</td>
<td>3</td>
<td>2</td>
<td>Cedro dolce 1x</td>
<td>09 28 225</td>
<td>003 34 665</td>
</tr>
<tr>
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<td>Bono</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>30</td>
<td>4</td>
<td>5</td>
<td>Solanum 2x</td>
<td>09 28 224</td>
<td>003 34 666</td>
</tr>
<tr>
<td>7</td>
<td>Bono</td>
<td>25</td>
<td>10</td>
<td>4</td>
<td>40</td>
<td>3</td>
<td>3</td>
<td>Bono 1x</td>
<td>09 28 221</td>
<td>003 34 669</td>
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<tr>
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<td>Bono</td>
<td>26</td>
<td>6</td>
<td>4</td>
<td>40</td>
<td>4</td>
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<td>Solanum 1x</td>
<td>09 28 506</td>
<td>003 34 140</td>
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<td>Caragana nitida 1x</td>
<td>09 28 504</td>
<td>003 34 129</td>
</tr>
<tr>
<td>10</td>
<td>Bono</td>
<td>35</td>
<td>15</td>
<td>4</td>
<td>15</td>
<td>4</td>
<td>10</td>
<td>Solanum 19x</td>
<td>09 28 503</td>
<td>003 34 129</td>
</tr>
</tbody>
</table>
### APPENDIX V: TABLE OF SPECIES COMBINED

Both tables show the different tree species that were found, the number of trees per tree species, the number of seedlings found per tree species and the number of seedling species found per tree species.

#### Plantation area:

<table>
<thead>
<tr>
<th>Species tree</th>
<th>number of trees found / ha</th>
<th>number of seedlings found / tree spec / ha</th>
<th>number of seedling species found / tree spec / ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burro</td>
<td>72</td>
<td>130</td>
<td>13</td>
</tr>
<tr>
<td>Liriodendron</td>
<td>19</td>
<td>180</td>
<td>18</td>
</tr>
<tr>
<td>Pseudotsuga</td>
<td>30</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Quercus</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Salix</td>
<td>29</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Cedrela dolosoides</td>
<td>13</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Eucalyptus</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Populus</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Acacia</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sauarea pittieri</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Thuja larch</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Quercus rubra</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Corokia</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Fagus</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cupressus</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>204</td>
<td>631</td>
<td>27</td>
</tr>
</tbody>
</table>

| Number of tree species found | 27 |
| Number of seedling species found | 27 |

#### Natural regeneration area:

<table>
<thead>
<tr>
<th>Species tree</th>
<th>number of trees found per ha</th>
<th>number of seedlings found per tree spec / ha</th>
<th>number of seedling species found / tree spec / ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burro</td>
<td>72</td>
<td>275</td>
<td>22</td>
</tr>
<tr>
<td>Poncirus</td>
<td>31</td>
<td>81</td>
<td>3</td>
</tr>
<tr>
<td>Cupressus</td>
<td>6</td>
<td>41</td>
<td>5</td>
</tr>
<tr>
<td>Sauarea pittieri</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Liriodendron</td>
<td>14</td>
<td>47</td>
<td>12</td>
</tr>
<tr>
<td>Cedrela dolosoides</td>
<td>3</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Pseudotsuga</td>
<td>13</td>
<td>63</td>
<td>7</td>
</tr>
<tr>
<td>Quercus rubra</td>
<td>6</td>
<td>34</td>
<td>8</td>
</tr>
<tr>
<td>Myrsine corinea</td>
<td>16</td>
<td>28</td>
<td>3</td>
</tr>
<tr>
<td>Populus</td>
<td>19</td>
<td>66</td>
<td>16</td>
</tr>
<tr>
<td>Sauarea montana</td>
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</tr>
<tr>
<td>unknown 15</td>
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<td>3</td>
</tr>
<tr>
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<td>13</td>
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<tr>
<td>unknown 11</td>
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<td>1</td>
</tr>
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<td>Gonocaryopteris rosea</td>
<td>3</td>
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<td>Gomphocarpus pubescens</td>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Shrub 2</td>
<td>3</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>unknown 20</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Inga Oerstediana</td>
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</tr>
<tr>
<td>Total</td>
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<td>728</td>
<td>22</td>
</tr>
</tbody>
</table>

| Different amount of tree species found | 22 |
| Different amount of seedling species found | 41 |