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An assessment of afforestation success at REGUA, Brazil

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Abbreviations

ABG = Above Ground Biomass
AR = (Brazilian) Atlantic Rainforest

BA = Basal Area

DBH = Diameter at breast height (1.3m above ground)
FAO = The United Nations Food and Agriculture Organization

GIS = geographic information system

Ha = hectare

N = number/amount

NGO = Non-Governmental Organization

R^2 = R square / coefficient of determination

REGUA = Reserva Ecologica of GUApiacu / Ecological reserve of Guapiaçu

SWD = Specific wood density (species-specific wood density)
UNFCC = United Nations Framework Convention on Climate Change

Abstract

Many of the world's forest have been destroyed and degraded, and the Atlantic Rainforest in Brazil is no exception, having its forest cover reduced to 8% of its original size by agricultural expansion and natural resource exploitation (Gonzalez & Marques, 2008). Efforts to mitigate deforestation involve reforestation of abandoned or degraded land and are a practical approach to climate change mitigation, restoration of forest services and storing carbon (UNFCCC, 2013). However, little research has been done on the success of these restoration efforts, and no standards exist that can define restoration success (Adams, 2015). By the performance of forest surveys, this study gives an overview of success of a restoration effort done by Reserve Ecológica de Guapiaçu (REGUA) in Rio de Janeiro Brazil. Indicators of success were based on diversity, vegetation structure and ecological processes for an afforested area planted by REGUA since 2004. The results of this research show positive indicators for biodiversity and vegetation structure. With these indicators, this study shows that the plantation method used by REGUA was successful.

1 - Introduction

1.1 - Tropical forest loss and degradation

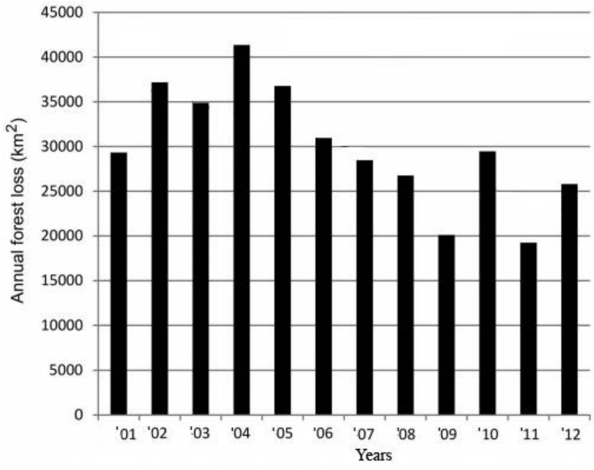

Figure 1 Annual forest loss totals in Brazil for 2001 to 2012. (Hansen et. al, 2013)

Worldwide tropical forests are decreasing in size. In 2012 the, Food and Agriculture Organization of the United Nations (FAO), stated that more than half of the world's tropical forests have been cleared (FAO, 2012). An estimated 130.000 km² of forests, roughly the size of Greece, is cut down every year (FAO, 2012). Between 2000 and 2012 an average of 25.000 km² of forest has been lost each year in Brazil (see figure 1); (Hansen et. al, 2013). In Brazil, the most common cause of forest loss is agricultural expansion. Remaining forests in Brazil suffer from forest degradation. Forest degradation is a loss of forest quality and functions such as erosion prevention and carbon storage. In Brazil the most common cause of forest degradation is fragmentation (Sandro Pütz, Jürgen Groeneveld, et al, 2014).

agriculture (Sandro Pütz, Jürgen Groeneveld, et al, 2014)

Fragmentation means that small pieces of forest are left standing after a forest is cut. These forest fragments are often smaller than 1 hectares (Sandro Pütz, Jürgen Groeneveld, et al, 2014); (see example figure 2). The problem of fragmentation is caused by the edge effect. When an edge is first created many rainforest trees die because of the changed conditions such as wind, light and heat (Lovejoy et al., 1986). Pasture or crops around a forest are hotter and drier and these conditions can penetrate up to 200 meters into a fragment (Laurance et al., 2002). The change in conditions at the edge of the forest leads to loss of biomass and biodiversity for both flora and fauna (Laurance et al, 2011). Some species of birds need a specific trees to nest in and others only eat insects that are only found in the inner parts of forests (Murcia, 1995). According to Ferraz (2003), isolated fragments smaller than 100 ha lose half their forest dependent birds within 15 years (Ferraz, 2003). Fragmentation can be devastating on the long term for the gene pool of a species. A small population will inbreed, making a population weaker or even die out because of a lack of genetic variability (Plattsburgh, 1998).

1.2 - The Atlantic Rainforest

The Atlantic Rainforest (AR), is located in the south-eastern part of Brazil. It extends as a narrow strip along the south coast, where it reaches Paraguay and Argentina (see map in figure 3). The AR has a high biodiversity and is on the list of 'biodiversity hotspots for conservation priorities' (Myers, Mittermeier, Fonseca, Fonseca, & Kent, 2000). The AR has 20.000 species of vascular plants, the whole of Europe has 12.000 vascular plants (E. T. LaRoe, G.S. Farris, C.E. Puckett, P. D.Doran, 1995). Of those 20.000 vascular plants found in the AR, 40% are endemic. Endemic means that a species can only be found at a certain location. Endemism in trees is particularly high, with more than half of the tree species to be found nowhere else. Out of 930 species of birds, 15% are endemic (Conservation International, 2008).

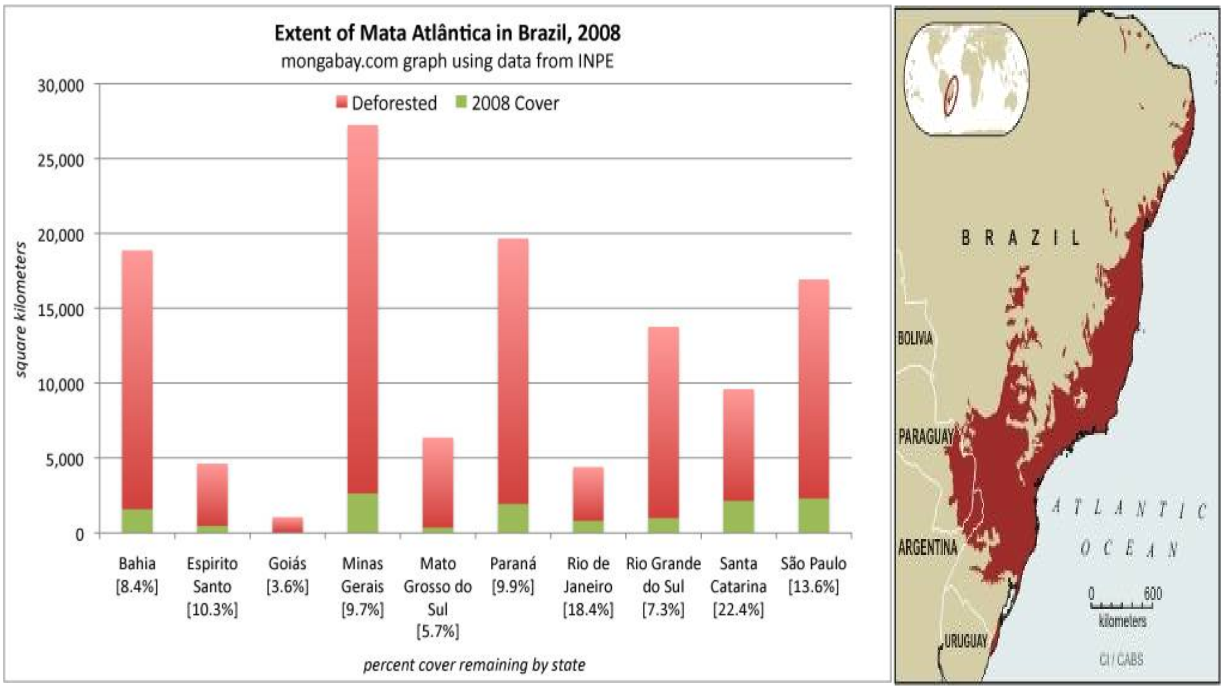

Figure 3 The amount of forest loss in red and forest cover remaining in green of the AR per state, both expressed in km² (Hance, 2010). On the right, a map is shown with the location and extent of the AR (Conservation International, 2008).

The AR is in a highly fragmented and mostly degraded state. Deforestation and degradation have been going on since the colonial times and have been devastating in the AR. Mining, timber extraction and agricultural expansion have reduced the forest to an estimated 8% of the original size (Gonzalez & Marques, 2008); (see figure 3).

1.3 - Forest restoration

A way to restore an ecosystem is to increase the size of a forest. This can be done through afforestation and reforestation. Afforestation is the establishment of a forest or stand of trees in an area where there was no forest. Reforestation is the reestablishment of forest cover, either naturally or artificially. The United Nations Framework Convention on Climate Change

(UNFCCC) states in a recent manual (2013) that afforestation and reforestation projects are likely to contribute to climate change mitigation, restoration of forest services, storing carbon and strengthening communities (UNFCCC, 2013). A lot of existing reforestation projects have partially or completely failed because trees planted did not survive or have been rapidly destroyed (Le, Smith, Herbohn, & Harrison, 2012)**.**

In Brazil, the most common restoration technique has been the development of plantations based on nursery-raised tree seedlings (Campos-Filho et al., 2013). In afforestation projects mostly agriculture land is bought by NGOs and investors. These lands were reforested or in some cases left fallow so that forests can restore themselves. Multiple efforts were made to patch forest fragments together, to decrease the impact of fragmentations (Campos-Filho et al., 2013).

An article of Conservation international(2008) states that 23.800 km² is officially under protection by a total of 108 national and state parks, 116 federal state biological and ecological station reserves. About 1000 km² is in the hands of about 442 private reserves (Conservation International, 2008). According to Tabarelli (2010) many of these protected areas lack trained staff and adequate financing which limits efficient management. Of these areas, 75% are too small to guarantee long term species persistence (Tabarelli, 2010).

The Brazilian forest code states that each land owner needs to reserve land for native vegetation. In the Amazon, this needs to be 80% of the property area and 20% in other biomes, like the AR (Soares-Filho et al., 2014). Since 2012 the forest code enables land owners to offset their reserved land debt on another property within the same biome (Soares-Filho et al., 2014). In practice, this means that landowners exchange their land, or buy extra land, that has forest or can be reforested. Often forestry companies are hired to reforest areas for landowners that need to increase their forest area (Locke, 2015).

1.4 - Defining reforestation success.

Defining ecological success is difficult to do. A cross literature study by Adams (2015) found that different reforestation projects had different ways to define success and that there is little cohesion between them. Most studies use ecological indicators such as seedling survival, canopy cover and basal area to determine success. Adams concluded that because of the lack of cohesion between studies no clear method to define success can be determined yet, for the subject has to be discussed more by the forestry community (Adams, 2015).

According to Le (2012), Reforestation success can be seen as a continues process, that starts with the successful establishment of the initial planting and can only be completely measured when a forest is mature. The realization of the full environmental and socio-economic benefits of the forest are the result of the whole process of forest maturation (Le et al., 2012). This means that how reforestation-success is defined depends on the age, or succession state of a forest. According to Reay and Norton (1999), assessing a forest that has not reached its mature state can only indicate likely future success (Reay and Norton, 1999).

Ruiz Jaen & Aide (2005) made an effort to determine which indicators were mostly used for defining success through literature study. In their report measurements of restoration success are subdivided into 3 categories, these are: diversity, vegetation structure and ecological processes. Studies often used two or more of these categories and multiple measurements to define success (Ruiz-Jaen & Aide, 2005). In this report a combination of diversity, vegetation structure and ecological processes measurements were used to determine restoration success. These 3 categories are explained below. The percentages given between brackets are the percentages of studies that used a certain measurement to define success.

- **Diversity**

  Diversity is measured by measuring the amount of different species within a certain category. Plant richness (79%) was the most common measures of diversity recovery. The majority of the studies measured only one group of organisms (61%) ; (Ruiz-Jaen & Aide, 2005).

- **Vegetation structure**

  The vegetation structure is the way plants organize themselves in relation to each other. Plant cover (62%), density (58%), biomass (39%), and height (39%) were the most common measures of vegetation structure. Most studies only included one or two measures of vegetation structure (69%) ; (Ruiz-Jaen & Aide, 2005).

- **Ecological Processes**

  Ecological processes are the processes that influence the distribution and abundance of organisms and the interactions between organisms. Measures of biological interactions (60%) were the most common ecological processes measured, followed by nutrient pools (47%) and soil organic matter (39%). Other biological interactions such as herbivory, dispersal, pollination, predation, or parasitism were mostly measured indirectly (Ruiz-Jaen & Aide, 2005).

1.5 - REGUA

Reserva Ecologica of GUApiacu (REGUA) has been planting trees on pasture land with the aim of creating a healthy ecosystem. REGUA's is protecting their remaining and planted forest from deforestation, hunting and over-extraction of natural resources. REGUA is also buying land to create new forest every year. Objectives stated on the REGUA website are: gaining a better understanding of the species presents through research, saving endemic species, creating forest corridors and raising awareness on forestry issues and education on these issues for young and old (REGUA, 2015).

About 50% of REGUA’s income is generated through tourism and the other part is sponsored by the world land trust, other NGO’s and private donors (Murray, 2012). Most tourist that come to REGUA are retired bird watchers that stay at the luxury birding lodge, that is part of the REGUA reserve (T. Locke, 2015).

REGUA also created a wetlands area out of pasture lands. In 2005 an area of 12 ha was flooded, and in the following years, more pasture lands were flooded, resulting in 40 ha of lowland wetlands that support a rich diversity of flora and fauna (REGUA, 2015). An example of the change in landscape can be seen in figure 4 below.

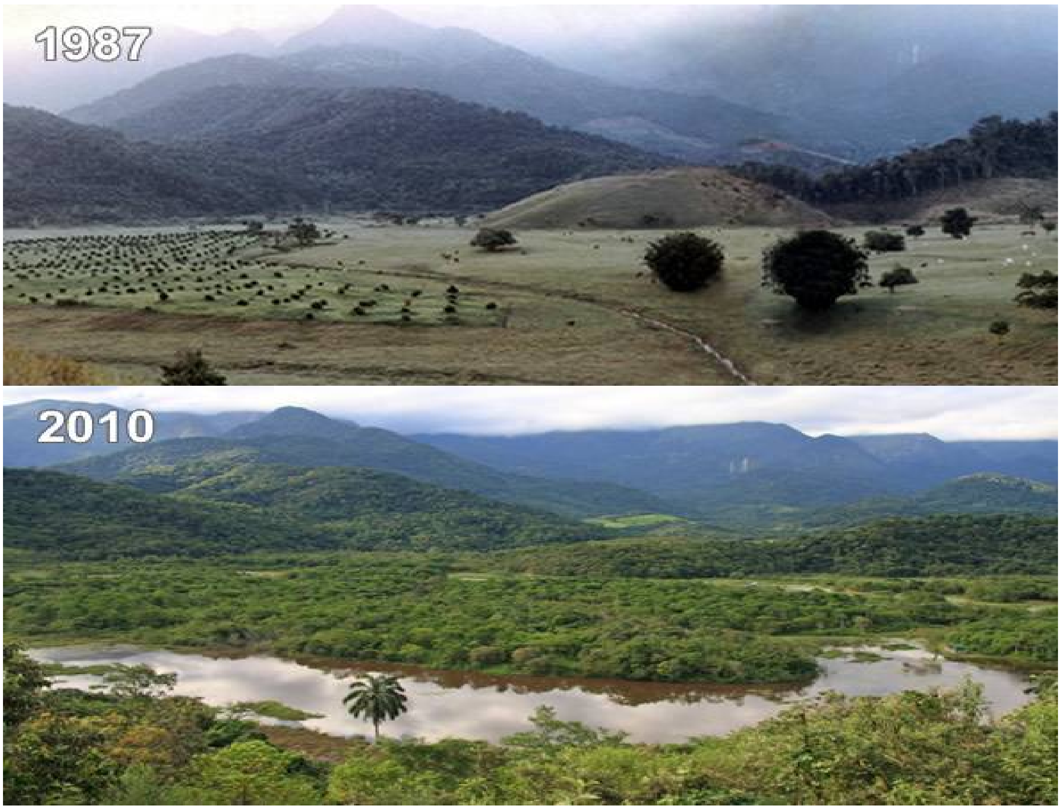

Figure 4 The effect of REGUA's restoration effort on the landscape. Before and after planting (years are shown in top left) (worldlandtrust, 2014). The lake displayed on the second picture was man-made, by REGUA.

1.6 - Study objectives

The main objective of this study is to give an overview of the success at REGUA's restoration effort. That the project is successful seems evident to all who visit and work at REGUA, but it has never been given scientific context. With evidence of success all involved stakeholders will be more prone to have trust in REGUA and its planting methods. In addition, all the people that work at REGUA, researchers, students, surrounding inhabitants, local stakeholders and interested tourists that come to REGUA will be able to see an objective overview of the success at REGUA.

This research aims to check whether REGUA has successfully created an ecosystem by planting a high diversity of trees. By doing so, this study hopes to give reasons to other organizations to repeat planting methods used at REGUA. The data gathered can also be used to improve REGUA's planting methods and the planting methods of other restoration efforts in the AR. Furthermore the data can also be used to support other types of forestry research.

1.7 - Research questions

The following research question and sub-questions were formulated to give purpose and direction to this research. The main question is:

Does the current state of REGUA's afforested areas indicate that REGUA restoration effort is successful?

The sub-questions are:

1. What is the state of the diversity at the afforested area of REGUA?
    a. What is the current number of tree species?
    b. What is the composition of tree families?
    c. Which species are found most frequently?
    d. How does diversity of trees change over the years?
    e. What are the diversity numbers different of types of animals?
2. What is the state of the vegetation structure at the afforested areas of REGUA?
    a. What is the amount of forest cover?
    b. How dense are canopy, scrub and undergrowth cover?
    c. What are the average height and diameters of trees?
    d. How much biomass is present at the planted forested at REGUA?
    e. How do the frequencies of different DBH classes compare to a natural forest?
3. What is the state of the Ecological Processes at the afforested areas of REGUA?
    a. What is the annual growth of selected tree species at REGUA?
    b. How does the composition succession states change over the years?

2 - Methods

2.1 - Study area

REGUA is a non-profit organization that is conserving the AR by restoring a degraded ecosystem to a healthy ecosystem that can support a great diversity of species (REGUA, 2015).

Figure 5 Location of the study area marked with a blue google marker Rio de Janeiro is shown on the bottom left of the map (maps.google.com, 2015).

REGUA is situated about 100 kilometers north-east of Rio de Janeiro city (see figure 5). REGUA is protecting about 9100 ha of forest (REGUA, 2015). The elevation of the reserve spans from 30m to 2,000 meter above sea level, providing a range of unique habitats including highland rainforest and lowland wetlands (Sattler, M 2011) ; (Murray 2012). The slope map in annex 1 shows that the slopes in the area range from 0 to 100% (Petrobras Ambiental, 2015).

REGUA is situated in the Guapiaçu River basin municipality. The economy in this area is mostly based on agriculture (Damasceno 2011). As seen on the land use map in annex 1 most of the Guapiaçu river basin is forests. A large part of this forest was planted by REGUA, or was natural forest that is now under the protection of REGUA (Petrobras Ambiental, 2015).

The Guapiaçu river basin was cleared for timber, agriculture or damaged through poor management practices. Some of the less productive lands were abandoned over the years. Most heavily sloped areas naturally regenerated with forests in the last decades, but the lower sloped unused pastures became covered in the tough grass named *Imerata cylindrical* (REGUA, 2015). This grass forms a dense mat of roots and grows up to one meter high, making it almost impossible for other plants to establish. Most of the now reforested lands studied in this research were covered with these *Imerata cylindrical* grasses until the plantations started, since 2004. (REGUA, 2015); (Locke, 2015). Other areas were bought from pasture owners, and there the dominant grass on these pastures was of the genus *brachiaria*, before the planting started.

The soils of the area studied are mostly cambisols or alluvial deposits (Murray, 2012). See the soil map and the description of soils in annex 2 for more information about soils in the area. Average yearly temperatures in the area range between 18 and 31 degrees. (Average Weather in

Rio de Janeiro, Brazil, 2015). The average rainfall is about 2,560 mm per year (Murray, 2012). For more information about the climate of the state of Rio de Janeiro see annex 13.

2.2 - REGUA's planting method

Every year REGUA buys land from cattle owners and farmers for planting trees. REGUA is planting about 20.000 trees per year on these lands. They started in 2004 with their first plantation and have been planting every year since. REGUA wants to increase its restoration area to at least 100 km², and aims for a high diversity to preserve endemic plant and animal species (Locke, 2015). Currently about 91 km² of forest is protected by REGUA. (REGUA, 2015)

Figure 6 A photo of volunteers and workers planting saplings for REGUA. Here it is evident that it was former pasture land before. (Photo made by the author, 2012)

Before planting the grasses of the former pasture land are exterminated with roundup (Locke, 2015). The planting distance is 3 x 3, or 3 x 4 meters distance from each other, depending on the amount of slope of the planting area (Locke, 2015); (See figure 6). All trees were planted as saplings. Planting was done by a crew of 12 workers and volunteers (Locke, 2015). After the initial planting workers of REGUA visit the areas 2-3 times a week during the first two months, to prevent overgrowth by cutting away grasses and vines. The amount of visits for maintenance decreased over time. After about 2 years the young trees are large enough and no more maintenance is needed (Noqueira, 2015).

The exact species planted are different almost every year, depending on which seeds could be germinated in their own nursery or bought from other nearby nurseries. The amount of species planted each year varies between 50 and 60 species per year (Lindner & Sattler, 2011); (Locke, 2015). The species that are planted most commonly in all plantation years are *Inga edulis*, *Gochnatia polymorphais*, *Trema micrantha*, *Piptadenia paniculata*, *Guarea guidonia*, and *Schizolobium parahyba* (Murray, 2012).

The first two years of planting were small and experimental for REGUA and these areas do not provide data that was comparable to the other years. Therefore, this study did not include the first two plantation years, of 2004 and 2005. In 2004 the plantation also included many exotic species, and therefore has a different composition of species then the other years. For the plantations that were done in 2006, 2007, 2008 and 2009 the method of planting were more consistent and therefore provided more reliable data. Before the years of plantation these lands were either used for pasture and covered with mostly *brachiaria* grasses or were already fallow and covered with *Imerata cylindrical* (Locke, 2015). No diversity measurements were taken at the time, but the owner REGUA, Nicholas Locke estimated that the area only contained few tree species (Locke, 2015). An example of a pasture in the AR, with a low diversity can be observed in figure 7.

Figure 7 Example of a pasture lands in the AR. The diversity is low and on these pasture lands very few trees are present.

2.3 - Fieldwork

The plot locations were chosen at random in the field keeping the influence of light in mind. To do this, all plots were established at least 10 meters from a path, river, lake or forest gap. A total of 24 plots were set up in the field. The location of these plots can be found in annex 3. Measurements were done in February and March 2015.

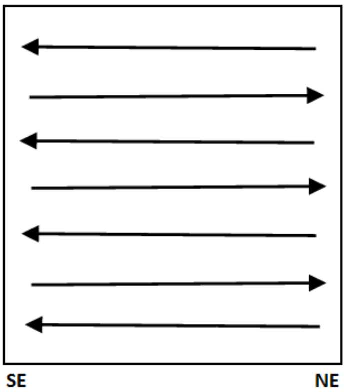

Figure 8 Example of a zig zag pattern.

The method of setting up plots was based on the method used by Murray (2012), who also did forestry research in the area (Murray, 2012). The plots of sizes were 10m*10m. The northeast corner was identified with a compass, and recorded with GPS device. To indicate the borders of the area ropes were used. The measuring of trees went in a zig zag pattern, starting from the NE like in figure 8.

The diameter measured at 1,30 meters height (DBH), height and species names were measured and noted on a field form for each tree (see annex 6 for the field form). Trees of a DBH of less than 2 cm were not measured, but were written down for a biodiversity measurement. Additional plot data, such as slope, groundcover, canopy cover and the amount of layers were written down on the field forms for the whole plot (see annex 6).

The trees were identified with the help of head of nursery Mauricio Noqueira who had sufficient knowledge of tree species. If a species was not identifiable in the field, a sample of leaves branches was taken to REGUA's lab to be determined later. Later these were determined by Aline Damasceno, Nicholas Locke and Jorge Bizarro.

For each plot the following additional data was estimated: canopy cover, scrub cover, undergrowth cover, the number of layers, the slope, coordinates of the NE corner of the plot and rate of measurement. An example of a canopy cover measurement be seen in figure 9 below.

Figure 9 Canopy cover of plot 10. For this plot, 75% canopy cover was estimated.

2.4 - Data analysis

All the field-data was typed into an excel database. Plot data was gathered in a separate EXCEL table. After all the data was collected a lists of species was created. Each tree species name, genus and family were identified as much as possible with the help of Aline Damasceno and various sources from the internet. When this data was linked with ACCESS the overall database data could be collected about family composition and individual species. The plantation ages used were 6, 7, 8 and 9 from the plantations done in the years 2009, 2008, 2007 and 2006. ACCESS was used to compare the different data tables, and these comparisons were used to create graphs in EXCEL, for the results.

2.4.1 - Diversity

The total biodiversity of trees was identified by counting the total amount of trees species found in the completed species list. A diversity measurement was done for a random 3 plots of all different planting years. All the species of trees for 3 plots together, or 300m² for each planting year gave an estimate of the biodiversity per ha for each plantation age.

Data of the diversity different types of animals was available on the research section of the REGUA website (REGUA, 2015). By studying this literature, a summary of the available diversity of animals was made.

2.4.2 - Vegetation structure

For the vegetation structure part of this research different indicators were used. These are plantation area, canopy-, scrub- and undergrowth- cover, DBH, height, above ground biomass (ABG) and diameter classes.

With a geographic information system (GIS) the area of the different plantation years was measured. The measurements were then put into a pie chart to create a clear overview of the plantation sizes. The canopy-, scrub- and undergrowth- cover were all measured with percentages, and the average of these percentages were displayed for each plantation year. DBH and height of the different plantation ages were also expressed in averages.

With ACCESS diameter classes were added to each tree in the data. After this, a query was made to count the amount of trees in each diameter class. Diameter classes each had 4,9 cm except for the smallest and the largest classes. The largest diameter class was a bigger because no trees were bigger than 31 cm. The first diameter class of 2 to 4,9 cm in DBH was smaller because trees under 2cm were not included in this study.

For this study, Chave's allometric equations for calculating biomass was applied in order to calculate the above ground biomass (AGB) (Chave et al, 2014). The formula is:

$$ABG_{est} = 0.0559\ (q * DBH^2 * h)^{0.976}$$

ABG_{est} is expressed per tree in kg. The DBH is in cm and the height (h) in meters. The q stands for the wood specific gravity and is expressed in grams/cm^{-3}.

The wood specific gravity for each species was determined and added to the annex 7 using Brown's appendix 1 from an FAO database (Brown, 1997). When a species was not found in the FAO database, the average value for the gene was used. If the gene was not know the value of 0.6 was used, because a similar research by Murray encountered the same problem and used this method (Murray, 2012). See annex 7 for all wood specific gravity used for each species.

The allometric model above was used first to calculate the amount of biomass per tree, and then to calculate the average ABG in tons per ha (Murray, 2012). The calculations were done in excel and afterwards expressed in a single graph. This graph shows the average biomass in ton per ha for each planting year.

The plot data used for the ABG calculations were of plots with a slope of 5 degrees or less, to decrease the influence of slope on the data calculated.

2.4.3 - Ecological processes.

For the ecological processes growth rates of 5 species, and the type composition were used as indicators. It was not possible to gather data on nutrient pools, organic matter and other biological interactions because of a lack of time in the fieldwork phase.

A comparison was made between the data gather for this research in 2015, data gathered by Damasceno in 2011 and the data gathered by Lara Murray in 2012 (Murray, 2012) (Damasceno, 2011). The 2008 area was used because this was the only area that was measured by all above named researches (see annexes 3, 4 and 5 for maps of the research areas).

The data found during the fieldwork was compared to the data found in 2011 and the data found in 2012. Only 5 individual species were found more than 5 times by all 3 researches. These species were: *Pouteria caimito, Hymenaea courbaril, Tibouchina granulosa, Piptadenia gonoacantha and Inga edulis.* (A description of these species can be found in annex 12). These trees in the 2008 area were 7 years old at the time of the fieldwork of this study. It is assumed that in 2008 the trees were all 0,5 meters high and had a DBH of 0,3 cm. First tables with the average DBH and height were made with empty values for the missing years (see annex 9). The growth rate of 5 individual species were displayed in a height and DBH graph. Graphs that were made using these tables. (These graphs can be found in annex 10.) A summary of growth rate for the 5 species was calculated by dividing DBH and height by the 7 years they had grown. This graph is displayed in the results.

For observations about the succession state of the REGUA forest, all tree species were categorized into 3 types: pioneers, secondary and climax species. The type of a succession states were defined for each species of tree, with the help of Aline Damasceno, and her report (Damasceno, 2012).

2.4.4 - Statistical analysis

This research attempted to do different kinds of statistical analysis for the data, and through trial and error decided to do statistical analysis for the growth rates of 5 different species, and the growth rates in ABG.

For the growth rates of 5 species, the DBH and height were put in separate graphs, for each of the 5 species. In each graph the average DBH, or the average height for each year of measurement (see chapter 2.4.3) was shown. A trend line was added to each graph, also displaying the formula of the trend line and the R^2.

For the ABG data gathered, a scatter-chart with a trend line was made. Data was gathered only from areas with a slope of less than <5 degrees, for the amount of slope has significant influence on the amount of ABG found (Murray, 2012). For the 16 plots that were made the ABG was calculated using Chave's formula (see chapter 2.4.2). The amounts of ABG were then expressed per ha, per plot. The ABG for each plots were displayed using the scatter-chart and trend line functions in EXCEL. The R^2 was included in the graph (see annex 11 for the result).

3 - Results

In this chapter the results of all the data found in the field are explained with graphs and tables.

3.1 - Diversity

3.1.1 - Species frequency

Total number of species

A total amount of 525 trees were measured. The total amount of tree species identified were 82. Of these, 69 species of trees were 2 cm or bigger in DBH. The remaining 13 species were found among saplings (the trees with a DBH under 2cm). Among the species found, 33 families and 72 genera were identified (see species list in annex 7).

Family composition

81% of trees measured belonged to 10 biggest families. The Fabaceae family contained 36% of all trees measured and was the biggest family (see figure 10 below). The 23 families not displayed in this graph all had 10 or less trees. See annex 8 for a complete family frequency table.

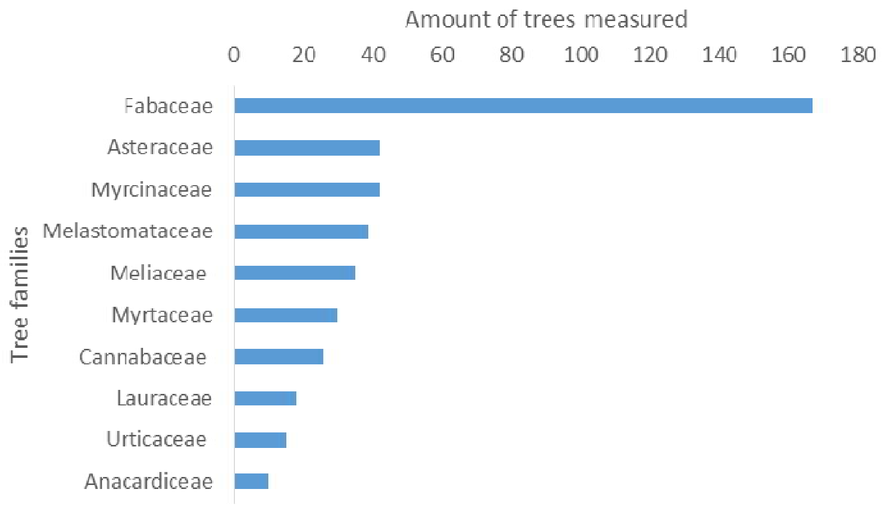

Figure 10 The 10 biggest families that were found most frequently.

Most frequent species

In figure 11 below a frequency graph of tree species that occurred at least 10 times is displayed. This graph has 12 species (out of 103). The species not shown in this graph haven an average amount of 3 trees per species, found in all plots (see annex 7 for full list of species and frequencies).

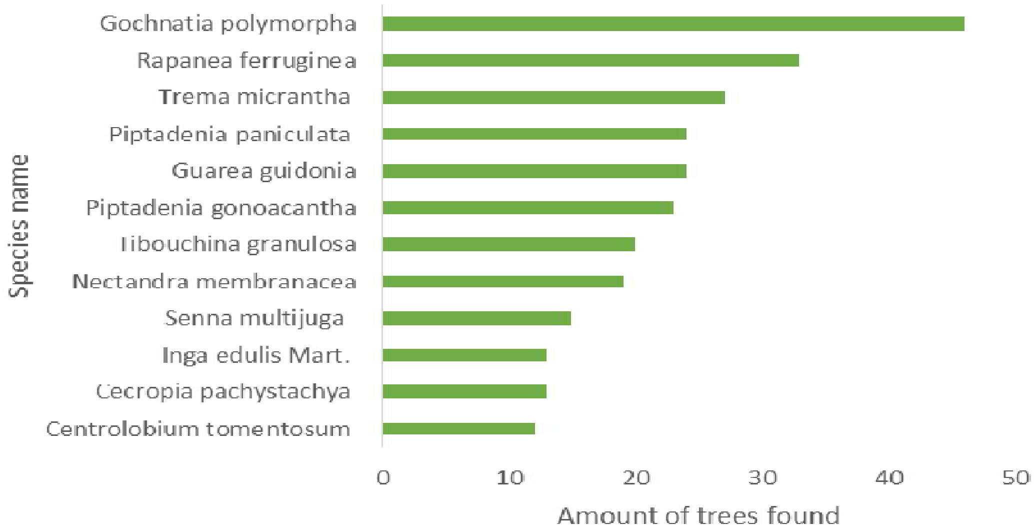

Figure 11 Amount of trees found per species of trees for the 12 most common species found at REGUA.

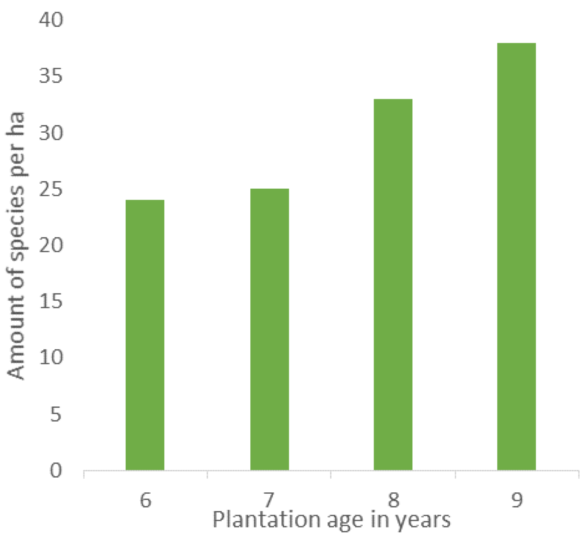

Figure 12 The amount of species of trees per planting age (in years) per ha.

3.1.2 - Diversity per hectare

In figure 12 the planting ages are shown with each the amount of tree species found for per ha. In the 6 year old plantation, 24 species were found and 38 species were found in 9 year old area. This shows that a 3 year older area shows 14 species more.

3.1.3 - Diversity of animals

The amount of birds grew from about 20 species in 1985 to 470 species of birds in 2015 (Locke, 2015); (REGUA, 2015). A ten year study on amphibians at REGUA found 73 amphibian species, of which nine are endemic to Rio de Janeiro state. (Almeida-Gomes et al. 2014). Out of 230 species of hawk moths found in Brazil, 76 species have been found at REGUA (Soares, Bizarro & Baston, et. al., 2011). A total of 204 species of dragonflies and damselflies were found at REGUA and its immediate surroudings (REGUA, 2015); (Kompier, 2015).

3.2 - Vegetation structure

3.2.1 -Vegetation cover

In the figure 13 the sizes of the planting areas are displayed in a pie chart. This data was gathered from the map in annex 3. It becomes clear that the area that was planted 6 years ago is much bigger than the other areas. The oldest area, planted 9 years ago, is small (3,3 ha big) compared to the other areas.

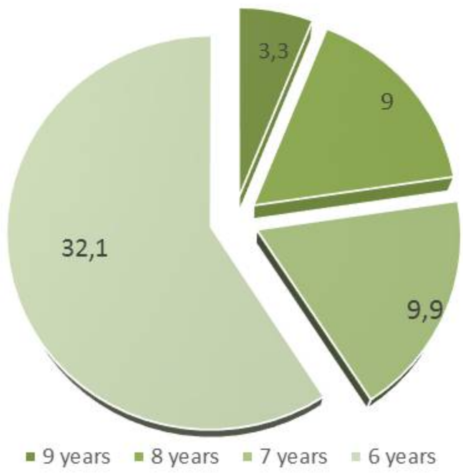

Figure 13 The amount of area (in ha) per plantation age.

Canopy, scrub and undergrowth cover

In table 1 below, the average amount of canopy, scrub and undergrowth cover is displayed for each plantation age (see table 1 below). The average amount of canopy cover for the whole study area was 67%. The scrub cover increases when the canopy cover decreases visa versa. The canopy cover does not change much in the different plantations. The amount of layers are all in the range between 3,3 and 4.

Table 1 Percentages of canopy, scrub and undergrowth cover for plantation ages 6 to 10.

Plantation age	Average percentage of canopy cover	Average percentage of scrub cover %	Average percentage of undergrowth	Average amount of layers #
6	67%	28%	20%	3,3
7	64%	35%	17%	3,4
8	69%	30%	18%	3,8
9	65%	23%	15%	4,0

3.2.2 - Height and DBH

In the figure 14 below the average DBH and height of trees are displayed per plantation age. An average increase in DBH can be observed. An average growth in height can be observed for from plantation ages 6 to 9.

In table 2 below the maximum height and DBH per plantation age is shown. The thickest, and the tallest tree was found in the youngest area. In the oldest area no trees were found above 16 meters, but note that less measurements have been taken in that area.

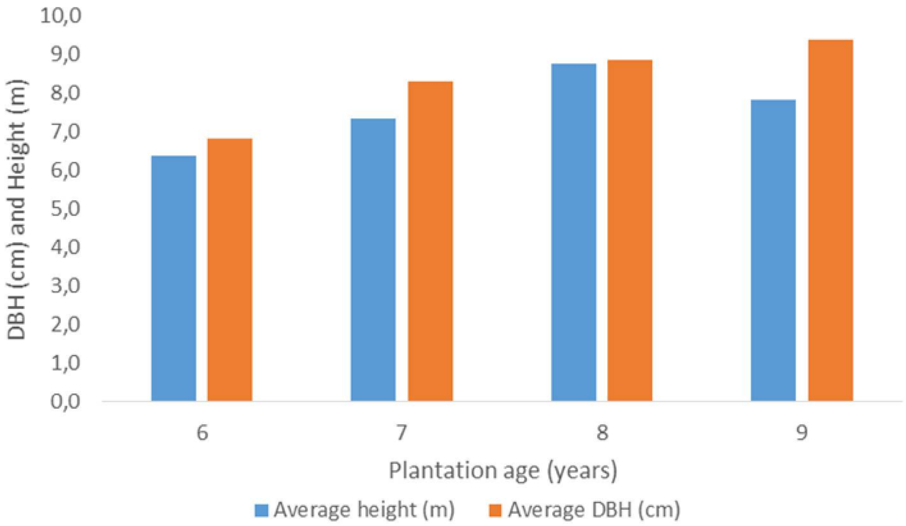

Figure 14 Average DBH (cm) and height (m) of trees found for different plantation ages.

Table 2 The maximum DBH(cm) and height(m) values and the amount of trees measured. All are displayed per plantation age. The years planted are shown.

Year planted	Plantation age	Maximum DBH (cm)	Maximum height (m)	Amount of trees measured
2009	6	30,6	21	135
2008	7	26,8	17	97
2007	8	30,5	21	88
2006	9	28,3	16	55

3.2.3 - ABG of trees

In the figure 15 below the amount of ABG is displayed in tons per ha, for the different plantation ages. Only the plots with an incline of 5 degrees or less, were included in the calculation of this graph (see chapter 2.4.2). The graph shows an increase in ABG from 47 tons per ha in age 6 to 91 tons per ha in plantation age 9. The R^2 was indicated using a scatter-chart with a trend line for the ABG per plot (see annex 11). It shows a linear increase in ABG that represents that 42% of the variance is in accordance to reality (R^2 = 0,4209).

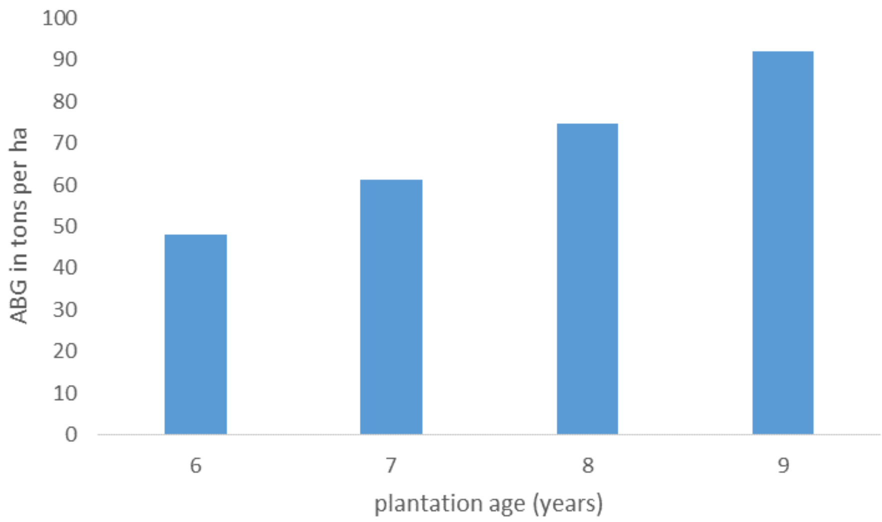

Figure 15 ABG (tons per ha), for each plantation age (years).

3.2.4 - Distribution of diameter classes

Figure 16 below displays the amount of trees per diameter class found in a certain planting area. This represents the distribution of diameter classes for all the trees measured in this research. The graph shows most trees found are in the lowest diameter class, declining to a low amount of trees in the higher diameter classes.

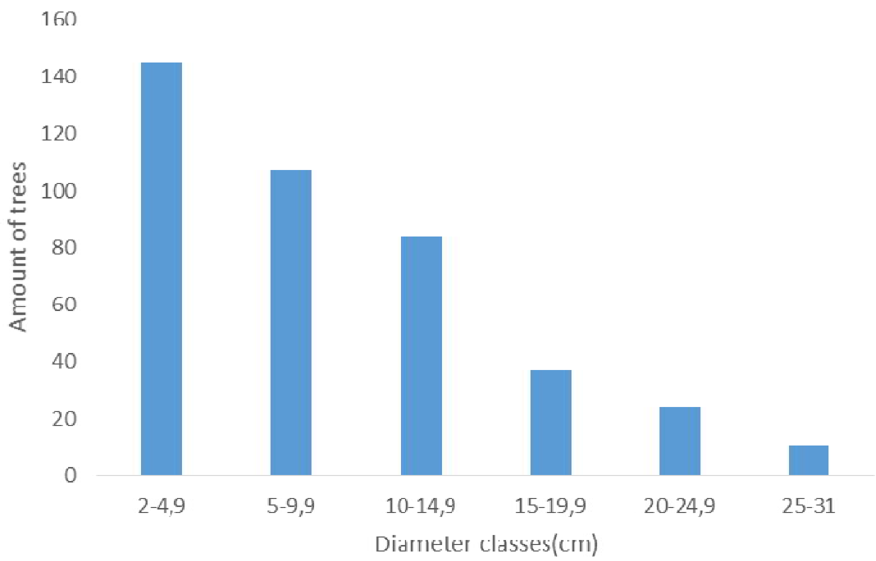

Figure 16 The amount of trees per diameter classes of all trees measured.

3.3 - Ecological processes

3.3.1 - Growth rates for five species

Figure 17 below shows the growth rates for height (m per year) on the left side, and for DBH (in cm per year) on the right side. *Pouteria caimito* and *Hymenaeae courbaril* are secondary species, the other species are pioneer species. In the graph it can be observed that the difference in growth between the secondary species and pioneers species is at least 0,9 meters per year for height, and 1,6 cm per year for DBH.

For the individual tree species displayed below, separate graphs for growth of the height and DBH have been made to provide more detailed information on the growth of the 5 species selected here. These can be found in annex 11.

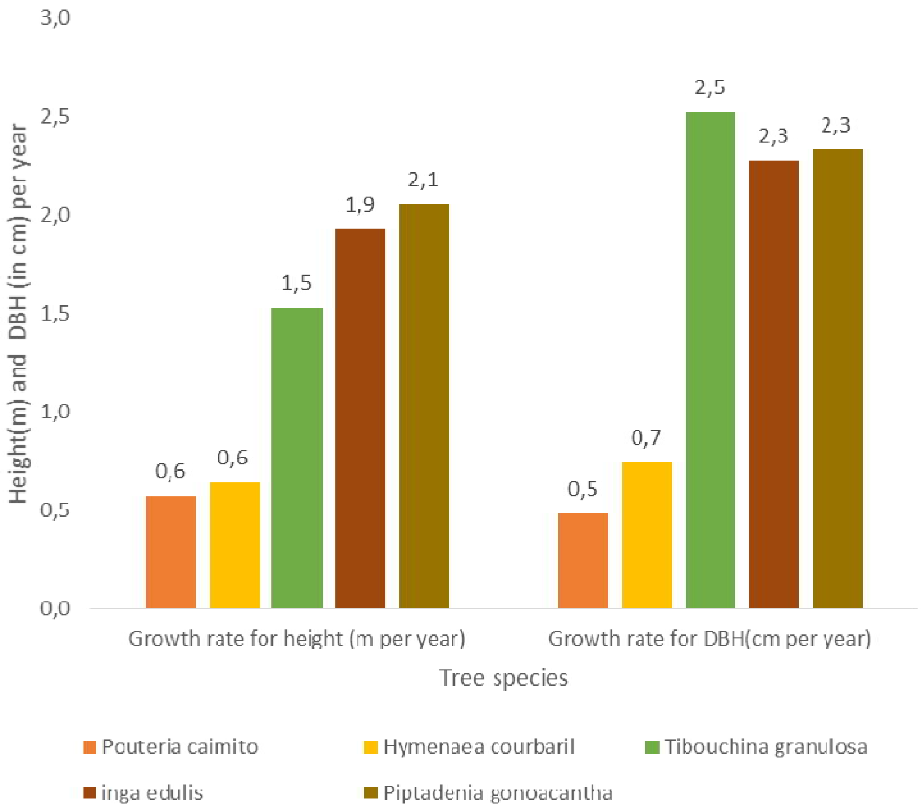

Figure 17 The growth rates per year based on average height and DBH found in the 2008 plantation.

A simple statistical analysis was done to indicate how each tree is growing over the years (see annex 10). However, too little data was represented to create statistical credibility.

3.3.2 - Succession states

In the graph below (see figure 18), the succession state was analyzed for each plantation age. The types of trees represented are pioneers (p), secondary species(s) and climax species(c). The majority of species found were pioneer. It is shown that the amount of pioneers ranges between

70% and 85% for the plantation ages 6 to 9. The percentage of pioneer species is declining as a parcel gets older. The percentage of climax species has 9% in the oldest part. The amount of secondary species grows from 6% in the 6 year old plantation, to 19% in the 9 year old plantation.

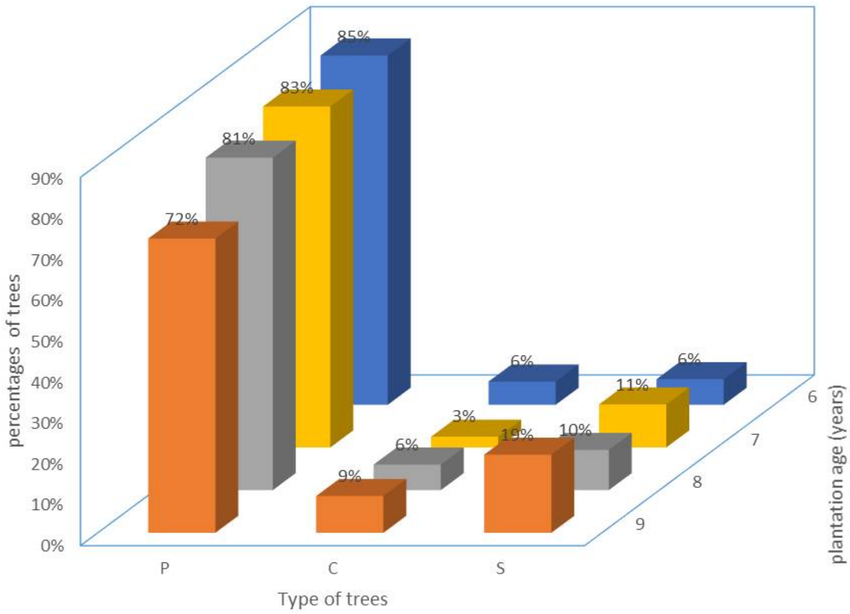

Figure 18 Percentages of pioneers (P), climax(C) and secondary (S) species are shown for the different plantation ages (on the right side).

4 - Discussion

4.1 - Diversity

The total tree diversity of 82 species (see chapter 3.1.1) was low compared to an average natural tropical forest, which has, on average, 300 species of trees per ha (Valencia, 1994). Compared to other secondary forest however, the diversity was very high. In a research by Götz (2004) the measured secondary forest had no more than 10 species of trees per ha. An agroforestry area measured by the same research had 20 species of trees per ha (Götz 2004). Another study of secondary forest by Carnevera & Montagnini (2001) found a similar diversity of 11 species in a secondary forest (Carnevale, N.J, & Montagnini. F. 2002).

No data was gathered about the diversity of pasture lands and therefore only an estimation can be given about the amount of trees present before this forest was grown. Logically, there were a low amount, probably less than 10, tree species present before trees were planted by REGUA. The high tree diversity can be seen as a clear indication that REGUA's aim of increasing species diversity was achieved.

All Fabaceae plants fixate nitrogen to their roots, making the soil more fertile. Fabaceae is the most common family in the tropics of Africa and the Americas (Burnham, 2004). That the biggest family found was Fabaceae, was an indication that the family composition is close to natural.

The species that are most frequently found (see chapter 3.1.1) were also found by Murray (2012) and Aline Damasceno (2011). These species have proofed to grow well at REGUA, but are also known to be successful in other parts of the MA (Murray 2012,); (Damasceno 2011). That these species are still frequently found after 6 to 9 years shows that these species will survive, and are a good basis for a reforestation project.

The diversity per ha shown in chapter 3.2.1 suggest that the species diversity is increasing every year. Field observations of this research suggest that this happens because of the process of natural distribution. However, a research by Chazdon (2003) shows that natural distribution is significantly slowed by human disturbances like long-term grazing (Chazdon, 2003). Although this was the case for all secondary forests involved in this research (see chapter 2.1), the increase in species diversity seems high. This high increase could be explained by the more mature forest from the nearby national park.

Because of a lack of time the diversity numbers of animals were not compared to diversity numbers found in other secondary forest. But it the numbers by themselves indicate a high diversity of animals (see chapter 3.1.3), and therefore show that REGUA's restoration effort had a positive impact on animal diversity.

4.2 - Vegetation structure

The results in chapter 3.2.1 show that size of the plantations increased over the years. The initial plantations proofed to the owners, workers and investors of REGUA that the method of planting used was reliable (Locke, 2015). Therefore, the increase in plantation size each year can be seen as an indicator of success. Accurate statistics of vegetation cover could not be made, because the exact boundaries of the area planted were not known. However, in the field it was observed that more than 95% of the vegetation cover survived and that most of the forest gaps have been filled by natural distribution and the increase of canopy cover.

The canopy measured are not very different from the canopy covers of a natural forest. Lemenih (2004) found that the average canopy cover of a natural tropical forest is 69%. The same research suggests that if the percentage of canopy cover is much higher it will result in decreased species diversity and growth of trees (Lemenih, Gidyelew, & Teketay, 2004). In chapter 3.2.1 it is displayed in table 2 that the canopy cover the research area, of 67%, is similar to the canopy cover of a natural forest of 69%. The average canopy cover is still lower, and is thus expected to increase over the years.

The highest tree and thickest tree were found in this youngest area, probably because more trees could be measured there. In 9 year plantation more plots were done, and thus showed more data. The 6 year old area was bordered by roads, lakes and in some parts heavily sloped and only 3 plots could be made. Not enough data could be gathered to create reliable data.

The DBH and height graph did suggest that the average DBH and height of all trees measured was high, but unfortunately not enough comparable data could be gathered through literature research that gave this evidence more ground. Many factors could have influenced the growth such as soils, slope and rainfall, and these have not been fully taken into account in this research.

The ABG of pastures were estimated by Schucknecht et. al. (2015) and found an average ABG of 0.74 tons per ha for pasture lands in Niger (A. Schucknecht, Kayitakire, Rembold, & A. Boureima, 2015). According this research, a biomass of 91 tons per ha can be achieved in 9 years. In general, secondary forests rapidly accumulate up to 100 t/ha of ABG for about 15–20 years after abandonment (Brown and Lugo, 1990). The ABG outcomes indicate that the forest grows 150% faster than the forest estimated by Brown and Lugo. This outcome suggests planted forest accumulates ABG 150% faster than a forest that is naturally regenerated. More research could be done on this topic to proof differences in ABG accumulation.

According to Leak (1996), a diameter classes graph of an undisturbed natural forest always show a reversed J shape, which has very few thick trees, an average amount of medium sized trees and a very high number of small trees (Leak, 1996). The forest measured shows a similar structure (see figure 15 in chapter 3.2.4). Because no measurements were taken for trees under 2 cm the graph is distorted. If these would have been measured there would be at least double the amount in the lowest class, which would make the total graph look more like a reserved J shape. A difference between diameter distributions of a natural forest and that of REGUA is the lack of trees bigger than 31 cm in the research area.

A study conducted by Ketterings (2001) displayed distribution of diameter classes for various forest stands in mixed secondary forests in Sumatra (Ketterings, Coe, van Noordwijk, Ambagau', & Palm, 2001). These can be found in Annex 14. The 15 year old stand measured shows a similar pattern to the forest of REGUA, but with bigger trees. These plantations are older and show what a distribution of a restoration effort can look like within 60 years.

4.3 - Ecological processes

In chapter 3.3.1 the growth rates were given for 5 species. Unfortunately very little literature was found about the growth rates of these species. Only for the species *Pouteria caimito* the growth-rate in DBH was found in another research. In this research *Pouteria caimito*, was growing at a rate 1.24 cm per year, within a secondary tropical forest (W. F. Laurance, 2003). When compared to the growth rate of 5 cm per year found by this research, it seems that for some reason the growth rate at REGUA is much higher. Too little data about other factors that influence growth were compared to confirm this.

The statistical analysis done for the growth rates are not sophisticated enough to represent actual scientific data. The scatterplots each have 4 points to refer to, and this is not enough to proof anything scientifically. What should have been made is a scatterplot that included each tree measured by the different researchers. Because of a lack of expertise this research failed to create such a graph.

The succession state graph (see chapter 3.3.2) shows a trend of decreasing amount of pioneer species compared to secondary and climax species. This trend is an indication that the forest is maturing to an ecosystem where eventually secondary and climax species take over. This is true according to Clark (1996), for he states that the amount of climax species always substituted the pioneer species in every forest succession, going from a young secondary forest, to an older secondary forest, and eventually to a natural forest (Clark, 1996). A forest will eventually evolve to a forest with mostly climax species.

The high percentage of pioneers, is higher than expected because according to owner Nicholas Locke (2015) 60% of the planted trees were pioneers (Locke, 2015). This difference seems to indicate a disturbance between pioneers, secondary and climax species. There is a chance that climax species are actually present in plentitude as a sapling, but were not measured because they were less than 2cm thick, and thus do not show in the results. Another explanation would be that there were many pioneers naturally regenerating that change the composition between climax and pioneer species.

4.4 – Statistics

Statistical significance was not achieved in this research because not enough cohesive data was gathered. Because of the limited amount of time we chose to minimize the number of plots and because of this factors that influence growth like soil type and slope, were not taken into account in the early stages of this research. Plot locations should have been as similar to each other as possible and factors that influence growth should be have contained, by keeping variances to a minimal.

However, without statistical analysis the success of a restoration effort can still be determined. Data gathered about diversity, DBH, height, canopy cover, ABG, distribution of diameter classes, growth rates and succession states can still be compared to other research to determine success.

5 - Conclusion and recommendations

5.1 - Conclusion

The results of this research indicated that REGUA's restoration effort was successful. The high diversity of trees suggest a good health of the forest, as did the averagely high percentage of the canopy cover. The majority of the results compared in the discussion suggested that REGUA currently has a healthy ecosystem or at least, is in the process of becoming one. Even without a statistical analysis, the results showed that the restoration project at REGUA was a success.

The diversity measurements gave positive indications. For a secondary forest a diversity of 82 tree species is very high, yet compared to the tree species found in a natural forest this diversity measured was still low. Because diversity of trees increased over the years (see chapter 3.2.3) and the change of the succession states (see chapter 3.3.2), it was expected that total diversity of trees will increase over the years. That the biggest family was Fabaceae indicated that the family composition of this forest was close to natural and when looking at the diversity of the separate forest stands the diversity was growing. The diversity of animals showed that the forest at REGUA supports a high diversity of birds, dragonflies, hawk moths and amphibians and this is also shows that the plantation effort was successful.

The vegetation structure at REGUA could be seen as close to natural because the canopy cover was only a few percentages lower than that of a natural forest and the distribution of diameter classes showed a similar pattern to a natural forest. The current averages of DBH, height and ABG at REGUA were still low, but indicated that the forest was growing in such a way that it could become very much like a natural forest. Overall, the vegetation structure measured pointed to success.

The composition of pioneers, secondary species and climax species also suggested that the forest was becoming more like a natural forest, but the fact that there were a higher percentages of pioneer species currently present than was originally planted, could mean that the species composition needs to be adjusted. Some frequently measured species all showed good growth, but no statistical analysis could confirm this. The indicators for the ecological processes showed that the planting method could still be improved.

Not much could be said about the future prospects of the growth in biomass, the change in succession states and growth of individual trees. When will a forest reach a stage of maturity? How long will it take for a secondary forest stand have the same amount biomass per hectare as a natural forest? A research of 1 years could never provide full answers to these kinds of questions.

Although statistical analysis did not provide proof of success, the abundance of positive indicators for diversity and vegetation structure showed that the planting method used by REGUA has a created a diverse and well-structured forest. When all the indicators point to success, a project can be rated as successful. This research concluded that the planting method at REGUA was successful.

5.2 – Recommendations

REGUA’s planting method should be defined in detail, and then repeated, not only by REGUA but also by NGO’s and forestry organizations across the Atlantic rainforest. The basis of this planting method should be tried in other parts of the world as well.

To improve REGUA’s plantation method, a new plantation could be planted with more climax and secondary species, to see if the composition between pioneers, secondary and climax species changes in a later stadium. Such a test could provide an even healthier ecosystem in a later stadium. Further research might provide methods of making afforestation more efficient.

Long term research on afforestation growth could be done at REGUA. Permanent plots should be established and maintained, preferably in a newly planted forest that uses the same successful planting method. Ideally, multiple permanent plots should be established, maintained and monitored every year to provide information on long term growth of an afforested area.

If more data is gathered about species compositions and growth rates the forest success could be more easily assessed. However, clear standards for success should be created through more research. An assessment of the success of a reforestation effort could provide an argument for further afforestation.

If this research is repeated to define success in another secondary forest the following improvements should be made to the research method: more plots should be done; more ecological processes, such as soil organic matter should be analyzed; a rating should be created to compare projects to each other to determine the rate of success of a project, next to answering the question whether a project is successful or not. Restoration success should be defined by the forestry community to define standards for success, and these should be used in future comparisons of success.

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Annex 1 – Map of Land use map and map of incline of the Guapiaçu river basin.

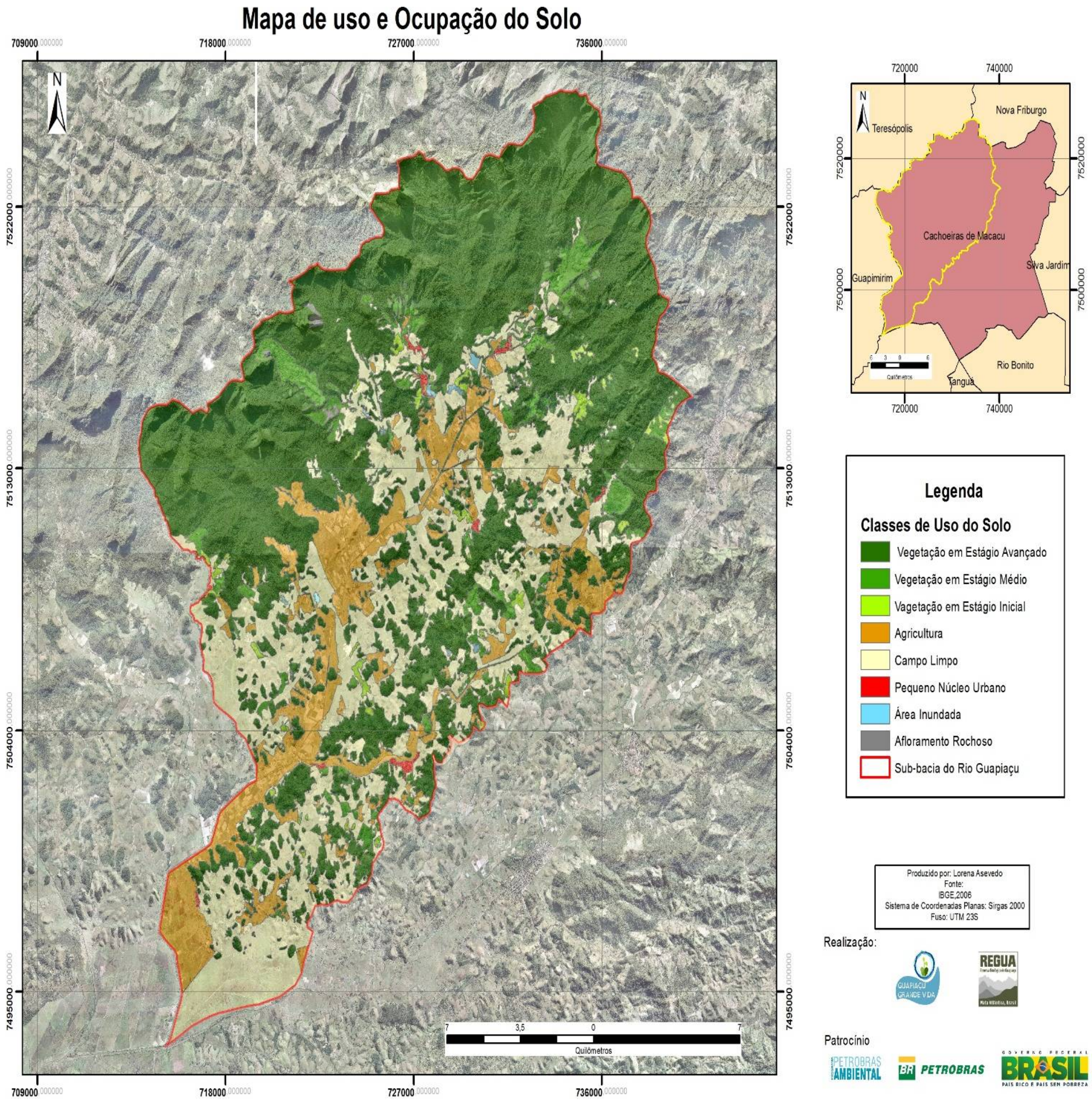

Figure 19 Land use of the Guapiaçu river basin. The different green areas are forests in different stages of growth. The orange area is agriculture land and the white area is pasture. (Petrobras Ambiental, 2015)

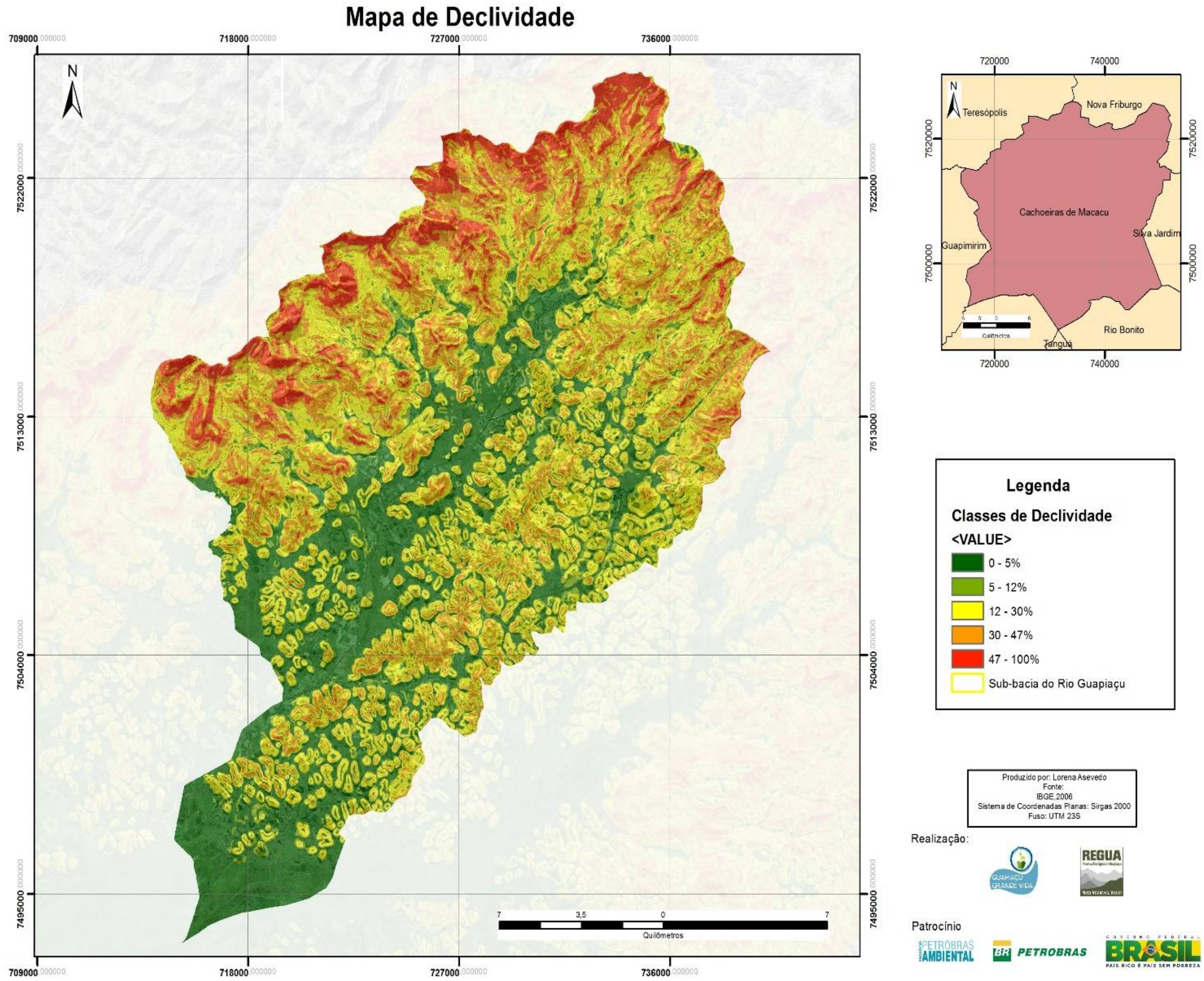

Figure 20 Map of slopes in the Guapiaçu river basin. The study area has a variation of slopes ranging between 0 and 100%. (Petrobras Ambiental, 2015)

Annex 2 - Soils type and catena’s

Cambisols are developed in medium and fine-textured materials derived from a wide range of rocks, probably from in alluvial, colluvium and Aeolian deposits. These soils are good for agriculture. This is common in areas with active erosion. **Acrisols** are clay-rich and associated with humid tropics such as Brazil. Low fertility and toxic amounts of aluminum pose limitations to agriculture. Crops include tea, oil palm, coffee and sugar cane. But these crops are not very productive. **Ferralsol:** very weathered, clay minerals and many iron-oxides which provide the red color. Good permeability and easily infiltrated. These are chemically poor soils.

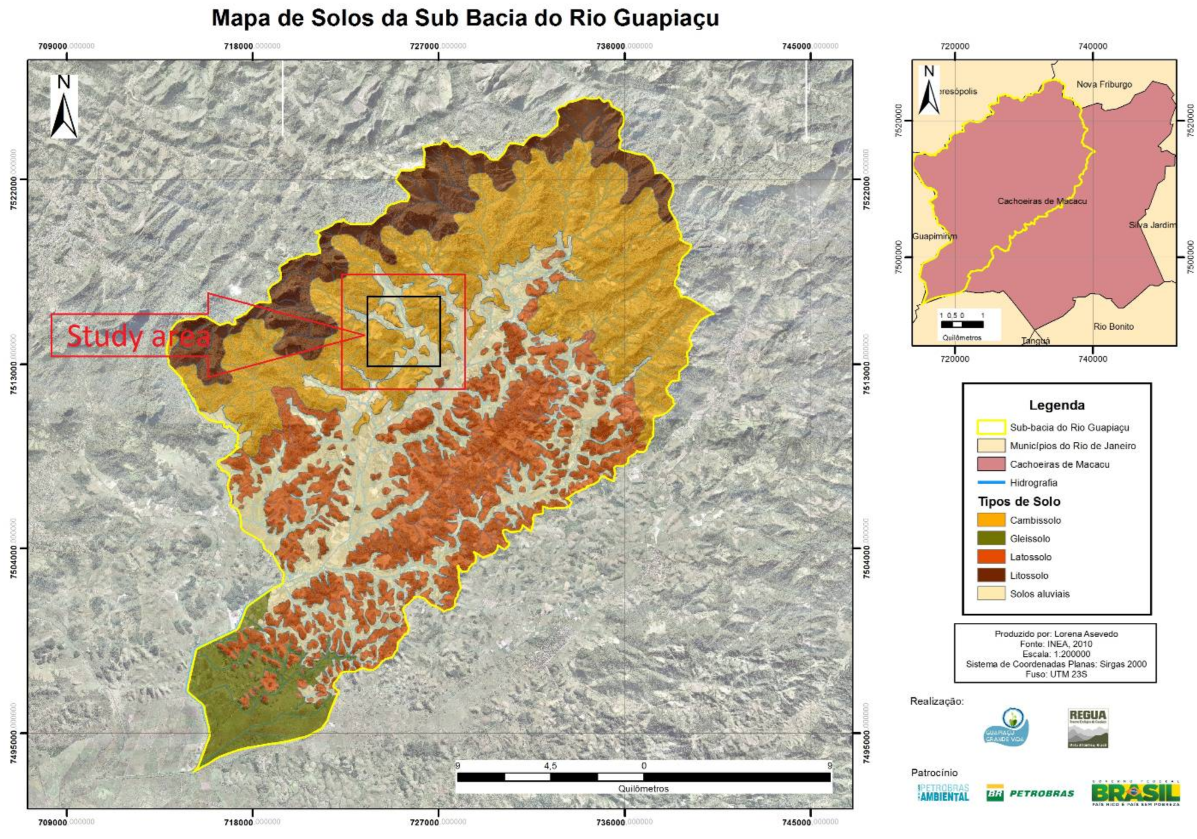

Figure 21 Soils of the Guapiaçu river basin. The study area is in the black square, and consists of cambisoils and alluvial soils (Petrobras Ambiental, 2015)

Annex 3 - Map of different planting areas

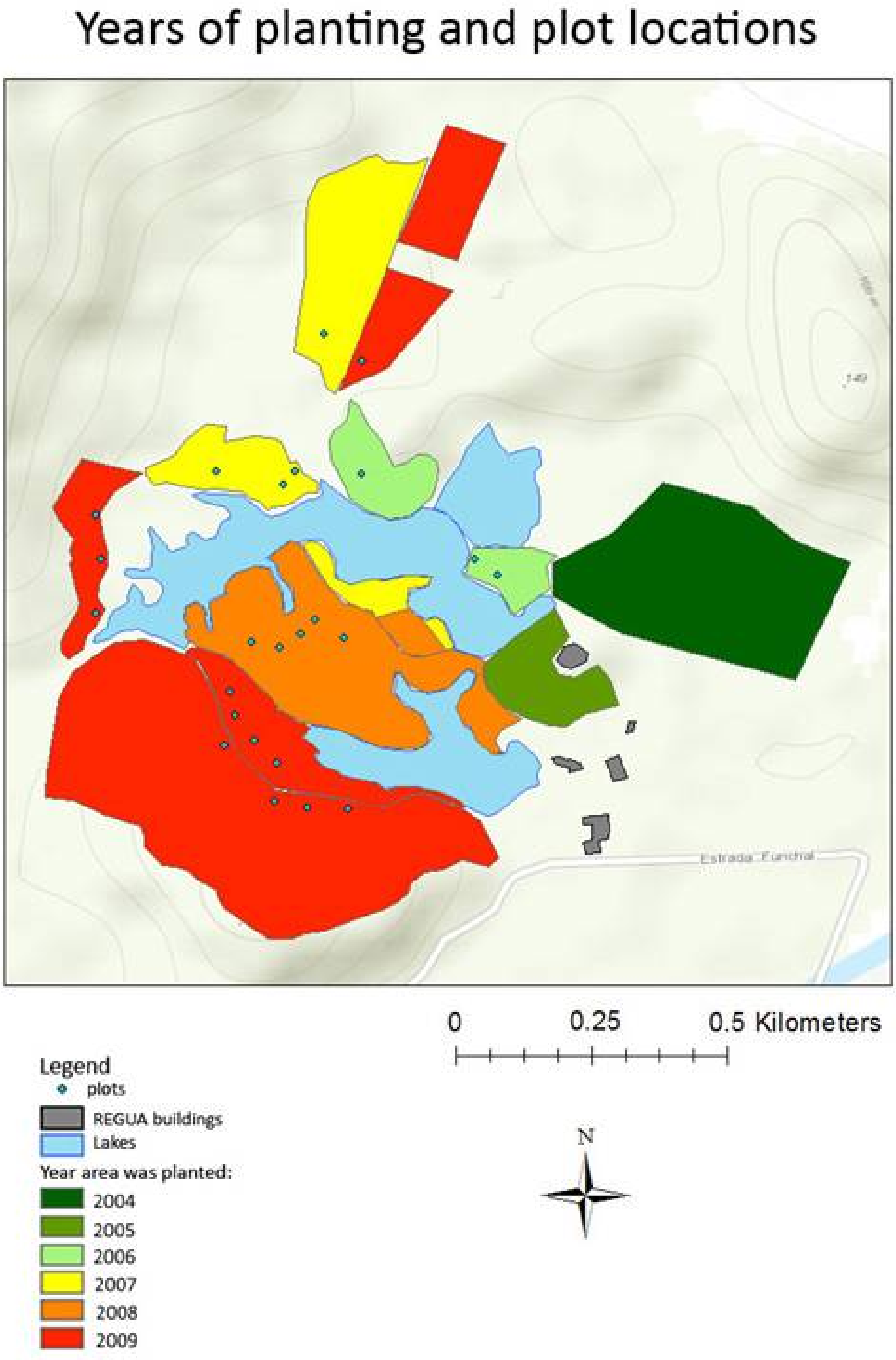

Figure 22 Map of the study area. Different years of plantation and plot locations are shown.

Annex 4 - Study site of Lara Murray

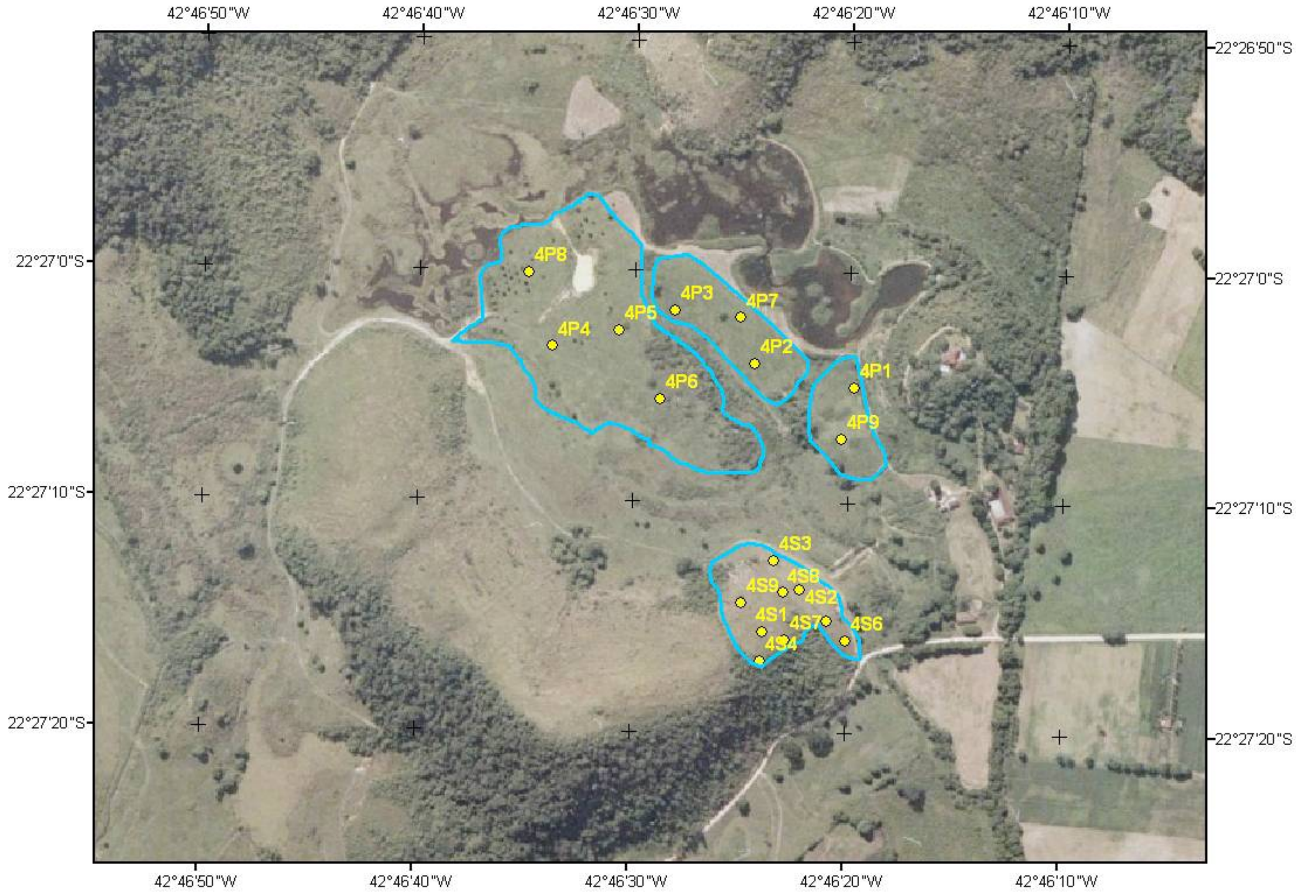

Figure 23 Plots and study areas of Murray (2012). Individual plots given in yellow. Note that the areas indicated are were already covered during her research (Murray, 2012)

Annex 5 - Study site of Aline Damasceno

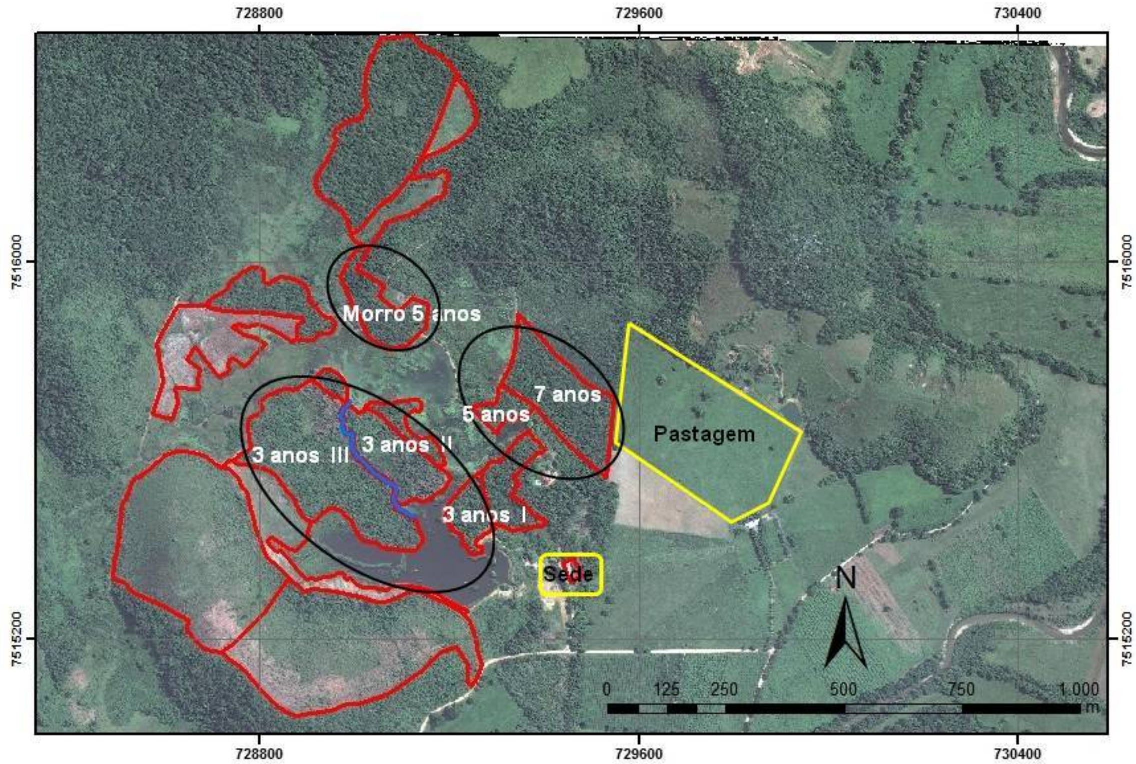

Figure 24 Study site of Aline Damasceno, the planted areas are indicated with red lines, area used for her research circled with black lines (Damasceno, 2011)

Annex 6 - Field-form used during this research

Gps coordinates:	x=	y=	
Plot no:		number of layers	
leaf characteristics		canopy cover%:	
Seed availeblility		Scrub cover%:	
Root structure		Undergrowth %:	
Signs of herbivory		Slope %:	
Soiltype:		Plotnotes:	

species name	Tag #	DBH	Height	Notes

Figure 25 The field form at REGUA, more than 30 were printed out, most plots only need 1 of these, but some needed 2. Each form was printed on A4 paper.

Annex 7 - Species found in all planted areas

Table 3 Species list, with type, wood density and amount of trees measured

Family	Local name	Species	Type	Wood density	Amount
Asteraceae	Cambara	Gochnatia polymorpha	P	0,76	42
Myrcinaceae	Capororoca	Rapanea ferruginea	P	0,60	42
Meliaceae	Carrapeta-verdadeira	Guarea guidonia (L.) Sleumer	P	0,61	30
Cannabaceae	Curindiba	Trema micrantha (L.) Blume	P	0,35	26
Fabaceae	Unha-de-gato	Piptadenia paniculata Benth.	P	0,68	24
Fabaceae	Pau jacaré	Piptadenia gonoacantha (Mart.) J.F. Macbr.	P	0,70	23
Melastomataceae	Quaresmeira	Tibouchina granulosa (Desr.) Cogn.	P	0,64	21
Lauraceae	Canela-de-agosto	Nectandra membranacea (Swartz) Griseb.	P	0,57	18
Fabaceae	Pau cigarra	Senna multijuga	P	0,60	15
Urticaceae	Embaúba	Cecropia pachystachya Trécul	P	0,36	15
Melastomataceae	Pixirica	Miconia albicans	P	0,60	13
Myrtaceae	Guamirim-facho	Calyptranthes concinna DC.	P	0,65	12
Fabaceae	inga edulis	Inga edulis Mart.	P	0,63	11
Fabaceae	Orelha de macaco	Enterolobium contortisiliquum.	P	0,55	11
Phytolaccaceae	Pau-d'alho	Gallesia integrifolia (Spreng.) Harms	P	0,60	9
Anacardiceae	Cajah mirim	Spondias mombin	ST	0,40	8
Fabaceae	Pau ferro	Caesalpinia ferrea	P	1,05	8
Siparunaceae	Limão-bravo	Siparuna guianensis Aubl.	P	0,34	8
Fabaceae	Araribá	Centrolobium tomentosum Guillemin ex Benth.	P	0,65	7
Fabaceae	Pseudopiptadenia	Pseudopiptadenia contorta	SI	0,60	7
Fabaceae	Sibipiruna	Caesalpinia pluviosa DC.	P	1,05	7
Verbenaceae	Tamanqueiro	Aegiphila sellowiana Cham.	P	0,60	7
Annonaceae	Pindaíba-vermelha	Xylopia sericea A. St.-Hil.	SI	0,63	6
Euphorbiaceae	Bolero	Joanesia principis	P	0,39	6
Fabaceae	Cassia sp.	Cassia sp.	NE	0,62	6
Fabaceae	Vinhático	Plathymenia foliosa	C	0,50	6
Myrtaceae	Araça	Psidium cattleyanum	P	0,74	6
Sapotaceae	Abiu	Pouteria caimito (Ruiz & Pav.) Radlk.	SI	0,60	6
Fabaceae	Ingá-bravo	Tachigali multijuga Benth.	C	0,56	5
Myrtaceae	Jamelão	Syzygium jambolanum	SI	0,59	5
Annonaceae	Araticum-de-paca	Annona cacans Warm.	P	0,60	4

Fabaceae	Inga-branco	Inga laurina	P	0,62	4
Fabaceae	Jacaranda de baiha	Dalbergia nigra	P	0,77	4
Fabaceae	Jatoba	Hymenaea courbaril	ST	0,77	4
Fabaceae	Pau sangre	Pterocarpus violaceus	SI	0,57	4
Solanaceae	Jurubeba	Solanum pseudoquina A. St.-Hil.	P	0,60	4
Bignoniaceae	Caroba	Jacaranda sp.	NE	0,55	3
Bignoniaceae	Ipê-de-jardim	Tecoma stans	P	0,60	3
Fabaceae	Machaerium sp.	Machaerium sp.	SI	0,70	3
Fabaceae	Maricá	Mimosa bimucronata	P	0,60	3
Fabaceae	Pacová-de-macaco	Swartzia langsdorffii Raddi	ST	0,59	3
Magnoliaceae	Pinha-do-brejo	Magnolia ovata (A.St.-Hil.) Spreng	C	0,52	3
Melastomataceae	Melastomataceae 1	Melastomataceae 1	P	0,60	3
Meliaceae	Cajarann	Cabralea canjerana	C	0,55	3
Rutaceae	Ameixa amerella	Eriobotrya japonica	P	0,65	3
Sapindaceae	Camboatã	Cupania oblongifolia	P	0,60	3
Sapindaceae	Saboniteira	Sapindus saponaria L.	P	0,60	3
Apocynaceae	Leiteira	Tabernaemontana laeta	P	0,60	2
Bignoniaceae	ipê amarelo	Handroanthus chrysotrichus	P	0,06	2
Celastraceae	Maiate	Maytenus robusta	SI	0,71	2
Euphorbiaceae	Mamoninha-do-mato	Mabea fistulifera Mart.	P	0,59	2
Euphorbiaceae	Tapiá	Alchornea sidifolia Baill.	P	0,49	2
Fabaceae	Angelim-doce	Andira fraxinifolia Benth.	P	0,60	2
Fabaceae	Angico vermelho	Anadenanthera peregrina	P	0,71	2
Fabaceae	Canela-louro	Nectandra megapotamica (spreng) mez	C	0,52	2
Fabaceae	Farinha seca	Albizia polycephala (Benth.) Killip.	P	0,52	2
Malvaceae	Castanha	Bombascopsis glabra	SI	0,44	2
Malvaceae	Paineira	Ceiba speciosa	ST	0,39	2
Malvaceae	Pau rei	Pterygota brasiliensis	P	0,58	2
Melastomataceae	Quaresma branca	Tibouchina sp.	P	0,60	2
Meliaceae	Cedro-rosa	Cedrela fissilis Vell.	SI	0,49	2
Myrtaceae	Guamirim sp	Calyptranthes sp.	P	0,65	2
Myrtaceae	Pitanga	Eugenia uniflora	P	0,65	2
Polygonaceae	Pau formiga	Triplaris americana	P	0,64	2
Sapindaceae	Maria-preta	Diatenopteryx sorbifolia Radlk.	SI	0,60	2
Sterculiaceae	Chichá	Sterculia chicha	C	0,55	2
Anacardiceae	Goncalo alves	Astronium graveolens	SI	0,82	1
Anacardiceae	Jobo	Tapirira guianensis	P	0,47	1
Arecaceae	Jarivá	Syagrus romanzoffiana	C	0,60	1
Bignoniaceae	Ipê-tabaco	Zeyheria tuberculosa	P	0,60	1
Boraginaceae	Erva-de-lagarto	Casearia sylvestris	P	0,60	1
Boraginaceae	Louro pardo	Cordia trichotoma	ST	0,53	1

Caricaceae	Mamão-jaracatiá	Jacaratia spinosa (Aubl.) A. DC.	P	0,55	1
Fabaceae	Albizia	Albizia sp.	NE	0,52	1
Fabaceae	Garapa	Apuleia leicarpa	C	0,60	1
Fabaceae	Guapuruvu	Schizolobium parahyba (Vell.) S.F. Blake	P	0,41	1
Fabaceae	olho de pavão	Adenanthera pavonina	P	0,70	1
Lacistemaceae	Lacistema	Lacistema pubescens Mart.	SI	0,60	1
Lecythidaceae	Jequitibá-branco	Cariniana estrellensis (Raddi) Kuntze	C	0,60	1
Lecythidaceae	Sapucaia	Lecythis pisonis Cambess.	ST	0,83	1
Myristicaceae	Bicuíba	Virola bicuhyba (Schott) Warb.	C	0,44	1
Myrtaceae	Grumixama	Eugenia brasilensis	C	0,65	1
Myrtaceae	Jambo	Syzygium malaccense	P	0,59	1
Myrtaceae	Myrtaceae 1	Myrtaceae sp.	NE	0,60	1
Sapindaceae	Camboata do morro	Matayba guianensis	P	0,70	1
Unknown	Unknown	Unknown	NE	0,60	1

Annex 8 - Amount of trees per family

Table 4 Amount of trees found per tree family

Amount of trees	Family
167	Fabaceae
42	Asteraceae
42	Myrcinaceae
39	Melastomataceae
35	Meliaceae
30	Myrtaceae
26	Cannabaceae
18	Lauraceae
15	Urticaceae
10	Anacardiceae
10	Annonaceae
10	Euphorbiaceae
9	Bignoniaceae
9	Phytolaccaceae
9	Sapindaceae
8	Siparunaceae
7	Verbenaceae
6	Malvaceae
6	Sapotaceae
4	Solanaceae
3	Magnoliaceae
3	Rutaceae
2	Apocynaceae
2	Boraginaceae
2	Celastraceae
2	Lecythidaceae
2	Polygonaceae
2	Sterculiaceae
1	Arecaceae
1	Caricaceae
1	Lacistemaceae
1	Myristicaceae
1	unknown

Annex 9 - Growth rate table for 5 most common species.

Table 5 Five species and their DBHs for years measured. Growth rate for DBH is stated in the last colon.

Species	2008	2009	2010	2011	2012	2013	2014	2015	growth rate
Pouteria caimito.	0,3			1,66	2,00			3,70	**0,5**
Hymenaea courbaril	0,3			2,63	3,50			5,50	**0,7**
Tibouchina grandulosa	0,3			11,40	13,50			17,96	**2,5**
Inga edulis	0,3			8,76	11,73			16,25	**2,3**
Piptadenia gonoacantha	0,3			11,13	11,40			16,62	**2,3**

Table 6 Five species and their heights for years measured. Growth rate for heights are stated in the last colon.

Species	2008	2009	2010	2011	2012	2013	2014	2015	growth rate
Pouteria caimito.	0,5			1,8	2,0			4,5	**0,6**
Hymenaea courbaril	0,5			2,3	3,5			5,0	**0,6**
Tibouchina grandulosa	0,5			5,5	6,2			11,2	**1,5**
Inga edulis	0,5			5,5	8,2			14,0	**1,9**
Piptadenia gonoacantha	0,5			6,8	10,4			14,9	**2,1**

Annex 10 - Growth rates for 5 species

For each figure below(figure 25 to 30) two graphs are displayed for 5 species. The average height is found in the graph on the left side, and in the graph next to it on the right the average DBH displayed. Measurements were done in 2008, 2011, 2012 and 2015, and thus only these measurements are displayed. In all graphs a polynomial tread lines was added to give an indication of DBH and height values for the years that no measurements were done.

The tread lines show a trend of growth slowing down or staying more or less the same over the years. All r square values found were above 98% and shows that the data is very close to the trend line. However, not enough points of reference were made to statistically proof the growth.

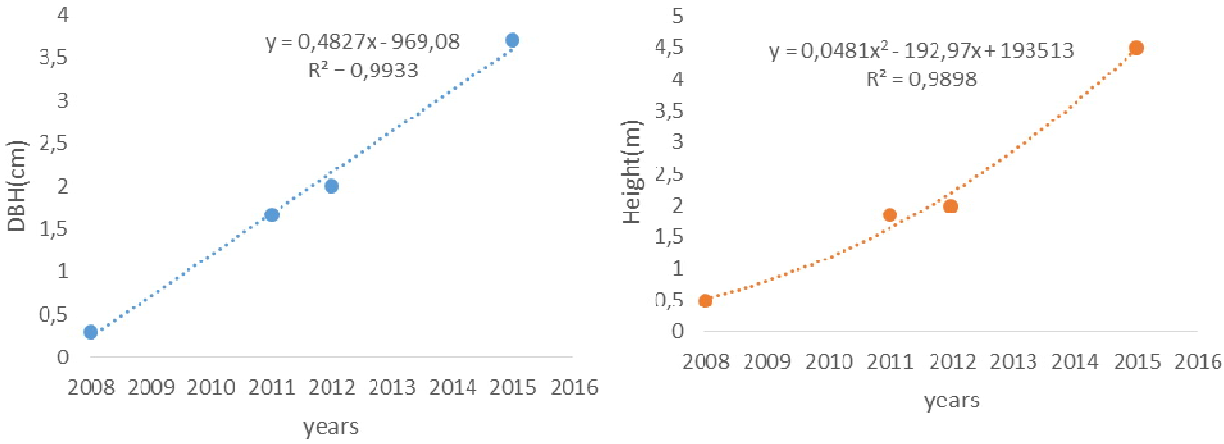

Figure 26 The DBH (left) and height (right) of Pouteria caimito (in two separate graphs), for each year it was measured. A Polynomial treat line was added to give an indication of how high it should would have been in the missing years. Local name is Abiu.

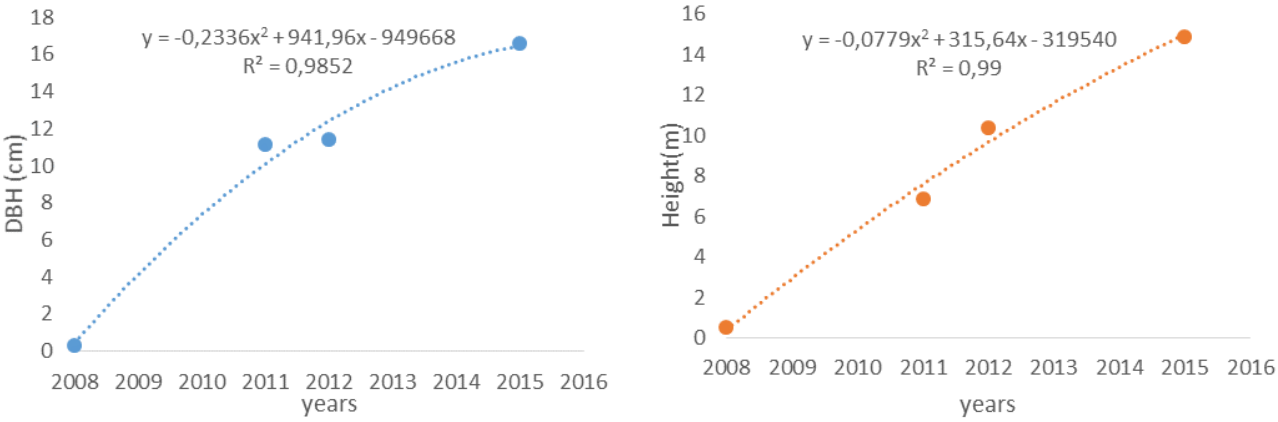

Figure 28 The DBH and height of Piptadenia gonoacantha, local name pau jacaré.

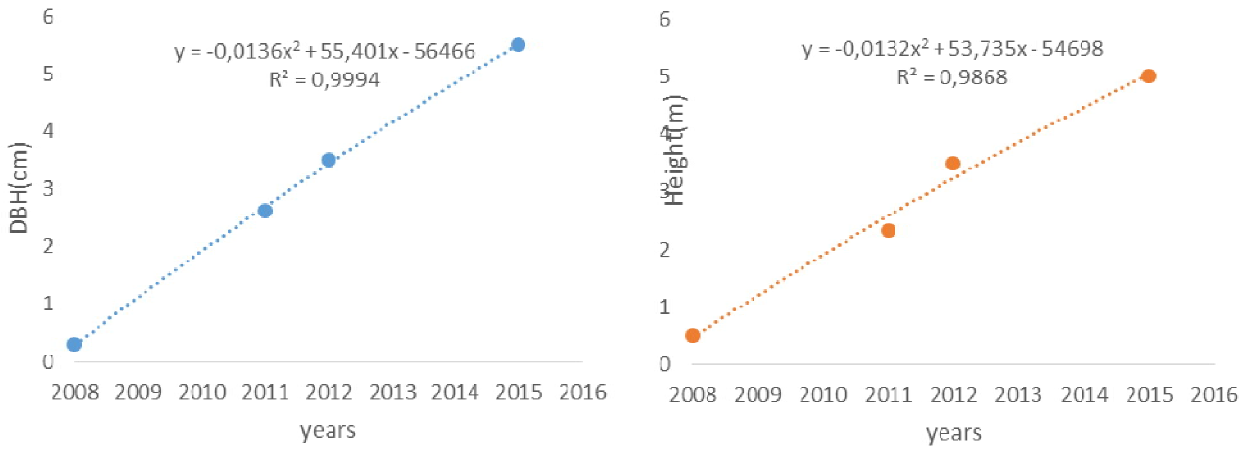

Figure 278 The DBH (left) and height (right) of Hymenaea courbaril. The local name is Jatoba.

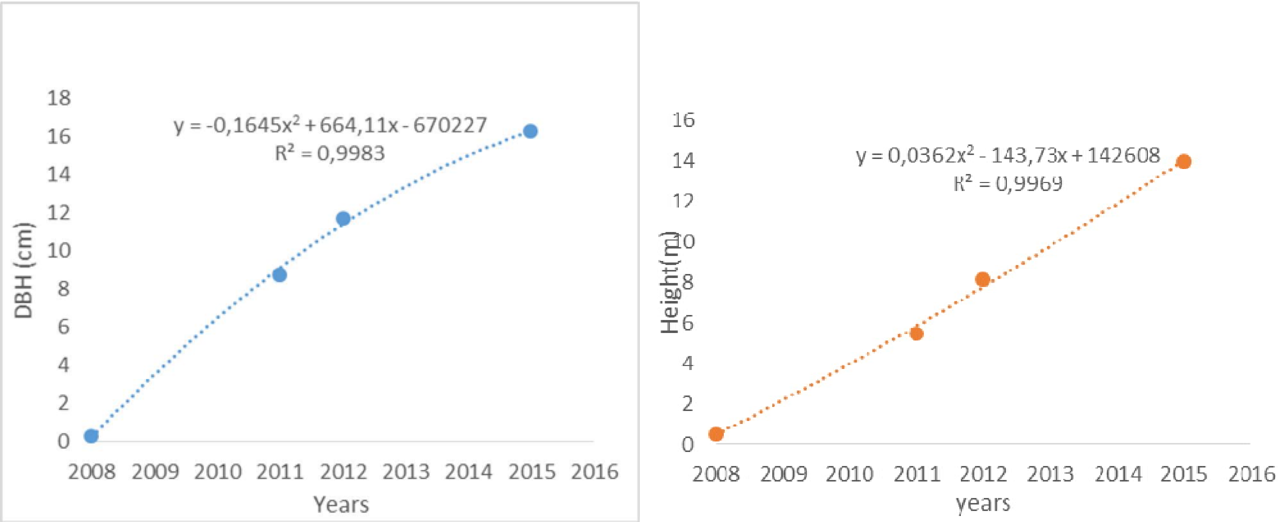

Figure 29 The DBH (left) and height (right) of Inga edulis. Local name is also Inga edulis.

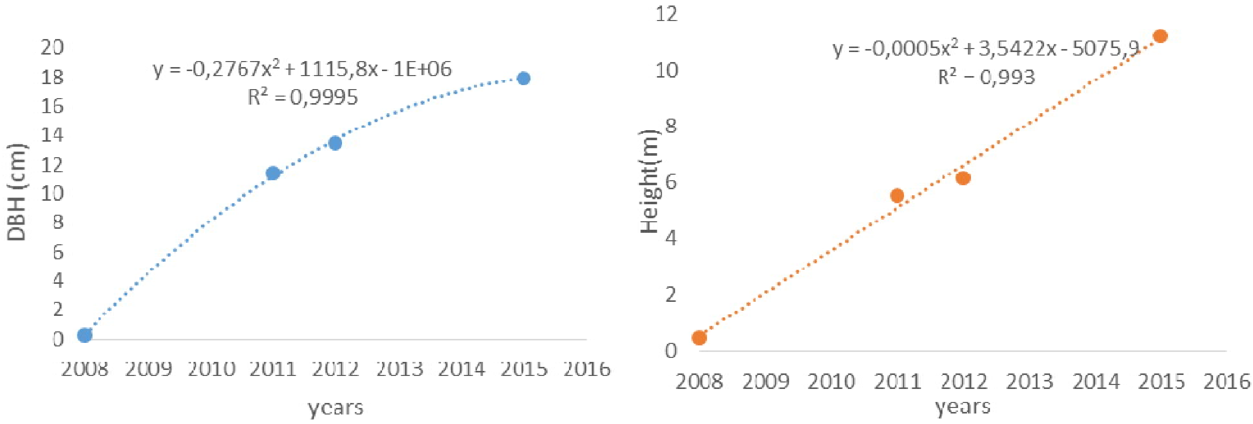

Figure 30 The DBH (left) and height (right) of Tibouchina grandulosa. The local name is Quaresmeira. The growth in height seems to slow down over the years, but the growth in DBH seems to stay linear. R^2 values are both above 99%.

Annex 11 - Regression model ABGs

In the graph below a regression model is shown between the plantation ages and the ABG per plot. Each dot represents the biomass of a plot, expressed in biomass per ha. The R square of 0.61, represents that 61% of the time the ABG will grow along this trend line. It represents a weak relation to reality.

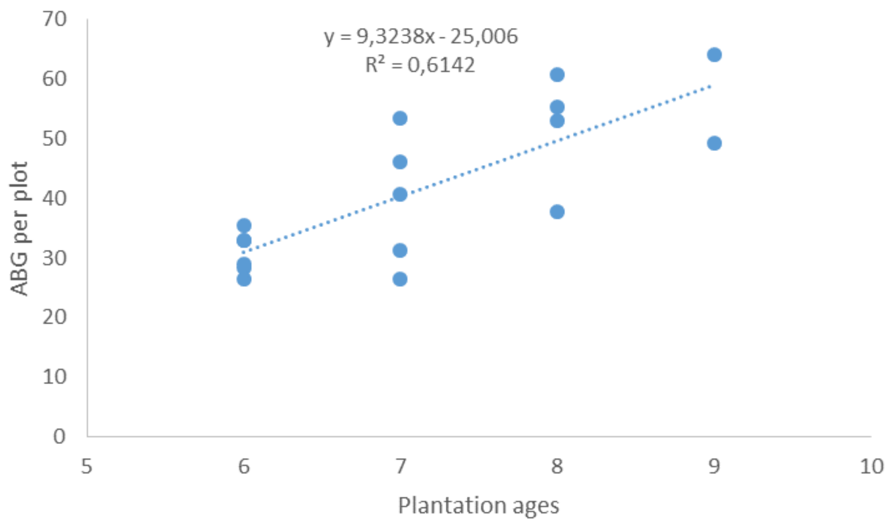

Figure 30 ABG per plot per plantation age, with a linear trend line. R^2 = 0,6142.

Annex 12 - Short descriptions of 5 chosen plant species.

Inga edulis

The FABACEAE INGA EDULIS is native to the Atlantic Forest and characteristically populates the margins of rivers in the region as well as secondary growth areas supplied with enough water. This pioneer species reaches 5-10m in height and prefers humid, swampy soils (Lorenzi, Brazilian Trees Vol. I, 2002). Known locally as the Inga-cipó, it is an ideal species for afforestation as it annually produces a large number of seeds which quickly and germinate. Moreover, the seedlings grow very quickly – they require only 3-4 months until they are suitable for replanting and develop in the field quickly (Lorenzi, Brazilian Trees Vol. I, 2002), providing ground cover and shade for succession species.

Pouteria caimito

The tree has a pyramidal or rounded crown; is generally about 10 m high but may reach 35 m in favorable situations. The leaves are alternate and highly variable; may be ovate-oblong, elliptic; 4 to 10-20 cm long, 3-6 cm wide; short-pointed at the apex, sometimes long-tapering at the base; smooth or with a few scattered hairs. The flowers, borne singly or in groups of 2 to 5 in the leaf axils, are cylindrical, 4- to 5-lobed, white or greenish; 1/6 to 1/3 in (4-8 mm) long. The fruit, downy when young, is ovoid, elliptical or round; 1 1/2 to 4 in (4-10 cm) long, sometimes having a short nipple at the apex; with smooth, tough, pale-yellow skin when ripe and fragrant, white, mucilaginous, translucent, mild-flavored, sweet or insipid pulp containing 1 to 4 oblong seeds, brown, with a pale hilum on one side. Until fully ripe, the fruit is permeated with latex and is very gummy and astringent. (Morton, J. 1987).

Tibouchina granulosa

The species name refers to the grainy, gritty texture of the leaves. This wonderful tree grows quickly as much as 12 meters in its native habitat but is usually about half that height in cultivation. Blooms 2-3 times a year, spring to fall. Flowering panicles at branch tips can completely cover the tree with rich, velvet-like blossoms. The stems are four-angled, and the new growth is clothed in a reddish bronze felt. The wonderful 8" long leaves have a dark green, are pubescent beneath but usually smooth and almost glossy above. The flowers are in erect terminal panicles and each five-petaled 5 cm wide blossom is a deep rose to violet in color. The varied-shaped stamens of this flower are visited by pollen-collecting bees (Top Tropicals, 2015).

Hymenaea courbaril

Jatobá is a huge canopy tree, growing to 30 m in height, and is indigenous to the Amazon rainforest and parts of tropical Central America. It produces bright green leaves in matched pairs, white, fragrant flowers that are pollinated by bats, and an oblong, brown, pod-like fruit with large seeds inside. The fruit is considered edible although hardly tasty; one of its common names, "stinking toe," is used to describe the smell and taste of the fruit! In the Peruvian Amazon the tree is called azucar huayo and, in Brazil, jatobá. The Hymenaea genus comprises two dozen species of tall trees distributed in tropical parts of South America, Mexico, and Cuba (Taylor, 2012).

Piptadenia genoacantha

A tree that quickly grows 8-20 m tall and 20-50 cm DBH, reaching up to 30 m tall and 90 cm DBH in adulthood; Trunk: straight, usually tortuous, with aculeate crests, features the full length. Bole usually short when isolated; However, in forest, it reaches up to 8 m long. Branch: cresting, dichotomous. Irregular canopy, close, umbellate, with thorns on thin branches. Bark: thickness up to 5 mm. The outer shell, with longitudinal linear ridges, joined by other smaller cross, remembering sometimes the alligator leather, which is why it takes the popular name; are present also spines a greater or lesser amount of up to 2 cm in length. The outer bark is rough in young trees, becoming rough or fissured as aging. The inner bark is yellowish. Flowers are beige-yellow, small, gathered in axillary inflorescences spikes from 5 to 9 cm in length and may be solitary or in groups of 2 to 3 in the upper armpits. Fruit is a legume, leathery, dry, and flat, with straight, brown margin, 8-15 cm long and 1.7 to 2.5 cm wide, with 4-10 seeds (Lima, 1985; Souza et al., 1990). Seed: brown-yellowish, flat, smooth, oval, without endosperm, not winged, measuring on average 9 mm long by 8 mm wide (Carvalho, 2004).

Annex 13 - Climate

Below in the tables are the average yearly maximum and minimum temperature and the average yearly precipitation of the state of Rio de Janeiro. The temperatures can be a bit lower in the higher parts (see elevation map) on this map and are averagely a few degrees lower inside of the forests. The average temperature do not fluctuated much over the year. Rainfall does fluctuate a bit more but still not a lot, with little rain in December and August and a more rain between January and April.

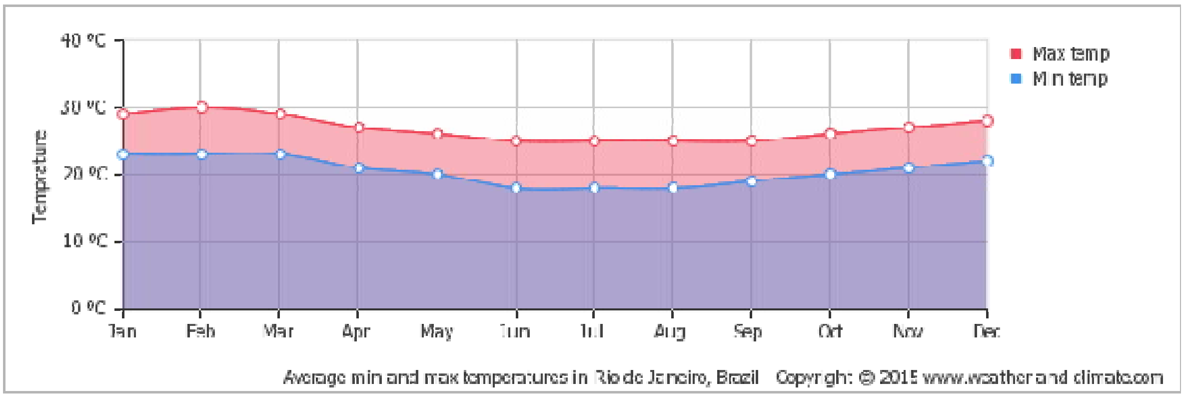

Figure 32 Average minimum and maximum temperatures in the state of Rio de Janeiro (Average Weather in Rio de Janeiro, Brazil, 2015).

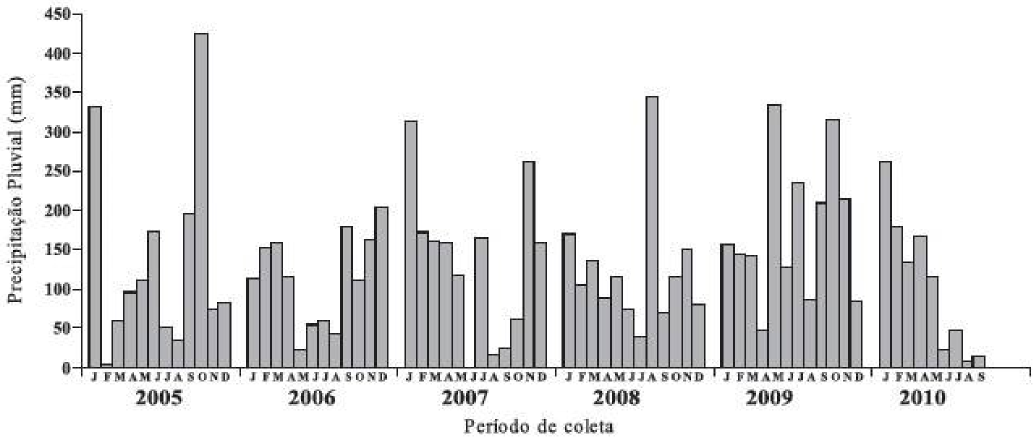

Figure 33 Average monthly values of rainfall in the state of Rio de Janeiro. On the vertical axis the amount of precipitation (in mm) is shown. On the horizontal axis the measurement period is indicated, the letters represent the months January till December (in Portuguese) for each year shown (Wagner Henrique Moreira, Edner Betioli Junior, Petean, Cássio Antônio Tormena, Sérgio José Alves, & Aurélio Teixeira Costa, 2012).

Annex 14 - Diameter distribution of another project

Below the diameter distribution is displayed for 5 secondary forests in Sumatra. Each line defines a different forest stand planted at different times. The age of each stand is displayed in the top right corner of the graph, and given a symbol. (Ketterings et al., 2001)

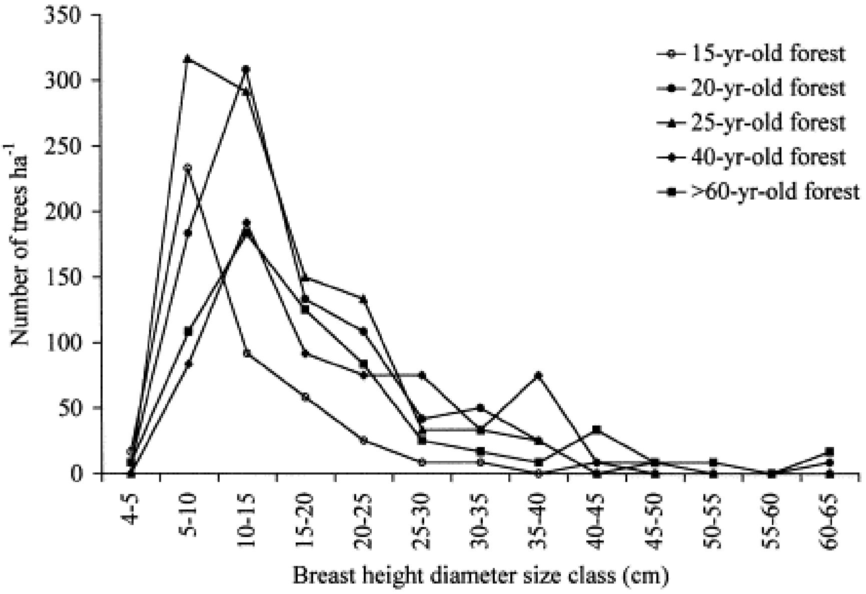

Figure 314 Frequency distribution of tree diameter classes for a mixed forest in Sumatra(Ketterings et al, 2001).