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Cloud Forest recovery - evaluation at Cloudbridge Nature Reserve, Costa Rica

A research study on the differences in forest structure in the succession towards primary cloud forest between naturally 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, Dept of Tropical Forestry, Van Hall Larenstein University of Applied Sciences

FOREWORD

For my study for Tropical Forestry and Nature Management at the Van Hall Larenstein University of Applied Sciences, Tijmen Hoogendijk and I carried out 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 seeks to determine 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. Should differences in the regeneration be found, I will attempt to provide an explanation. 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 effective 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 recent years more and more nature conservationists have 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 animals to migrate through more extensive areas and so spread their gene pool, thus sustaining healthy populations. For this reason a reforestation project was started at Cloudbridge Nature Reserve to link the national park of the mountain regions of Chirippó with other large private nature reserves.

There is still a lack of knowledge on the best methods of reforesting former pasture farm land and how restoration of the original vegetation can be accelerated. To initiate this slow recovery process, researchers have tried to come up with successful technical approaches to reforest abandoned pasture lands.

Specific problems encountered at Cloudbridge 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 the pastures after the abandonment of the pasturing of cattle and are thus being hindered in their growth and development.

When Cloudbridge was established in March 2002, large areas still consisted of former pastureland. Tree replanting was first started that same year, 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 were not monitored according to these parameters. **This research will monitor forest recovery in these naturally regenerated areas for the first time.**

This study is specifically designed to compare whether manual tree planting has established a more advanced successional stage of forest structure than those areas which had been left for natural recovery on sites with comparable environmental circumstances. This will enable us to determine 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 reforestation strategies being compared, 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 have progressed to a further stage of forest recovery development compared to the naturally regenerated areas. However, this is due to only a small selection of the replanted tree species. Most of the initially planted tree species were not even found in the field during our monitoring. *Amongst the planted trees, a considerable number of tree species have 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 finding of this difference in forest structure development between replanted and naturally regenerated areas is a sign that the manual 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 were measured during our field work. This is only partly due to the tree species that have actually been replanted, as in the replanted areas a significant number of trees have regenerated naturally.

My conclusion from the data from the field and further literature research is that the following list of fifteen tree species provides the most promising planting mix in order to accelerate the recovery of the forest structure on abandoned pasture lands at Cloudbridge:

- Guitite (*Acnistus arborescens*)
- Alder (*Alnus acuminata*)
- Cedro dulce (*Cedrela tonduzii*)
- Guarumo (*Cecropia polyphlebia*)
- Poro (*Erythrina poeppigiana*)
- Maicillo (*Gonzalagunia rosea*)
- Burio (*Heliocarpus americanus*)
- Guayaba de Montana (*Inga sierrae/ oerstediana*)
- Guaba (*Inga punctata*)
- Ratoncillo (*Myrsine coriacea*)
- Wild avocado (*Persea caerulea*)
- “Calagra”(sp.?) (*Psychotria 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 factor 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 Cloudbridge Nature Reserve.

2. PROBLEM STATEMENT

In recent years more and more nature conservationists have 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 is easier for animals to migrate through these larger areas, to spread their gene pool and thus sustain healthy populations. For this reason a reforestation project was launched at Cloudbridge Nature Reserve to link the mountain regions of Chirippó National Park in the Cordillera Talamanca mountain chain, with another large private reserve, creating a biological corridor.

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, researchers have attempted to come up with good technical approaches to reforest abandoned pasture lands. Specific problems encountered at Cloudbridge 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 their growth and development are being hindered.

This research aims 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. A further goal is 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.

3. RESEARCH QUESTIONS

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 in achieving this goal and thus recommended for planting during future reforestation efforts in the Cloudbridge nature reserve, or similar high altitude reserves.

This study compares 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 were left for natural regeneration on sites with comparable environmental circumstances within the Cloudbridge nature reserve?*

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

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

Sub-question 3: What are the light level conditions provided by the different tree species 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 Cloudbridge. 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 Chirippo National Park, which has the status of a 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 the naturally regenerated and the replanted areas were established in 2002 (nine years old) and two were established in 2006-2007 (four - five years old). The sites within the same age classes are selected on similar environmental circumstances to give an unbiased comparison of regeneration between replanted and naturally regenerated areas. All the research areas used to be former pasture lands which had 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 were selected on age by using information provided by the Reserve's Program Director, Tom Gode. Furthermore, GIS data of Cloudbridge Reserve developed by John Tingerthal was used to select the plots and transects. In appendix I is a map which shows where the different plots and transects are located. In appendix II there are maps for every plot.

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

SAMPLING METHOD

After the transects 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 being:

- Species of tree
- Number of seedlings
- Species seedlings
- Coordinates tree
- Crown coverage (%)
- Undergrowth cover
- DBH (cm) per tree
- Height (m) per tree
- Crown diameter (m)

The parameters DBH, height, crown diameter and crown cover were estimated. An 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 were consulted to select the most suitable species to be planted under the environmental circumstances present in the Reserve in order to help the reserve staff to make the best decisions regarding their future reforestation efforts.

LIMITATIONS OF THE RESULTS

Because of the large size of the area, it was impossible to investigate ecosystem recovery at individual tree scale. Due to this constricting factor, 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.

Sampling was necessary – i.e., not all the trees and seedlings in the different areas were measured, but only some of them. Using these samples, it was possible to make an estimate per hectare by extrapolating the data gathered. These data do not display the actual values, but they do provide us with a realistic estimate.
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 in the canopy occurs. A huge number of tropical tree species depend on canopy gaps for seed germination or growth beyond sapling stage. The term gap or canopy gap is generally uses to refer to such open areas within forest canopies. Gaps are normally caused by the wind felling one of more canopy dominants. These gaps 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 micro-climate. 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 vary as well; the micro-climate is most extreme in the center with less marked 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 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 establishment of tree plantations are a way to accelerate natural regeneration of native species on abandoned pasture lands (Chapman and Chapman, 1996). However, 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 (Whitmore, 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 creates a suitable condition for climax species to germinate and grow. Pioneer species grow fast and will produce a canopy as quickly 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 study 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. Neighboring 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). Forests 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 themselves in 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 to grow before reaching a dominant canopy position. In contrast with the pioneer species, 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. The response of competing vegetation may depend on the 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

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

Common name	Average crown diameter (m)	Average crown cover (%)	Average crown cover (m²)	Number of found trees in natural regeneration	Total shade cover in all plantation plots in m²
Burio	3,9	31	3,8	23	87
Solanum	3,5	44	4,2	10	42
Cecropia	5,5	45	10,7	2	21
Saurauia pittieri	3,0	60	4,2	1	4
Mexican elm	3,6	50	5,1	5	25
Gonzalagunia rosea	2,0	40	1,3	2	3
Cedro dulce	2,5	70	3,4	1	3
Psychiotra sylvivaga	2,8	45	2,7	4	11
Saurauia rubiformis	2,5	53	2,6	4	10
Myrsine coriacea	2,6	58	3,1	5	15
Pepper bush	2,7	50	2,8	6	17
Saurauia montana	3,0	65	4,6	2	9
Unknown 12	1,5	40	0,7	2	1
Oreopanax Xalapensis	1,5	30	0,5	1	1
Unknown 11	2,0	50	1,6	1	2
Cinchona pubescens	2,0	30	0,9	1	1
Shrub 2	4,0	30	3,8	1	4
Unknown 20	4,0	30	3,8	1	4
Inga oerstediana	4,0	50	6,3	1	6
				Total shade cover plantation in m²	266
				Total shade cover plantation per ha	833

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

Common name	Average crown diameter (m)	Average crown cover (%)	Average crown cover (m²)	Number of found trees in plantation	Total shade cover in all plantation plots in m²
Burio	3,5	38	3,6	23	83
Quercus	2,7	69	3,8	9	35
Alder	5,3	50	11,2	3	33
Cedro dulce	2,5	63	3,1	4	12
Tree fern	5,0	20	3,9	1	4
Solanum	3,7	45	4,7	6	28
Psychiotra sylvivaga	4,3	54	7,8	16	126
Mexican elm	4,1	54	7,3	19	139
Saurauia pittieri	3,0	60	4,2	1	4
Cecropia	3,0	60	4,2	1	4
Oreopanax spec	2,0	40	1,3	1	1
Saurauia rubiformis	3,0	60	4,2	1	4
Ratoncillo	4,0	40	5,0	1	5
Poro	3,5	63	6,0	4	24
Bocconia frutescens	3,0	80	5,7	1	6
Black pepper bush	5,5	75	17,8	2	36
				Total shade cover plantation in m²:	544
				Total shade cover plantation per ha:	1700

Table 2: Total shade cover in replanted areas.

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 amount of provided shade per hectare per tree species. This data could be used to select the tree species to be recommended for planting in the future on Cloudbridge.

Nr	Seedling species	Number/ ha
1	Solanum	184
2	Myrsine coriacea	116
3	Saurauia rubiformis	44
4	Oreopanax xalapensis	22
5	Saurauia pittierii	28
6	Inga oerstediana	6
7	Saurauia montana	28
8	Burio	56
9	Miconia spec	13
10	Quercus?	13
11	Ginchona Pubescens	91
12	Oreopanax spec.	22
13	Persea schiedeana	6
14	Ulmus Mexicana	16
15	Psychiotra sylvivaga	6
16	Cecropia	13
17	cedrula tonduzii	9
18	Alder	6
19	Vismia spec	3
20	Conzalagunia rosea	6
21	unknown 4	3
22	unknown 9	3
23	unknown 10	3
24	unknown 11	3
25	unknown 13	3
26	unknown 14	9
27	unknown 15	3
28	unknown 16	3
29	unknown 17	3
30	unknown 18	3
31	unknown 19	3
32	unknown 21	3
33	unknown 22	6
34	Unknown 23	3
35	Unknown	3
36	Unknown 27	3
	Total	746,875

Table 3: Seedling amounts that were found in the natural regenerated areas.

nr	Seedling species	Number/ ha
1	Burio	91
2	Solanum	381
3	Quercus?	78
4	Miconia spec	53
5	Styphaolobium monteriridis	22
6	Saurauia pittierii	81
7	Cedrula tonduzii	41
8	Saurauia rubiformis	16
9	Inga oerstediana	19
10	Myrsine coriacea	50
11	Unknown 2	6
12	Unknown 3	25
13	Saurauia montana	34
14	Ginchona pubescens	6
15	Ulmus mexicana	22
16	Oreopanax spec	13
17	Gonzalagunia rosea	6
18	Bocconia frutescens	13
19	Vismia spec	3
20	Psychiotra sylvivaga	6
21	Erythrina costaricensus	0
22	Unknown 5	3
23	Unknown 6	3
24	Unknown 25	6
25	Unknown	3
26	Unknown 27	9
27	Unknown 28	6
28	Unknown 29	6
29	Unknown 30	9
	Total	1013

Table 4: Seedling species that were found in the replanted areas.

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, most seedlings were 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.

Common name	DBH (cm)	Height (m)
Burio	19,6	8,8
Quercus	11,1	6,8
Alder	16,7	8,7
Cedro dulce	11,0	5,5
Tree fern	15,0	3,0
Solanum	6,4	3,8
Psychiotra sylvivaga	17,3	9,9
Mexican elm	12,4	8,4
Saurauia pittierii	5,0	5,0
Cecropia	15,0	11,0
Oreopanax spec	5,0	2,5
Saurauia rubiformis	6,0	4,0
Poro	12,5	6,5
Bocconia frutescens	3,0	4,0
Black pepper bush	5,0	3,6
Gonzalagunia rosea	2,0	3,0
Myrsine coriacea	10,8	8,7
Saurauia montana	7,5	7,5
Unknown 12	5,0	5,0
Oreopanax Xalapensi	5,0	5,0
Unknown 11	5,0	5,0
Ginchona pubescens	5,0	5,0
Shrub 2	5,0	5,0
Unknown 20	10,0	10,0
Inga oerstediana	10,0	10,0

Table 5: Average physiological characteristics per tree 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 and 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. Furthermore, it has been discovered 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 such as soil humidity, sunlight intensity and soil temperature may suppress the regeneration and development of tree seedlings. Overall, it can be concluded that pioneer species are to be recommended as the most suitable 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 number of regenerated seedlings between the natural regenerated area and the replanted areas, monitoring of the areas 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 in a more developed stage of forest recovery, 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.

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 managed 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 important 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 environment of an established forest to which they are adapted.

In all rainforest ecosystems, colonization of pioneer species after disturbance creates a suitable environment for climax species to germinate and grow. Pioneer species grow very fast and must produce canopy cover as quickly as possible, which will reduce the number of weeds, create a favorable microhabitat and microclimate for climax species to germinate and often increase soil nutrients. (eg nitrogen fixing by such trees as the alder (Alnus acuminata).

Planting of climax species should be postponed until pioneer species have established a micro climate 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 FIXERS

- Alder (*Alnus acuminata*)

- A fast-growing, nitrogen-fixing 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. It can reach heights of 80feet within four years.

- Poro (*Erythrina poeppigiana*)

- A fast-growing, shade intolerant and nitrogen-fixing tree which is used widely by farmers in the surrounding area and throughout whole Costa Rica for a variety of purposes, including living fences. 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 large size within a relatively short amount of time.

- Guayaba de Montana (*Inga sierrae/ oerstediana*)

-A medium to large nitrogen-fixing 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-fixing 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 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 to shade out 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, attracts a wide variety of seed dispersing and pollinating animals. Easily propagated by branch cuttings makes this an 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 ability to be propagated by branch cuttings. The tree has a short life-span and is likely to be overgrown after some 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 developed stage of forest succession.

FAST GROWING GRASSLAND COLONIZERS

- Calagra (*Psychotria sylvivaga*)

We couldn't find this tree listed 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, birds and insects in the tropical forest. It is one of the main food sources of monkeys and the tree frequently serves as 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 is likely one of the few tree species able to compete 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 litter layer thus created from its leaves and coarse wood debris serve to stifle the growth of exotic grasses and forms a substrate on which seedlings of other tree species can develop. The tree has a short life-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 copious quantities of seeds which attract birds and other seed dispersers like squirrels.

- Mexican Elm (*Ulmus Mexicana*)

The Mexican elm is a shade tolerant conifer 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 more developed stage of forest succession.

IMPORTANT CLOUD FOREST CANOPY TREES:

- Cedro dulce (Cedrela tonduzii)

This tree is native to the cloud forest and is a half shade tolerant species which can reach great heights in maturity. From literature studies and from our observations in the field, it can be concluded that this species creates a wide crown with an open foliage. During dry periods, this tree loses its foliage which makes it a less suitable species to compete with exotic grass species in the initial stage of replanting efforts. For this reason this tree is recommended for planting at a later stage of forest succession.

- Oak (*Quercus copeyensis*)

This oak is an abundant tree in the primary cloud forest; it is a shade-tolerant species which produces an 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 at a later stage of forest recovery is recommended. After maturing, almost no light passes through the dense foliage, and large areas of low light level conditions are created under the tree's crown.

DISCUSSION

Overall, the forest structure in the replanted areas was found to be further advanced than in the areas that were left for natural regeneration. Also, the average number 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 developed stage of forest succession is mainly due to naturally regenerated trees while most planted tree species were not found 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.

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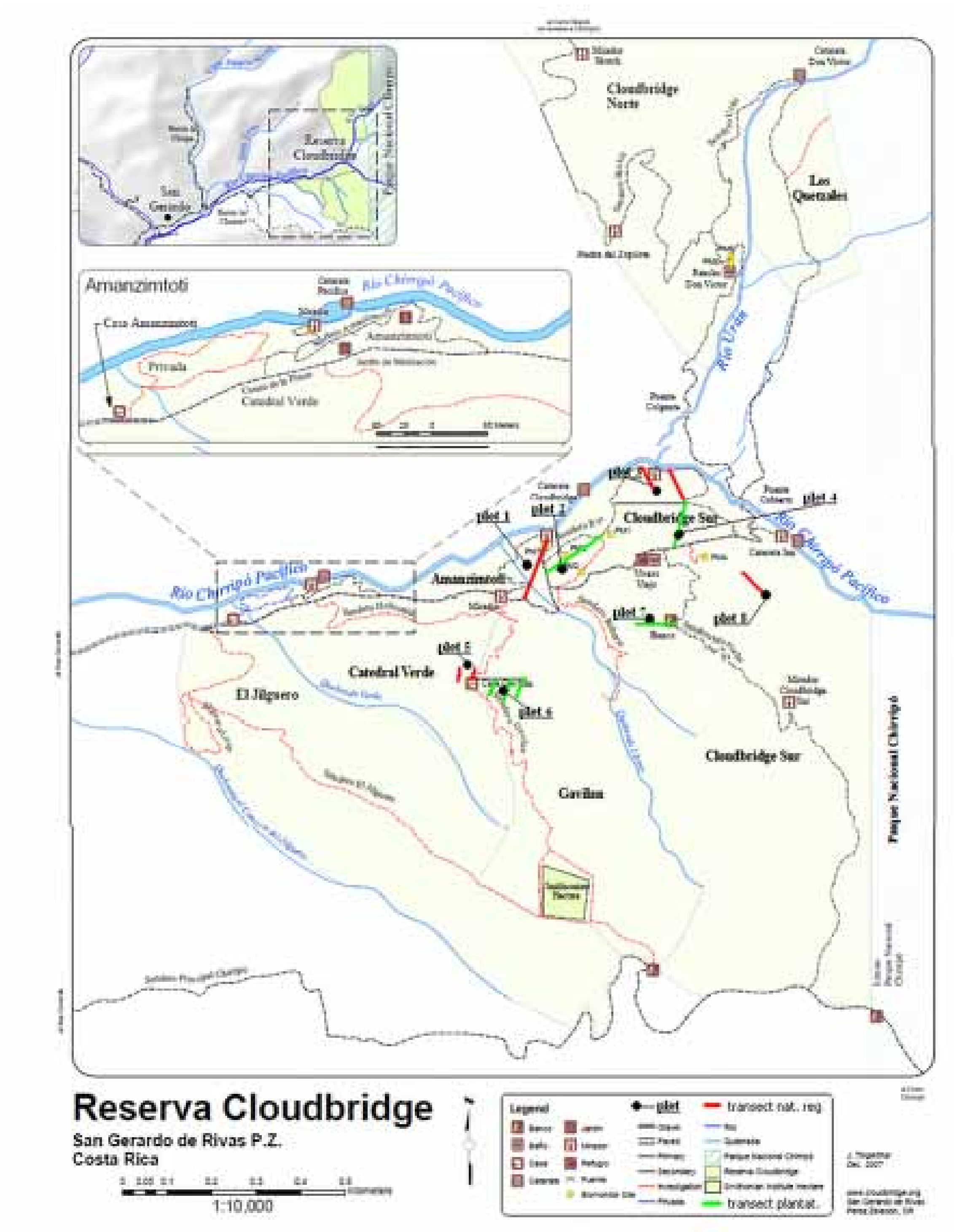
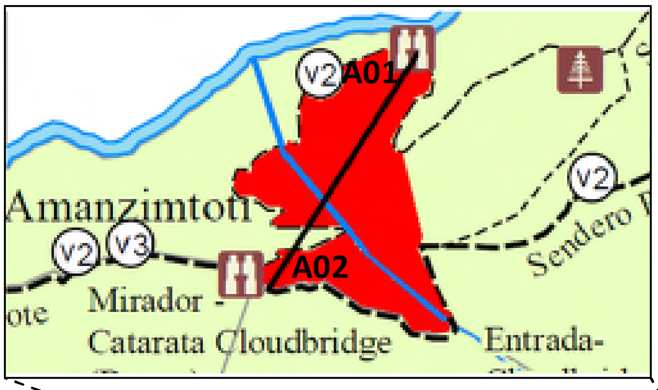
APPENDIX I: MAP CLOUDBRIDGE RESERVE



APPENDIX II: MAPS SAMPLE PLOTS

Map plot 1: Transect A01-A02



A01 ▬ A02 *Transect A01-A02*

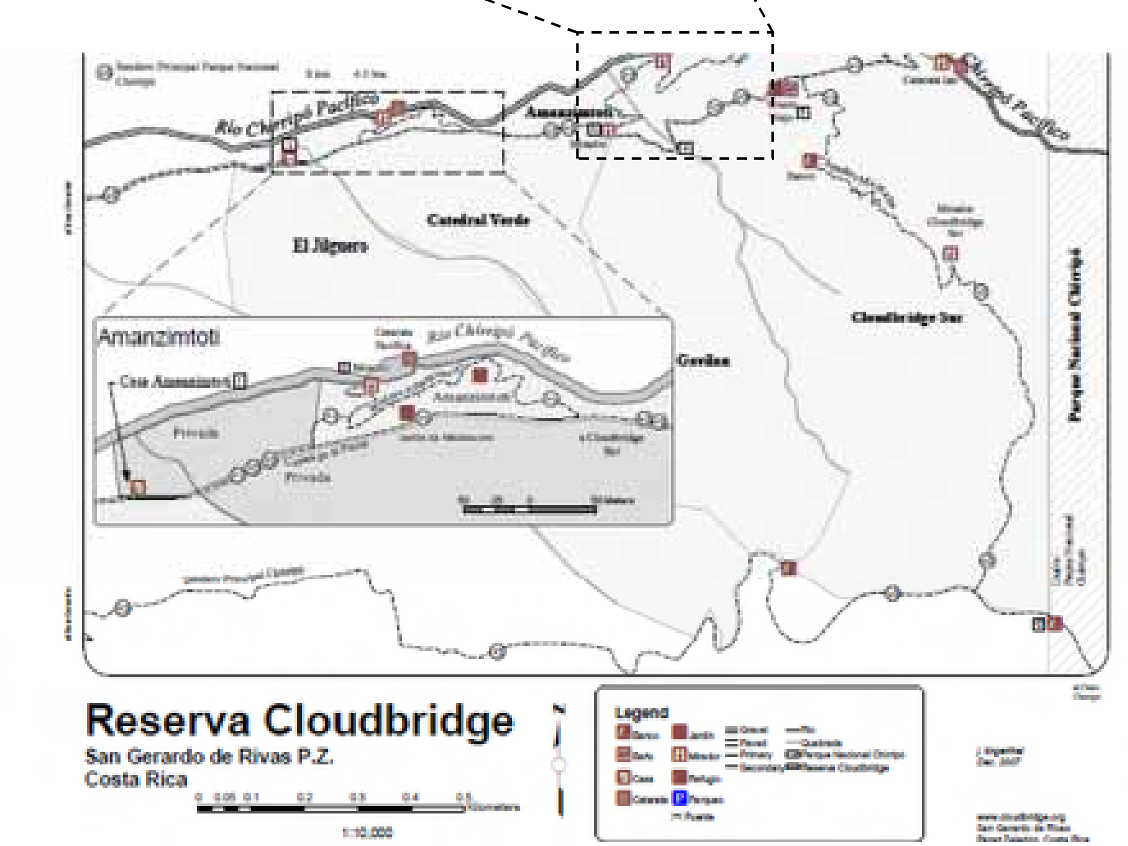
Plot 1

Information:

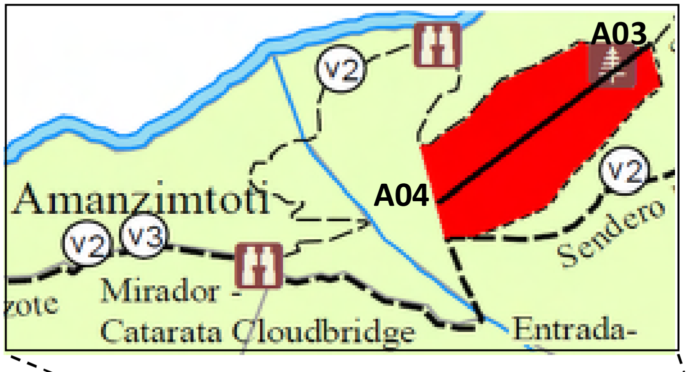
Area	Natural regeneration
Yrs of regeneration	10
Distance transect (m)	100
Altitude (MAS)	1648 - 1682

Coordinates

A01	A02
N 09 28 422 W 083 34 288	N 09 28 366 W 083 34 346



Map plot 2: Transect A03-A04



A03 ▬ A04 *Transect A03-A04*

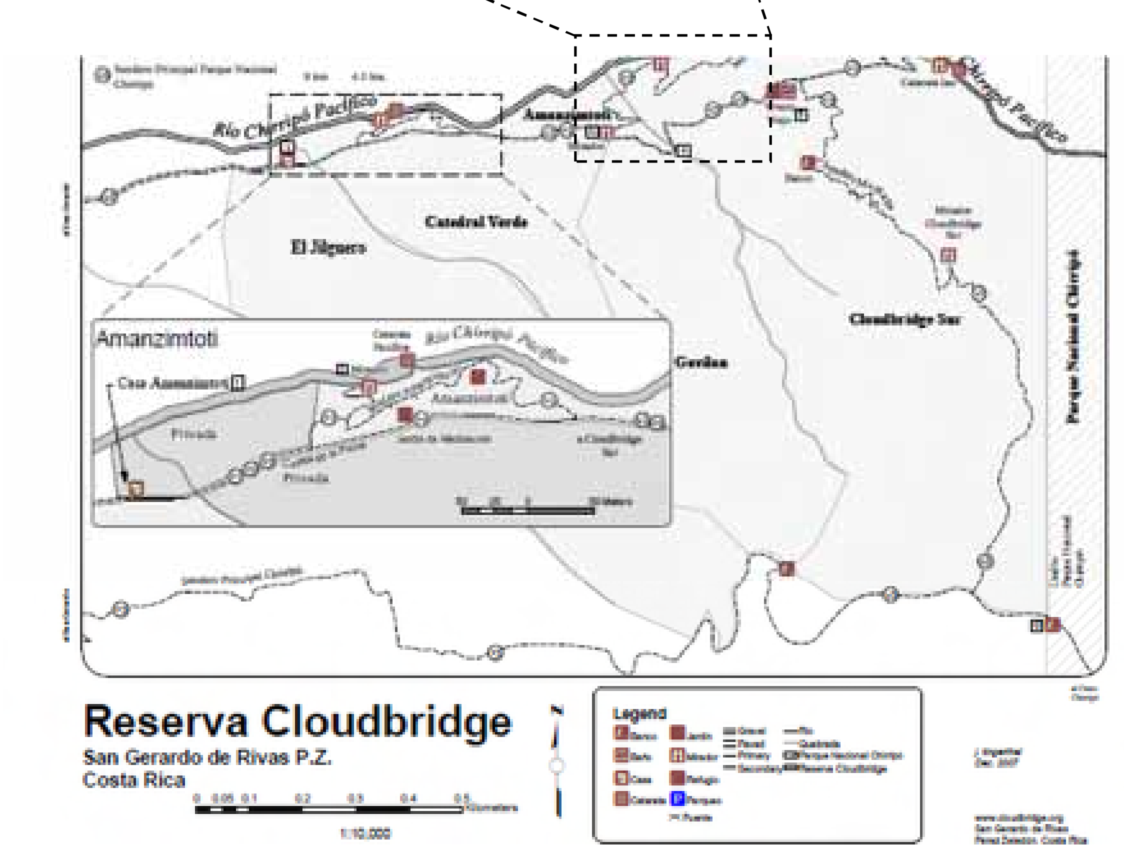
Plot 2

Information:

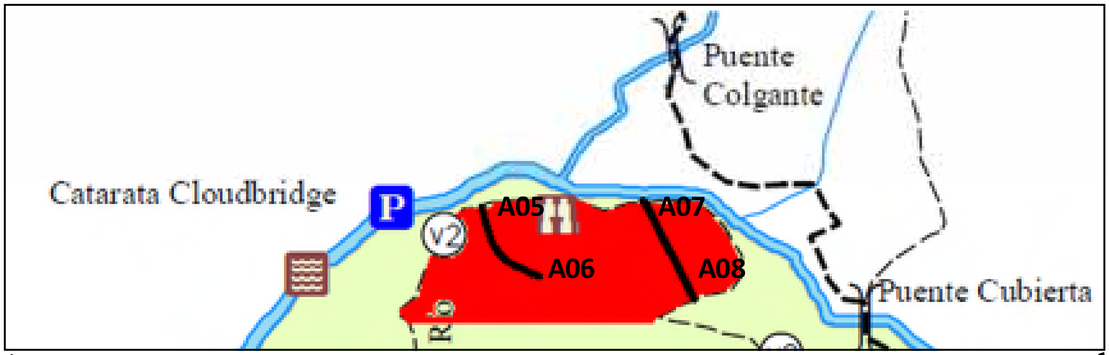
Area	Plantation
Yrs of regeneration	10
Distance transect (m)	100
Altitude (MAS)	1645 – 1629

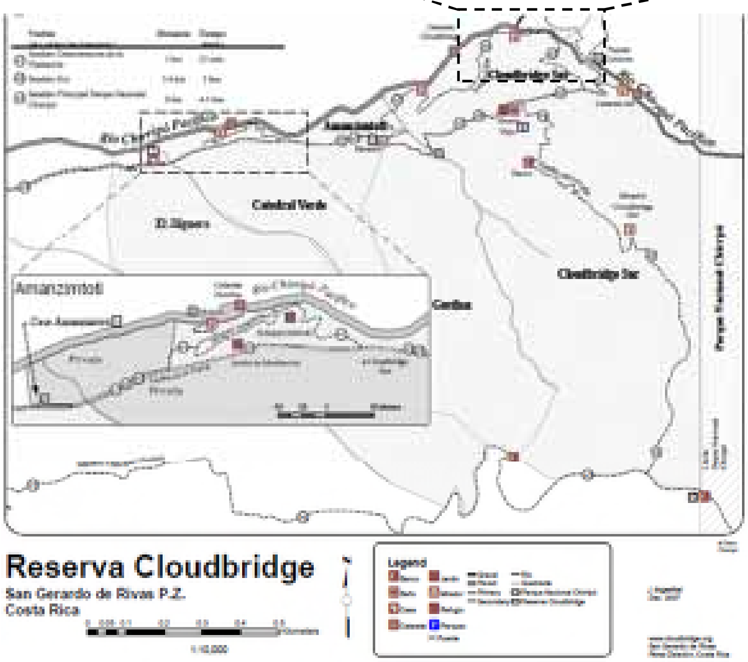
Coordinates

A03	A04
N 09 28 404	N 09 28 428
W 083 34 265	W 083 34 223



Map plot 3: Transect A05-A06 / A07-A08





Transect A05-A06 / A07-A08

Plot 3

Information:

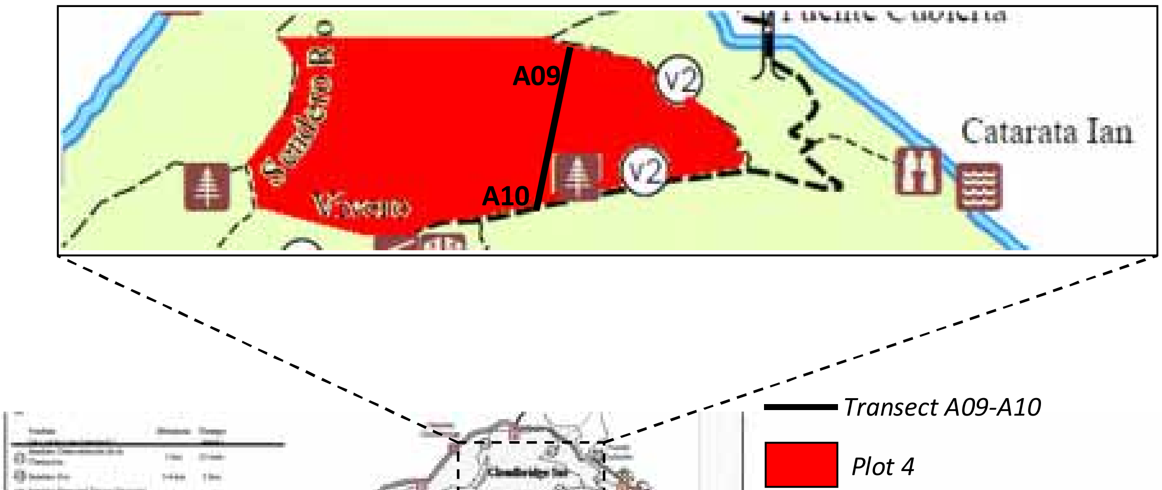
Area	Natural regeneration
Yrs of regeneration	10
Distance transect (m)	100
Altitude (MAS)	1588-1645

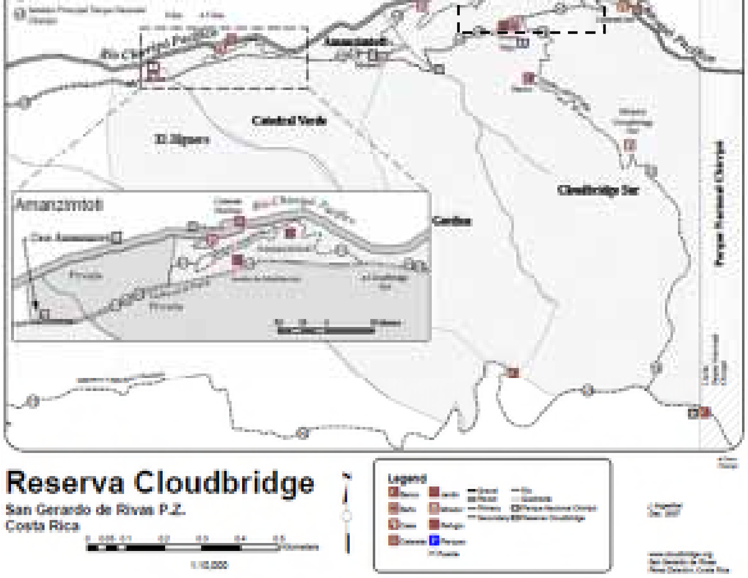
Coordinates

A05	A06
N 09 28 278	N 09 28 260
W 083 34 673	W 083 34 683

A07	A08
N 09 28 239	N 09 28 241
W 083 34 671	W 083 34 679

Map plot 4: Transect A09-A10





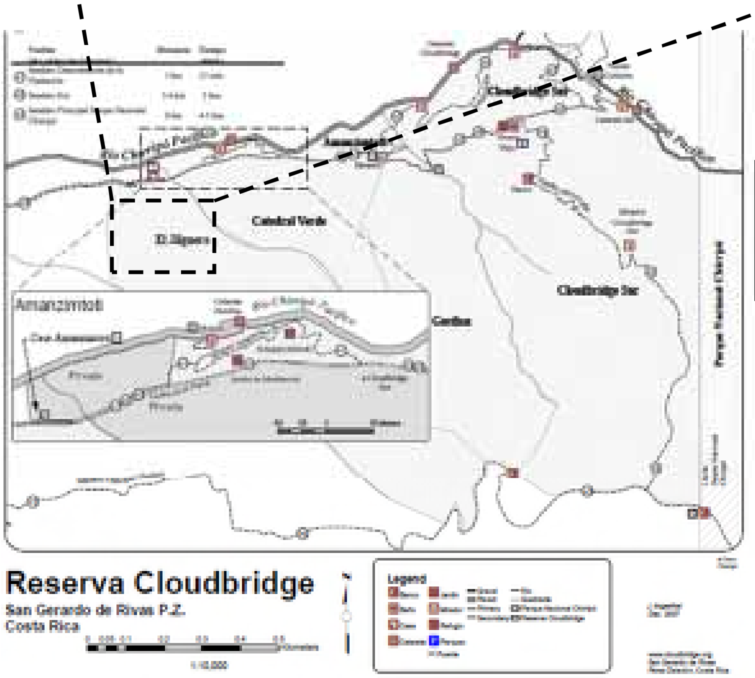
Information:

Area	Plantation
Yrs of regeneration	10
Distance transect (m)	100
Altitude (MAS)	1695-1713

Coordinates

A09	A10
N 09 28 227 W 083 34 663	N 09 28 229 W 083 34 670

Map plot 5: Transect A11-A12 / A23-A24



Transect A11-A12 / A23-A24

Plot 5

Information:

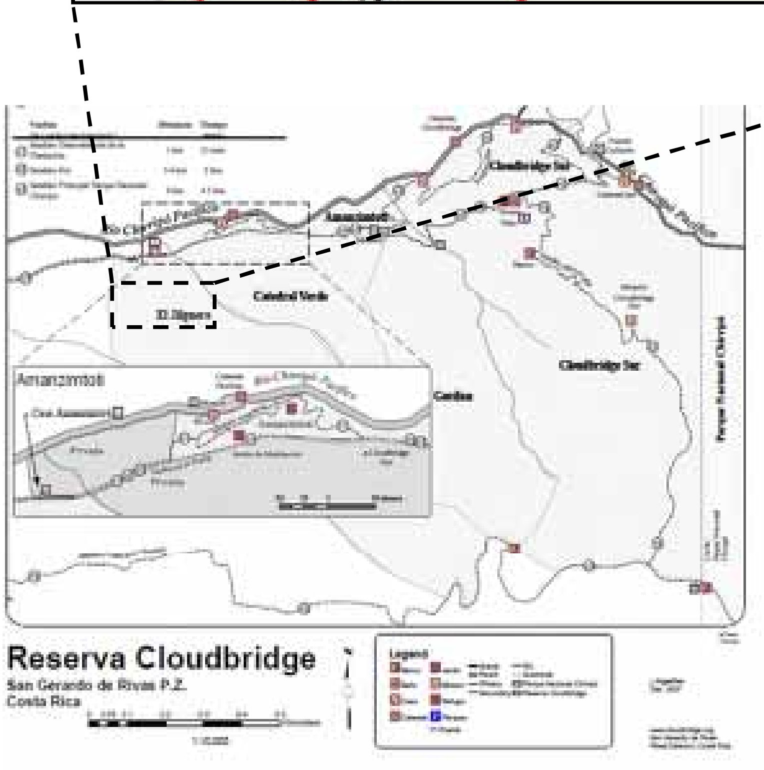
Area	Natural regeneration
Yrs of regeneration	5
Distance transect (m)	100
Altitude (MAS)	1597- 1680

Coordinates

A11	A12
N 09 28 486 W 083 34 186	N 09 28 481 W 083 34 161

A23	A24
N 09 28 282 W 083 34 653	N 09 28 266 W 083 34 654

Map plot 6: Transect A13-A14 / A15-A16 / A21-A22



Transect A13-A14/ A15-A16 / A21-A22

Plot 6

Information:

Area	Plantation
Yrs of regeneration	5
Distance transect (m)	100
Altitude (MAS)	1597 - 1705

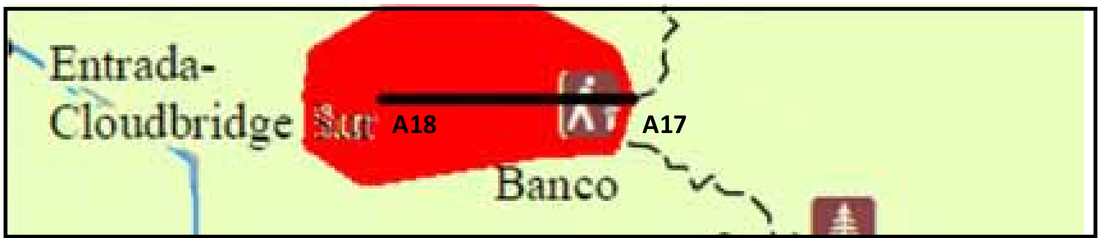
Coordinates

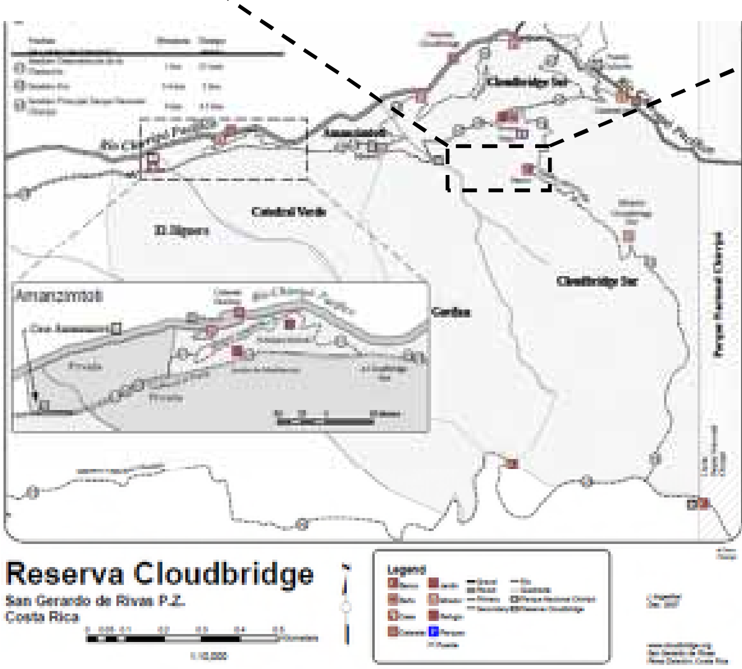
A13	A14
N 09 28 507 W 083 34 136	N 09 28 488 W 083 34 106

A15	A16
N 09 28 472 W 083 34 113	N 09 28 429 W 083 34 137

A21	A22
N 09 28 283 W 083 34 673	N 09 28 225 W 083 34 678

Map plot 7: Transect A17-A18





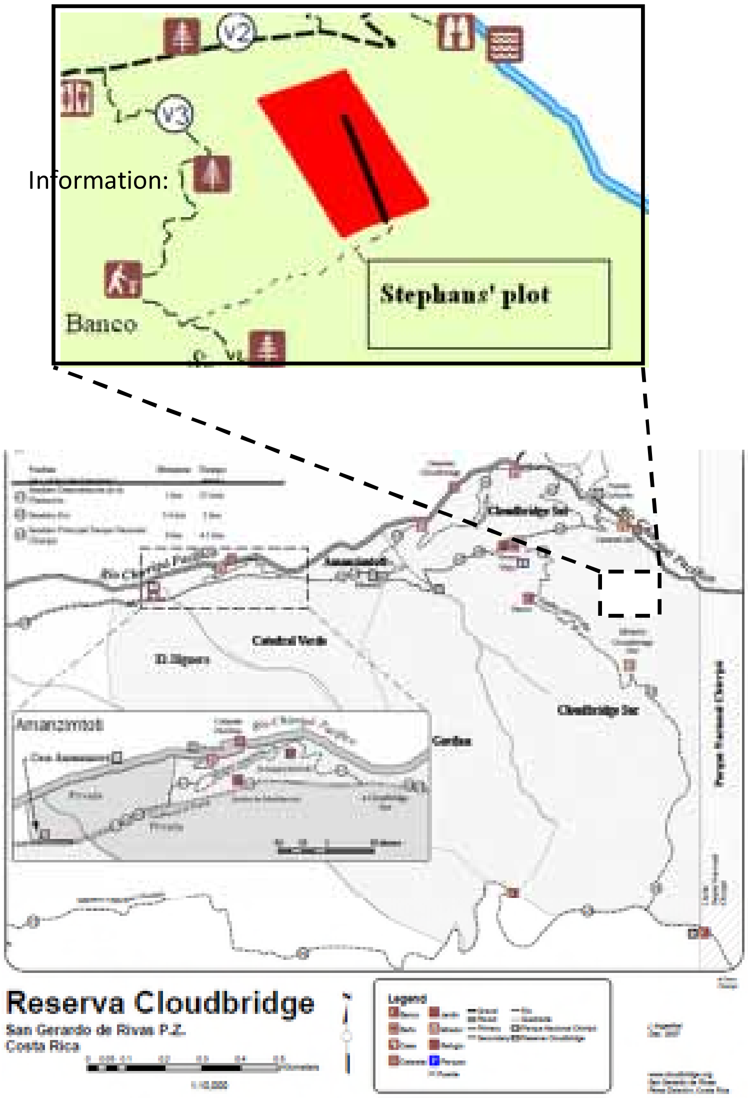
Information:

Area	Plantation
Yrs of regeneration	10
Distance transect (m)	100
Altitude (MAS)	1790-1805

Coordinates

A17	A18
N 09 28 313 W 083 34 173	N 09 28 326 W 083 34 137

Map plot 8: Transect A19-A20



Information:

Transect A19 – A20

Plot 8

Area	Natural regeneration
Yrs of regeneration	10
Distance transect (m)	100
Altitude (MAS)	1779 - 1793

Coordinates

A19	A20
N 09 28 287 W 083 34 040	N 09 28 357 W 083 34 033

APPENDIX IV: EVALUATION FIELD FORM

Field form Regeneration evaluation Cloudbridge

Conducted by:
Date inventory:
Plot:
Transect: Distance (m):
Coordinates:

Altitude:
Years of reg:

Under grow cover
0 = only grass/ ferns
1 = grass/ herbs
2 = herbs/ shrubs
3 = few seedlings
4 = many seedlings

nr	species	DBH (cm)	Height (m)	cr. Diam (m)	cr cover (%)	und. Cover	nr. sdlings	sp. Seedlings	coordinate N	Coordinate W

APPENDIX: IV: EXAMPLE WORKSHEET

Field form Regeneration evaluation Cloudbridge

Conducted by:	Michiel Spek and Tijmen Hoogendijk				Under grow cover
Date inventory:	29-3-2011				0 = only grass/ ferns
Plot:	1				1 = grass/ herbs
Transect :	A01 – A02	Distance (m):	154		2 = herbs/ shrubs
Coordinates:	N 09 28.422	N 09 28.366			3 = few seedlings
	W 083 34.288	W 083 34.346			4 = many seedlings
Altitude:	1648 MAS – 1682 MAS				
Years of reg:	10				

nr	species	DBH (cm)	Height (m)	cr. Diam (m)	cr cover (%)	und. Cover	nr. sdlings	sp. Seedlings	coordinate N	Coordinate W
1	Burio	25	8	4	30	2	0		09 28 419	083 34 281
2	Burio	20	7	3	30	3	1	Solanum	09 28 418	083 34 283
3	Burio	10	3	1.5	60	2	0		09 28 417	083 34 288
4	Solanum	5	5	8	80	4	6	Myrsine coriacea 1x	09 28 401	083 34 314
								Solanum 2x		
								Ginchona pubescens 3x		
5	Burio	30	15	10	20	3	4	Solanum 2x	09 28 397	083 34 329
								Ginchona pubescens 2x		
6	Burio	15	12	3	10	2	0		09 28 396	083 34 329
7	Burio	20	10	2	20	3	4	Oreopanax xalapensis 1x	09 28 395	083 34 330
								Ginchona pubescens 3x		
8	Cecropia	5	8	3	30	4	3	Ginchona pubescens 3x	09 28 393	083 34 328
								Myrsine coriacea 1x		
								Solanum 1x		
9	Burio	30	15	3	10	3	1	Miconia spec. 1x	09 28 390	083 34 329
10	Burio	30	10	2	20	4	7	Quercus ? 2x	09 28 386	083 34 331
								Solanum 2x		
								Quercus ? 1x		
								Oreopanax xalapensis 2x		
11	Burio	30	15	4	10	3	3	Saurauia pittieri 1x	09 28 383	083 34 334
								Ginchona pubescens 2x		
12	Burio	40	15	5	20			Erythrina costaricensus 1x	09 28 363	083 34 329
								Saurauia rubiformis 2x		
								Ginchona pubescens 1x		
								Inga oerstediana 1x		
13	Saurauia pittieri	5	5	3	60	3	2	Solanum 1x	09 28 366	083 34 340

Example of sheet were all the trees of one species of all different plots are compiled.

Burio Plantage

nr	species	DBH (cm)	Height (m)	cr. Diam (m)	cr cover (%)	und. Cover	nr. sdlings	sp. Seedlings	coordinate N	coordinate w
1	Burio	15	8	3	30	3	1	Miconia spec 1x	09 28 413	083 34 249
								Saurauia montana 1x		
2	Burio	15	8	2	30	4	5	Quercus ? 1x	09 28 413	083 34 249
								Miconia spec 1x		
								Saurauia pittieri 3x		
3	Burio	10	10	3	25	4	7	Ulmus mexicana 1x	09 28 229	083 34 661
								Solanum 1x		
								Quercus ? 5x		
4	Burio	25	12	5	30	4	5	Solanum 2x	09 28 229	083 34 665
								Vine 2x		
								Cedro dulce 1 x		
5	Burio	10	6	3	40	3	2	Styphaolobium monteriridis 1x	09 28 225	083 34 666
								Solanum 2x		
6	Burio	5	8	3	30	4	5	Solanum 2x	09 28 224	083 34 666
								IMG ?? 3x		
7	Burio	25	10	4	40	3	3	Burio 1x	09 28 221	083 34 669
								Solanum 1x		
								Conzalagunia rosea 1x		
8	Burio	20	6	4	40	4	5	Burio 2x	09 28 506	083 34 140
								Solanum 1x		
								Miconia spec 2x		
9	Burio		5	2	100	3	1	Saurauia pittieri 1x	09 28 504	083 34 129
10	Burio	35	15	4	15	4	19	Solanum 19x	09 28 503	083 34 129

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:

	Species tree	number of trees found / ha	number of seedlings found/ tree sp/ ha	number of seedling species found/ tree / ha
1	Burio	72	113	17
2	Ulmus mexicana	59	198	14
3	Psychotria sylvivaga	50	178	18
4	Quercus ?	20	54	5
5	Solanum	19	53	5
6	Cedro dulce	12	3	1
7	Erythrina costaricensis	11	60	8
8	Alder	9	8	2
9	Pepperbush	6	30	6
10	Cecropia	1	9	2
11	Saurauia pittieri	1	16	3
12	Tree fern	1	0	0
13	Oreopanax spec	1	9	2
14	Saurauia rubiformis	1	16	3
15	Myrsine coriacea	1	0	0
16	Boconia frutescens	1	13	1
17	A19-A20 or A30	1	0	0
	Total	266	935	
		number of tree species found	17	
		number of seedling species found	38	

Natural regeneration area:

Species tree	number of trees found per ha	number of seedlings found per tree species/ ha	number of seedling species found/ tree species
Burio	72	275	22
Solanum	31	81	11
Cecropia	6	41	3
Saurauia pittieri	3	3	1
Ulmus mexicana	16	47	12
Cedro dulcia	3	9	1
Psychotria sylvivaga	13	63	7
Saurauia rubiformis	6	34	8
Myrsine coriacea	16	28	3
Pepperbush	19	68	10
Saurauia montana	6	22	6
unknown 12	5	6	2
Oreopanax xalapensis	1	13	2
unknown 11	1	8	1
Gonzalagunia rosea	1	9	2
Cinchona pubescens	1	6	2
Shrub 2	6	6	1
unknown 20	1	0	0
Inga Oerstediana	1	13	2
Total	222	738	
Different amount of tree species found	*22*		
Different amount of seedling species found	*42*		