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Master Thesis

Reforestation on different treated areas in south-western Costa Rica

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Abstract

We investigated the influences of two different types of treatments, which are (1) Total freeing of newly planted trees and (2) leaving of competitors on reforestation areas in the Southwest of Costa Rica between the years 2007 and 2010. Furthermore, we analysed the natural regeneration referring to (1) the former mentioned treatments and (2) the neighbourhood to forests (primary or secondary). Using fixed circles of measurement (area = 100m²) the newly planted trees concerning species, diameter (in 50cm height) and height were measured as well as the natural regeneration. For the latter the families of the species were identified together with the amount of their appearance. Due to the current data, only three of the 53 planted species were analysed more closely regarding their growth. Therefore, we focused on *Terminalia amazonia* (J.F. GMEL.) EXELL, *Carapa guianensis* AUBL., and *Cedrela odorata* L. A not statistically verified tendency was found for a better growth without treatment. Reasons for that can be found in variables not taken into account, for instance soil ameliorating species nearby or different sizes in planting age. Concerning the natural regeneration the results were as followed: Treated areas have with 139 plants/ha clearly less regeneration than untreated areas with 351.7 plants/ha. The Simpson index and the according Evenness are equal for both types of areas with 0.88 (0.86) and 0.96 (0.92). Referring to neighbourhood the natural regeneration is similar. Areas with forests nearby have clearly more regeneration (358.6 plants/ha) then areas without forests (67.1 plants/ha). The Simpson index and die Evenness are with forest at an amount of 0.87 and 0.91; in area without forest at 0.81 and 0.91. Throughout the most dominant families are *Melastomaceae*, *Piperaceae* and *Fabaceae*. Due to plantation's age a rerun of data collection is strongly recommended in several years. This might validate or refute these tendencies.

Keywords: Costa Rica, reforestation, growth, natural regeneration, treatment, freeing

Zusammenfassung

Untersucht wurden die Einflüsse von zwei verschiedenen Behandlungsmethoden (eine totale Freistellung der neu gepflanzten Baumarten und ein belassen der Konkurrenzvegetation) auf Wiederbewaldungsflächen im Südwesten Costa Ricas, die in den Jahren 2007-2010 bepflanzt wurden. Desweiteren wurde die natürliche Regeneration untersucht bezüglich (1) der vorher benannten Behandlungen und (2) der Nähe der Flächen zu einem bestehenden Wald (primär oder sekundär). Mit Hilfe mehrerer zufällig angelegter fixer Probekreise (a=100 m²) wurden sowohl die neugepflanzten Arten bezüglich Durchmesser (in 50 cm Höhe) und Höhe aufgenommen als auch die Naturverjüngung. Hierbei wurden die Familien der Pflanzen bestimmt, sowie die Anzahl ihres Vorkommens. Aufgrund der Datenlage, konnten nur drei der 53 gepflanzten Arten genauer bezüglich ihres Wachstums untersucht werden. Es handelt sich hierbei um *Terminalia amazonia* (J.F. GMEL.) EXELL, *Carapa guianensis* AUBL., *Cedrela odorata* L. Bei diesen ergab sich eine statistisch nicht zu belegende Tendenz, eines höheren Wachstums ohne Freistellung. Gründe hierfür lassen sich in unbeachteten Drittvariablen finde, z.B. in der Nachbarschaft zu bodenverbessernden Pflanzen oder in unterschieden bezüglich der Größe im Pflanzalter. Bezüglich der Naturverjüngung ergab sich folgendes: Behandelte Flächen hatten mit 139 Pflanzen/ha deutlich weniger Naturverjüngung als unbehandelte Flächen mit 351,7 Pflanzen/ha. Der Simpson Index und die entsprechende Evenness waren bei beiden Flächentypen ungefähr gleich bei 0,88 (0,86) und 0,96 (0,92). Ähnlich verhielt sich die Naturverjüngung bezüglich der Nachbarschaft. Flächen mit Wald in direkter Umgebung hatten deutlich mehr natürliche Regeneration (358,6Pflanzen/ha) als Flächen ohne Wald (67,1 Pflanzen/ha). Der Simpson Index und die Evenness waren mit Wald bei 0,87 und 0,91; in Flächen ohne Wald lagen die Werte bei 0,81 und 0,91. Die durchgehend dominantesten Familien waren *Melastomaceae*, *Piperaceae* und *Fabaceae*. Wegen des jungen Alters der Pflanzungen wird dringend zu einer Wiederholung der Datenaufnahmen in einigen Jahren geraten um Tendenzen zu validieren oder zu wiederlegen.

Schlüsselwörter: Costa Rica, Wiederbewaldung, Wachstum, Naturverjüngung, Behandlungsmethoden, Freistellung

1 Introduction

1.1 Deforestation in the tropics

Biannually the Food and Agriculture Organization of the United Nations (FAO) releases the so called "State of the world Forest". This report exposes the status quo of the forests worldwide. Tab. 1 shows that Central America, with a loss of 1.19% in the last decade, has a huge impact in the vanishing of tropical rainforests. According to the geographical area Central Americas' forests are not very big, but have a big influence on the change rate.

Subregion	Area (1 000 ha)			Annual change (1 000 ha)		Annual change rate (%)	
	1990	2000	2010	1990–2000	2000–2010	1990–2000	2000–2010
Caribbean	5 901	6 433	6 932	53	50	0.87	0.75
Central America	25 717	21 980	19 499	-374	-248	-1.56	-1.19
South America	946 454	904 322	864 351	-4 213	-3 997	-0.45	-0.45
Total Latin America and the Caribbean	978 072	932 735	890 782	-4 534	-4 195	-0.47	-0.46
World	**4 168 399**	**4 085 063**	**4 032 905**	**-8 334**	**-5 216**	**-0.20**	**-0.13**

Table 1: Forest area in Latin America and the Caribbean, 1990 - 2010 (FAO, 2011 Chapter 1)

Tab. 2 illustrates, that Costa Rica, with a growth of 0.9%, counteracts the general trend of deforestation. Nevertheless, the site conditions (cf. Chapter 2.2) between these countries are similar. A reforestation programme in Costa Rica would gather information that could be used by other comparable countries to devise on a concept of dealing with this problem.

Country / area	Extent of forest 2010			Annual change rate			
				1990–2000		2000–2010	
	Forest area (1 000 ha)	% of land area (%)	Area per 1 000 people (ha)	(1 000 ha)	(%)	(1 000 ha)	(%)
Belize	1 393	61	4 628	-10	-0.6	-10	-0.7
Costa Rica	2 605	51	576	-19	-0.8	23	0.9
El Salvador	287	14	47	-5	-1.3	-5	-1.4
Guatemala	3 657	34	267	-54	-1.2	-55	-1.4
Honduras	5 192	46	709	-174	-2.4	-120	-2.1
Nicaragua	3 114	26	549	-70	-1.7	-70	-2.0
Panama	3 251	44	956	-42	-1.2	-12	-0.4
Total Central America	**19 499**	**38**	**475**	**-374**	**-1.6**	**-248**	**-1.2**

Table 2: Forest area and area change of Central America (FAO, 2011 Annex)

According to FAO (2011 Chapter 1), "forest area continued to decline in Central and South America, with the leading cause of deforestation being the conversion of forest land to agriculture and urbanization. Within the region, the largest decline in forest area continued to be in South America, although this has slowed and in percentage terms remained stable since 1990.The largest percentage loss of forest area continued to take place in Central America, although the rate has fallen in this subregion since 2000. Chile, Costa Rica and Uruguay were among the countries that increased their forest areas." ROSERO-BIXBY and PALLONI (1996) state, that in recent years, the Costa Rican government has been a world leader in the efforts to preserve the environment.

The existence to counterexamples to the general trend gives hope, but of course the loss of rainforests is not stopped. It is essential to impede the worldwide depletion of forests.

According to PIOTTO (2004) there is an increasing interest of the farmers to establish pure and mixed plantations. They aim for using native species as well as exotic trees with rapid growth and high commercial value.

1.2 Project "Regenwald der Österreicher"

This readiness for planting is used by "Regenwald der Österreicher" (Rainforest of the Austrians), which aides farmers devising concepts of reforestation. They provide material and pay workers.

Parallel to the project a research station near La Gamba, a village in the county Puntarenas in Southwest of Costa Rica (cf. Chapter 2.1) is built up.

Since the beginning this project handles the protection of tropical forest in Costa Rica by buying areas and integrating them into the national park "Piedras Blancas".

An additional aim of the project is to involve local farmers in the reconstruction of devastated forests and to implement biological corridors.

According to EVANS (1992) planting in rainforests is done after for four reasons:

- Industrial use,
- Domestic use,
- Environmental use,

- Tree-planting as an integral part of rural development for amenity, shade, shelter, food.

The project „Regenwald der Österreicher“ is involved predominantly with the last two points,

More information about the project’s aim can be found by having a closer look on its history.

In 1991 the association “Regenwald der Österreicher” was founded by Prof. Michael Schnitzler in order to buy areas of the Esquinas rainforest. The areas are bought with donations and endowed to the national park administration of the Republic of Costa Rica and integrated into the Piedras Blancas national park. Additionally, 1993 the Tropenstation La Gamba was founded to support scientific research concerning rainforests (VEREIN REGENWALD DER ÖSTERREICHER, n.d.). Besides this the association has several more intentions:

- Reforestation,
- Paying of two rangers,
- Protection of wild cats,
- Regional development, and
- Eco-tourism.

According to this aims the association contributes its part to protect precious rainforest.

1.3 Aim of the investigation

1.3.1 Difference in growth of planted trees according to treatment

A first point of interest is the growth rate of trees planted within the project’s area. There are two kinds of areas, namely the treated and the untreated ones. Planted trees without competitors, by freeing circularly or because of the type of not-planted other species belong to the „treated’ group. Trees witch have to deal with competitors belong to the „untreated’ group. (cf. Chapter 3.1.1).

The hypothesis is that the growth of the planted trees is influenced by these different treatments. Trees, which have to handle competitors will grow slower then trees without competitors. This question seems to be important because treatment implies work, which has to be done by the farmers or employees. If a treatment is not necessary or the effect is marginal, time and effort can be saved.

1.3.2 Difference in natural regeneration according to forests nearby

A second point of interest in this thesis is the influence of the surrounding to the natural regeneration of the reforested areas. There might be a difference whether there is a forest nearby or not. A difference is expected as surrounding forests can serve as seed supply. This thesis does not distinguish between secondary or primary forests.

1.3.3 Difference in natural regeneration according to treatment

Like mentioned above (Chapter 1.3.1) and defined in Chapter 3.1.1 the areas are treated differently. By cutting out space for the planted trees it is expected, that the natural regeneration is diminished. If there is a noticeable difference in the incoming families or not is scrutinised in this thesis.

2 Background

2.1 Area

Costa Rica is located between Nicaragua in the North and Panama in the South, enclosed eastwards by the Caribbean and westwards by the Pacific Ocean (cf. Fig. 1). The "Piedras Blancas" National park is situated in the Southwest of Costa Rica in the county Puntarenas.

The Village La Gamba is located at a longitude of -83.20 and latitude of 8.7, directly on the edge of the National park. The investigated areas are situated around La Gamba, but are not part of "Piedras Blancas". In fact, they are private property of local farmers.

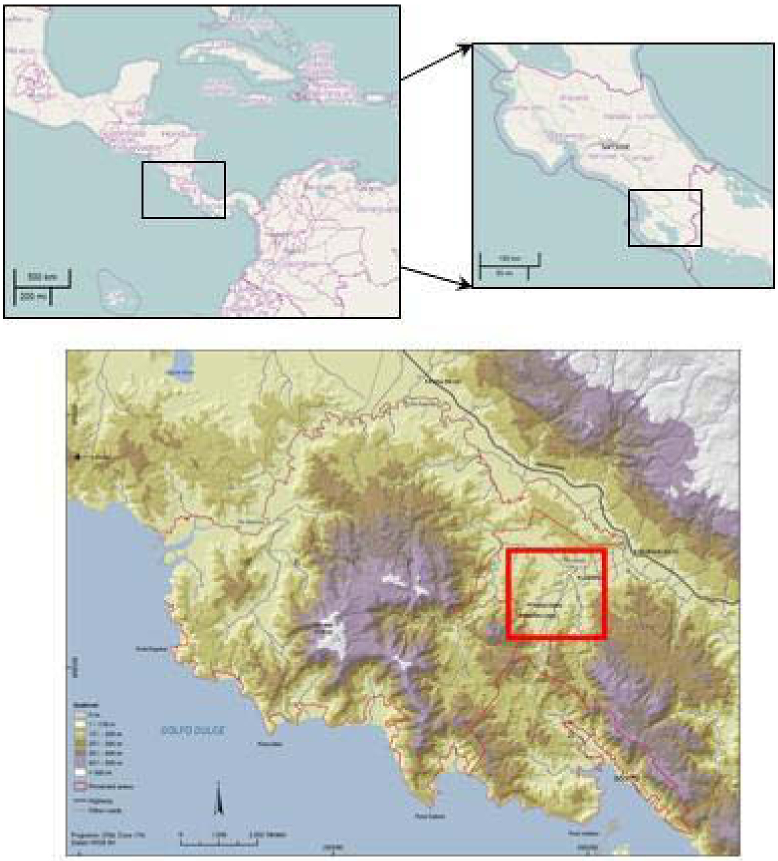

Figure 1: Location of the investigated area in Costa Rica. (OSM 2011; Tropenstation La Gamba 2011)

2.2 Site conditions

2.2.1 Site conditions of the tropics in general

We now give a short introduction about the climatic circumstances in tropical rainforests in general, followed by a more precise description of the local conditions in the considered area.

The two most important parameters concerning tropical rainforests are temperature and precipitation.

Temperature

After LAMPRECHT (1986) the low seasonal fluctuations of temperature are significant for the tropics in general. In contrast, the daily fluctuation is remarkable. After RICHARDS (1996) the daily fluctuation amounts between 6° C and 10° C, in Sena Madureira/Brasilia even about 13°C.

Not surprisingly, there is a correlation between the sea level and the annual average temperature. Lamprecht (1986) lists the average annual temperature sea level of different Stations in Venezuela (cf. Tab. 3)

For Costa Rica, Region Brunca, ARIAS AGUILAR (2002) found a correlation between the average annual temperature and sea level with a determination coefficient of $r^2 = 0.97$.

Station	Sea level [m]	annual average [° C]
Maracaibo (Venezuela)	6	27,8
Valencia (Columbia)	478	24,6
Tujillo (Peru)	790	23,8

Table 3: Average annual temperatures of Venezuelan stations in dependence to sea level (LAMPRECHT 1986)

Precipitation

After RICHARDS (1996) the precipitation lays between 1 700 and 10 000 mm, sometimes even more. A level of 3 000 mm is already defined as very high which amongst others occurs on the coastlands of southern Central America.

The topography, i.e. valleys and mountains, has a considerable impact on the regional and local precipitation. A clear correlation between precipitation and sea level is not evident. Clearly, the rain regime has a high effect on the vegetation (LAMPRECHT 1986). The rain intensity is characteristic for tropical precipitation. The periodicity, i.e. when and how intense the dry season occurs, duration and regularity is of significant importance for the natural vegetation as well as for land use.

In the low latitudes there are hygric seasons, only the all-the-year humid tropics are seasonless.

According to LAMPRECHT (1986), the relative air humidity during nights exceeds 95 percent in the inner part of the forest. During the day the magnitude can be between 15-25 percent in the crowns, which is a similar to data of open land.

Referring to LAMPRECHT (1986), additional factors are:

Light

The length of days varies only a little during the year. For this reason there are only short-day plants and day-neutral plants in the tropics. The high radiation is often reduced by the cloudiness and the high air humidity.

Soil chemistry

Due to the age of soils in the tropics, the all-the-year high temperatures, and a high amount of precipitation, they are heavily weathered and deeply leached. They contain only few nutrients, an extraordinary bad starting point for reforestation and restoration. Saving the existing nutrients can be achieved by using different strategies.

By forest clearance for pasture or agriculture, soil is laid open and nutrients are leached. Indeed the ash generated by fire clearance is firstly acting like fertilizer, but the circuit of nutrients is destroyed and the nutrients get lost by leaching. This makes a restoration difficult. Also many of the mykorrizhae are lost, which usually hold back the nutrients.

Mechanical factors

For the sake of completeness mechanical factors have to be mentioned, although for this thesis they are not relevant. LAMPRECHT (1986) names wind (cyclone, hurricanes, and typhoons), lightning, volcanoes, heavy precipitations, animals (e.g. leafcutter ants) and fire. All those factors can have an important impact.

2.2.2 Specific site conditions

The Tropenstation La Gamba has its own weather station where climatic data is logged regularly.

If not cited otherwise, the following characterization of climatic and geological circumstances refers to WEISSENHOFER, A. and HUBER, W. 2001.

Climate

In the years 1999 and 2000 complete data sets of rainfall were recorded in the Tropenstation La Gamba. The average annual precipitation in this period amounts 6 241 mm. Fig. 2 shows that there is hardly a season that can be called "dry-season" but only a season with lesser precipitation. The months with the most intense fall of rain normally are October and November, although in the measured years the highest precipitation rate was in September with 1 104 mm. In 1999 and 2000 the average number of rainy days was 286.5. The maximum number of rainy days were in September (29 days) and the minimum in March (16 days).

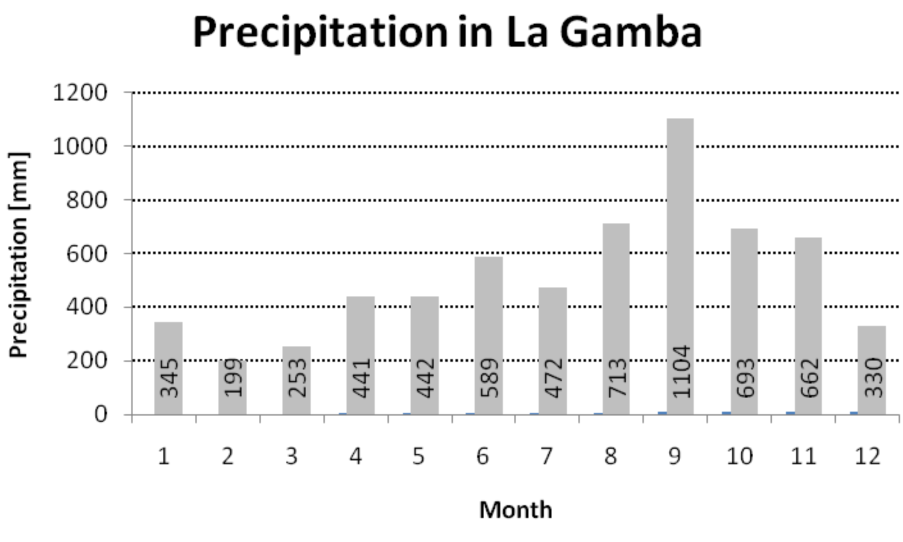

Figure 2: Monthly average precipitation in [mm] in the years 1999 and 2000 in the Tropenstation La Gamba

Temperature and humidity

The temperature was measured regularly since May 1997. Mean annual temperature was recorded as 27.4°C outside the forest with monthly average range from 23.2°C to 31.5°C. In comparison with the atmospheric temperature inside the forest there was a clear difference. The mean annual temperature inside the forest was recorded with 25.2°C with a monthly average range from 22.3°C to 28,0°C. A complete data set is also available for the period 1999 to 2000 (Fig. 3).

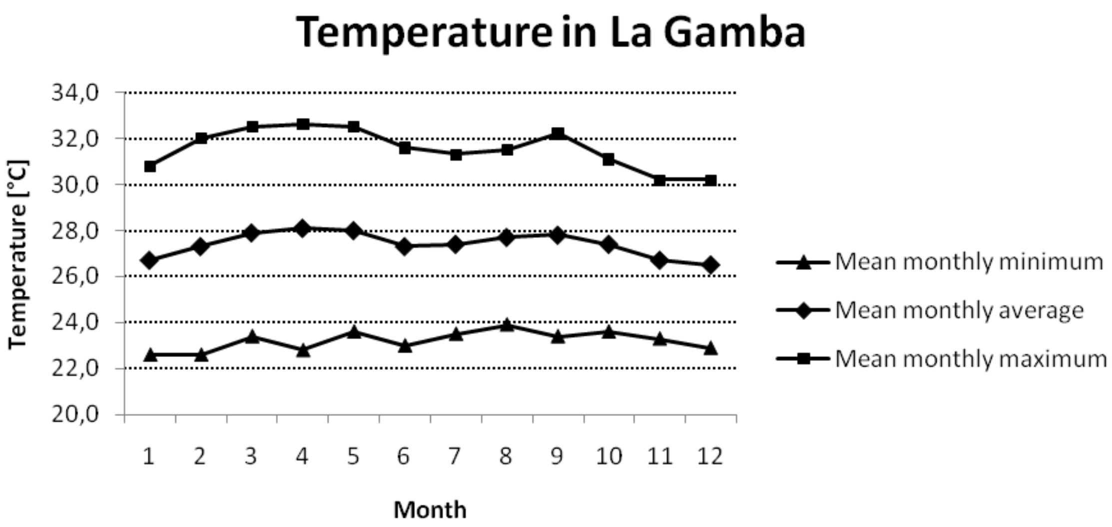

Figure 3: Mean temperature gradations in [° C] at the Tropenstation La Gamba 1999 - 2000

In the less rainy season from January to March and sometimes until April and May the range of the monthly average of the daily temperatures is ascertained with 10 to 13 °C. During the rainy season in October and November the lowest daily range occurs with around 2.5 °C. However, the air temperature on the forest floor is almost constant with a range of only 1.4°C. The daily variation appears to be greater than the variation between the seasons.

With 88.3 % the relative humidity is constantly high at the Tropenstation, inside the forest the humidity actually reaches 97.7%. An indicator for the humidity is the daily appearing of fog in the morning, sometimes in the evening and after heavier rain falls, which proves that the air is saturated with water. In this case air temperatures are lower.

2.3 Natural land cover

Despite its small size Costa Rica has one of the greatest diversity of life zones worldwide (ROSERO-BIXBY, L. and PALLONI, A. 1996). The map in Fig. 4 combines the original 17 life zones, which are shown in Fig. 5 into six categories.

The investigated area belongs to the tropical wet area which in 1973 was covered by forests to 54 %. The deforestation rate in the decade „73-„83 was 49%. This value is lower than in the premontane wet and tropical moist areas. Because of high precipitation and low accessibility the land is less desirable for agriculture (ROSERO-BIXBY, L. and PALLONI, A. 1996 after SADER and JOYCE, 1988).

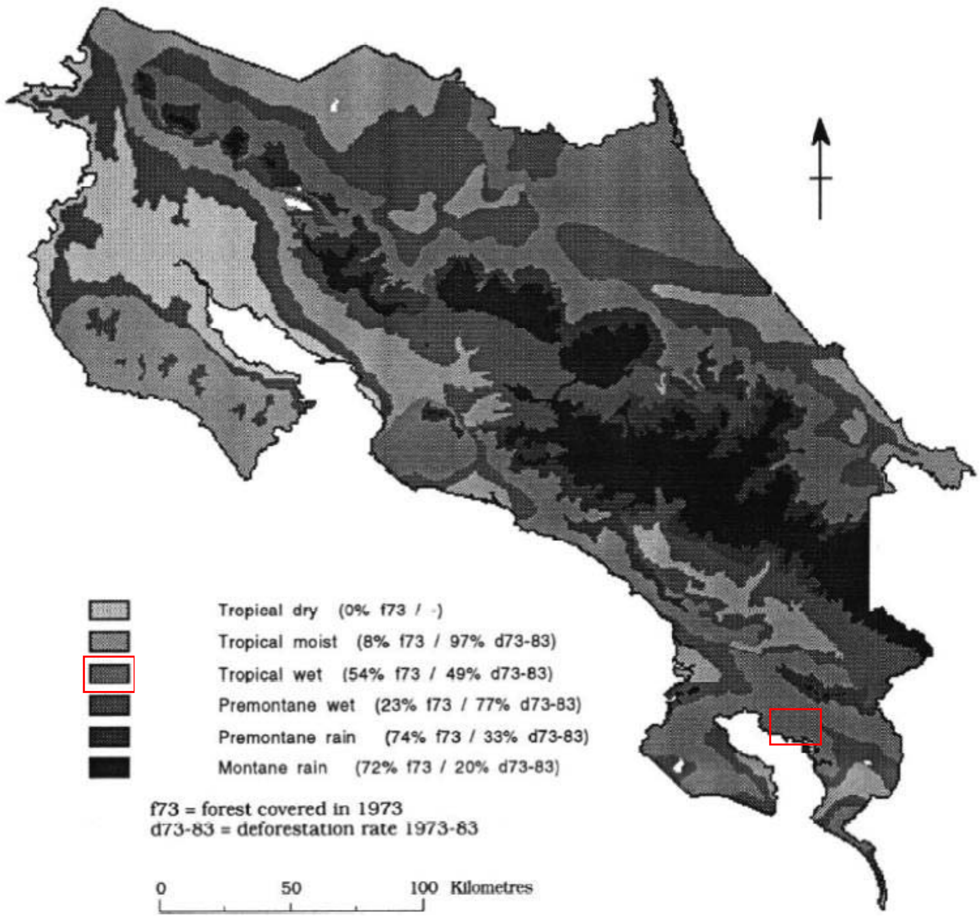

Figure 4: Lifezones and Forest cover in Costa Rica (after ROSERO - BIXBY and L., PALLONI, A. 1996)

Fig. 5 below demonstrates the original 17 life zones, which are again subdivided into 33 units. The investigated area belongs to the unit 17b (ZAMORA, N. 2008 after TOSI 1969 and HOLDRIDGE 1967). Unit 17b is titled as: Laderas de Osa y filas Costeña, Cruces y Cal. The landscape is undulating, full of gorges, and encloses the vegetation of the inner peninsula de Osa, the bill of Burica and the coasts Costeña, Cruces y Cal. The sea level is between 40 and 500 meters. This unit is defined by its vegetation core consisting of three distribution ways: in the north to the named coasts, to the northwest over the coasts and to the south and southeast. ZAMORA, N. (2008) suggests a better evaluation of the coasts.

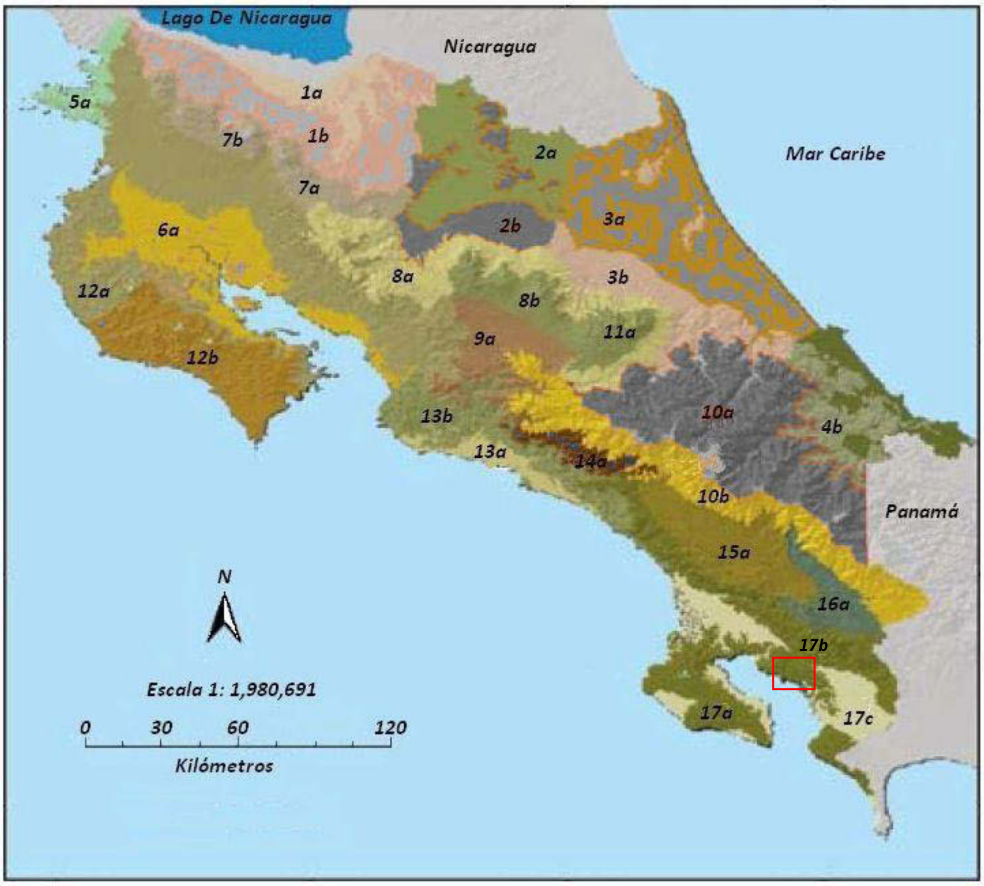

Figure 5: Map of phytogeographical units in Costa Rica (ZAMORA, N. 2008)

2.4 Actual situation

In the 1960s and 1970s Costa Rica experienced one of the highest deforestation rates. Deforestation and population growth radically changed the Costa Rican landscape in the 20th century. About 50% of Costa Rican territory was cleared of its primary forest cover.

In the 70s more than 1% of the Costa Rican territory was cleared each year which equates approximately 4% of forest-covered land. (ROSERO-BIXBY, L. and PALLONI, A. 1996)

According to ROSERO-BIXBY, L. and PALLONI, A. (1996), the danger of forest clearing varies substantially across the six life zones, from 97% in tropical dry zones to 20% in montane rain forests. Another critical point is the proximity to roads, because deforestation probability is strongly associated with accessibility. The risk of deforestation decreases quickly with increasing distance to forest edges and roads

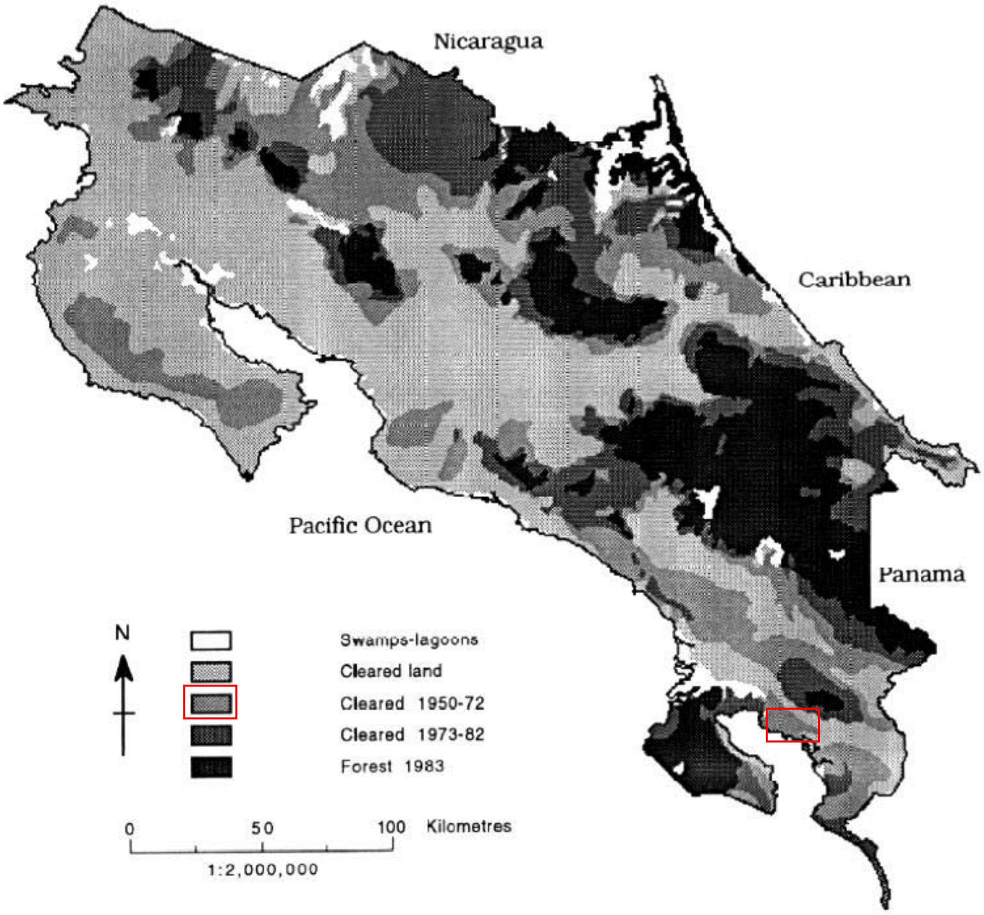

Figure 6: Deforested Land in Costa Rica, 1950 - 1983 (after ROSERO - BIXBY, L., PALLONI, A. 1996)

The investigated area is in Puntarenas, a part of Costa Rica that was cleared from the 1950s to the 1972 (Fig. 6). It is more or less situated close to roads and populated areas. For examples of devastated land in the concerned region see Appendix A.

3 Material and Methods

3.1 Description of investigated areas

In the following the ten areas, where plots were established and recorded for this study are listed. The numbering indicates an internal numbering used by the project, which we adopted for congruence reasons. For various reasons some of the areas were not adequate for the investigation, e.g. some of the farmers quit the project, or the areas are too small, that is why the labelling of the areas is not consecutive.

The ten areas chosen for this thesis are very diverse and therefore characterized shortly below. As important parameters of characterizations are considered:

- sea level
- the usage
- the surrounding

The sea level is important because the precipitation is correlated with the sea level. A different sea level relates to a different water supply which is in the tropical one of the most important site conditions (cf. Chapter 2.2).

Knowledge of former usage is important because the history of the area gives us a hint of the soil status and the possible natural regeneration. Naturally, a former pasture has different conditions then an area that was not used at all since years.

For investigation and statistical analysis it is of utmost importance to notice that the areas are not perfectly alike. A classification is aspired, but difficult (cf. Chapters 3.1.1 and 3.1.2). For sketches of the areas and photos see Appendix B

<u>Area F 1</u>

The owner of this 0.8 ha area is Ernesto Avellan. The area is plain and has a sea level of 97 m.

Before the plantation the area was used as a pasture but then for a long time not used at all. When the plantation was founded the area, consisted of shrubs and beginning woody regeneration. Now the objective of the plantation is to enrich the area with different species. The newly planted individuals are cultivated in rows which are completely freed. Between the rows nothing was cut, so the rows are shadowy.

The surrounding consists of two branches of the Quebrada Gamba, pasture and secondary forests.

Area F 3

Maria E. Reyes is the owner of this plain area which was reforested in the past few years. The size of the reforested area in 2007 and 2008 was 0.162 ha. In 2010 a new area was added and now the area is 0.2 ha in size. The sea level is 102 m.

Formerly used as pasture the area is now reforested for river protection. Therefore the area is long and narrow along the Quebrada Bolsa. It is covered by short grass growing between the newly planted trees.

As mentioned before, the area is situated between the Quebrada Bolsa on one side and pasture on the other side.

Area F 5

The size of this area, which belongs to Efrain Vilatoro Camacho, is 0.2 ha and the sea level is 85 m.

The area is plain and separated by a small ridge in two parts, F5a and F5b. F 5a is more shady than F 5b, therefore in F 5b the grass is much higher (waist-high) than in F5a. All the trees are freed within a radius of approximately 70 cm.

The area is surrounded by the Quebrada Chorro and secondary forest. F5b has a boundary to a more swampy land.

Area F 7

Area F 7 is property of Ovidio Cruz. The size of the area is 0.2 ha. The sea level is between 102 and 110 m.

The slopy area is part of an agroforestry; there are also cocoa trees and banana trees which agglomerate at the bottom of the hill where the area is situated. On the top of the hill is a primary forest.

Area F 10

Arturo Quiros is the owner of this 1.5 ha area. The sea level is 103 to 119 m.

This slopy area is a former pasture and is used for river protection. The area is very steep on the top and on the bottom abruptly flattening. The greater part of the area is totally freed but in some parts competitors are left.

The area is surrounded by the Rio Bonito on one side and on the other side by the farmyard of the owner.

Area F 12

This 0.15 ha small area belongs to Luis Sanchez. The sea level is 103 m. The area is plain and very similar to the area of Maria E. Reyes (F 3). It is situated between the Rio Bonito and a pasture. The plants are completely free. Only short grass is growing between the individual plants.

Area F 15

Teofilo Vargas Leon is the owner of area F 15. The plain area is 84 m above sea level and used as river protection. The trees are all freed circularly. High grass is growing between the newly planted trees.

The area is surrounded by the Rio Bonito and a pasture.

Area F 18

Area F 18 is property of Maria Sanchez. The size of the area was 3.5 ha in 2008, 2.5 ha in 2009 and 2 ha in 2010. With 495 to 511 m above sea level it is situated much higher than the others.

Since 2008 this slopy area is in the programme and each year there are plantations in order to restore the forest.

The area is situated parallel to a street and on the other side there is primary forest.

The area is clearly different from the other investigated areas. As discussed in Chapter 2.2.1 the sea level is correlated to the precipitation and therefore a different amount of rainfall can be assumed. Furthermore, the area is (beneath F22) the most distinct area of the programme and therefore a different assemblage of species can be assumed.

Additionally, F 18 is very steep with a slope up to 70°, and therefore difficult to measure. As this area is part of the reforestation programme, it is added to the investigated areas and the same data as in the other areas was collected.

<u>Area F 22</u>

Leticia Sanchez is owner of this 2.5 ha area The sea level is with 438 m much higher than the sea level of the other areas (except area F 18).

The area is part of a farmyard. F 22 is permeated by steep ridges (until 70°). There is already an old growth forest, which is used for wood production. Beneath this forest enrichment takes place in order to restore a natural mixture of species.

The total area is sized 5 ha, so the part where the plantation takes place is mostly influenced by the already existing forest.

The area is clearly different from the other investigated areas. As discussed in Chapter 2.2.1 the sea level is correlated to the precipitation and therefore a different amount of rainfall can be assumed.

Moreover area F 22 is the only area which is already reforested and enrichment under an already existing forest was made. A complete shading of the newly planted trees is given.

As this area is part of the reforestation programme, it is added to the investigated areas and the same data as in the other areas was collected. Restrictions for the collection of data had to be made for F 22 because it was impossible to measure the distance to the edges because they were unclear. The data is not present in the collection. Furthermore, this area is the most distinct area of the programme (beneath F18) and therefore a different assemblage of species can be assumed.

For this reasons it is doubtful if there is comparability to the other areas.

<u>Area F 26</u>

This area is owned by the Tropenstation itself and called „Finca La Bolsa'.

The size of the reforested area in 2010 was 0.1 ha. The sea level of this area is between 96 and 112 m. The area consists of two slopes and a small valley.

The aim of this reforestation is to join two separated forests. In former times the area was used as pasture and farmland.

The plants were set in rows. There is a lot of natural restoration, which is left between the rows. As there is firstly planted in 2010 many of the plants were at the date of data acquisition yet too small and dropped out of the measurement criteria.

The surrounding is as mentioned above two forests, which might be a possible source for natural restoration. On the end of the valley the farmyard of Ovidio Cruz (F 7) is situated.

3.1.1 Clustering of areas according to treatments

That the treatment is influencing the growth is one of the hypotheses discussed in this thesis. Does different treatment influence the growth of different species?

There are two mainly types of treatment to which we grouped the areas (Tab. 4):

„Group 1':

The plants grow solitary from other plants, there are no important competitors. This classification group includes areas with only short grass growing between the individuals and areas which were treated with amply freeing from competitors.

„Group 2':

The plants are not freed that amply like in group 1, so there are still competitors to the new plants. This group also includes those areas which are planted in rows where the planted rows itself were freed. Between the rows the natural regeneration is still growing.

Group 1: free	**Group 2: not free**
F3, F5, F12, F18, F10,	F1, F7, F10, F15, F26,

Table 4: Classification of the investigated areas according to their treatments

3.1.2 Clustering of areas according to forests nearby

Aim of this classification is to divide into two groups of neighbourhood. The surrounding is important; seed income is influenced by the proximity of seed sources. The incoming woody plants and their diversity shall be scrutinized.

Areas with a primary or secondary forest in the neighbourhood	Areas without a primary or secondary forest in the neighbourhood
F1, F5, F7, F18, F26	F3, F10, F12, F15

Table 5: Classification of the investigated areas according to their neighbourhood

As explained above (Chapter 3.1) area F22 was left out, because of a complete different situation.

3.2 Experimental Design

In July to August 2010 we visited all of the study sites and selected data plots randomly. For this geometrical sampling procedure with unbiased inclusion probability each point was surrounded by a circle with a radius of 5.64 m which means an area of 100.00 m² per plot. In each area at least four points were chosen (cf. Fig. 7 below). If the area was big enough, more points where possible. In some cases only three points where possible because of the condition of the area (size, steepness). In one case due to the shape of the area a full inventory was possible (F3). The first point was selected by throwing a rock, the next point were defined by a distance of about 20 m to one orientation, and so on, so that ideally a square is drawn. If one of these points is outside the area, a substitute is taken by going back 2 m.

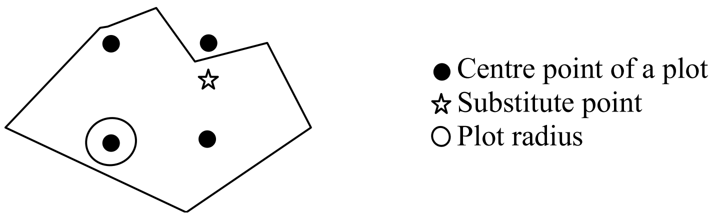

Figure 7: Configuration of experimental design of an idealised area

For analysing the data were extrapolated to the amount/hectare. So if one plot has the size of 100.00 m², the blow-up factor amounts 100 (cf. Formula 1) which means, that one tree is representing 100 trees/hectare.

$$BF_{ha} = \frac{10\ 000}{Size\ of\ samle\ plot}$$

Formula 1: Blow-up factor for the geometrical sampling

An exception is area F3, where a total inventory was made. Since area F3 is 0.2 ha in size the blow-up factor here is 5 (cf. Formula 2).

$$BF_{\text{ha}} = \frac{10\ 000}{Size\ of\ area}$$

Formula 2: Blow-up factor for the total inventory

3.3 Measurement and analysis

The species of the trees were identified in the field, if there were any uncertainties a photos of the plant, a sample of a leaf etc. was taken to the Tropenstation for identifying. A comparison with the herbarium as well as help from the gardeners and relevant literature including dichotomous keys made it in most cases possible to identify the trees. Nevertheless some of the woody natural regeneration plants and some of the planted seedlings could not be identified or only to the genera.

Literature that was consulted to identify the plants was:

FLORES–VINDAS, E. OBANDO-VARGAS, G. 2003

HARRIS, J.G. WOOLF HARRIS, M. 1994.

JIM. NEZ MADRIGAL, Q. 1995

JIMENEZ, Q., POVEDA, L. N/A

KELLER, R. 1996.

MANUAL DE LAS PLANTAS DE COSTA RICA. 1998.

WEISSENHOFER, A., HUBER, W. 2001

Analysis itself was administrated with the spread sheet programme Microsoft Office Excel 2007©.

3.3.1 Planted Trees

In the data acquisition there were considered trees that were higher than 50 cm. The diameter was determined to the millimetre accurate with a π-tape in a height of 50 cm if greater than 1 cm. Diameter less than 1 cm are clustered as 0.5 cm. The heights of the trees were measured with a measuring tape if possible; the higher ones were measured to ± 50 cm with a Bitterlich Spiegel-Relaskop with a metric-standard scale.

3.3.2 Natural regeneration

Additionally to the planted trees the woody natural regeneration was recorded. For each plot the distance to the area in each orientation was estimated and the surrounding was recorded. Some of the areas are used as part of agroforestry, therefore the woody species that are useful for fruits are taken out of analysis, because it was not sure if they are planted or natural income.

More over the plots of each area were not analysed separately. It emerges, that 20 m distance from plot to plot in one area was not enough to see a difference among each other according to the distance to the areas' edges. So the areas are analysed entirely.

For numbering the biodiversity of the natural incoming plants the Simpson index was calculated with the Formula 3 (adapted):

$$D = 1 - \sum_{i=1}^{s} \frac{n_i(n_i-1)}{n(n-1)}$$

D	Simpson index
n_i	number of individuals of species *i*
n	total number of individuals

Formula 3: Simpson index after SIMPSON, C.H. 1949

In this form the formula provides an index starting with '0' representing no diversity and '1' representing a maximum of diversity.

The „Evenness' quantifies the evenness of species in a sample. It gives a hint how equal the sample is numerically. It is calculated with the Formula 4:

$$E = \frac{D}{1-\frac{1}{s}}$$

E	Evenness
D	Simpson index
s	number of species

Formula 4: Evenness after SIMPSON, C.H. 1949

Again E lies between 0 and 1. If there is less variation E is high and vice versa.

4 Results

4.1 Planted trees

4.1.1 Choice of species and origin of seedlings

Due to the fact of biodiversity of tropical rainforests Richards states in 1996 that “the most important single characteristic of tropical rain forest is their astonishing wealth of plant and animal species”.

From this enormous range of species the choice what to plant is not easy to decide and depends on several interacting circumstances.

EVANS (1992) asks three main questions, which in reality are closely related and cannot be answered separately:

1. What is the purpose of the intended plantation?

2. Which species are potentially available for planting?

3. What will grow on the sites available?

The connection between the questions can be seen in Fig. 8.

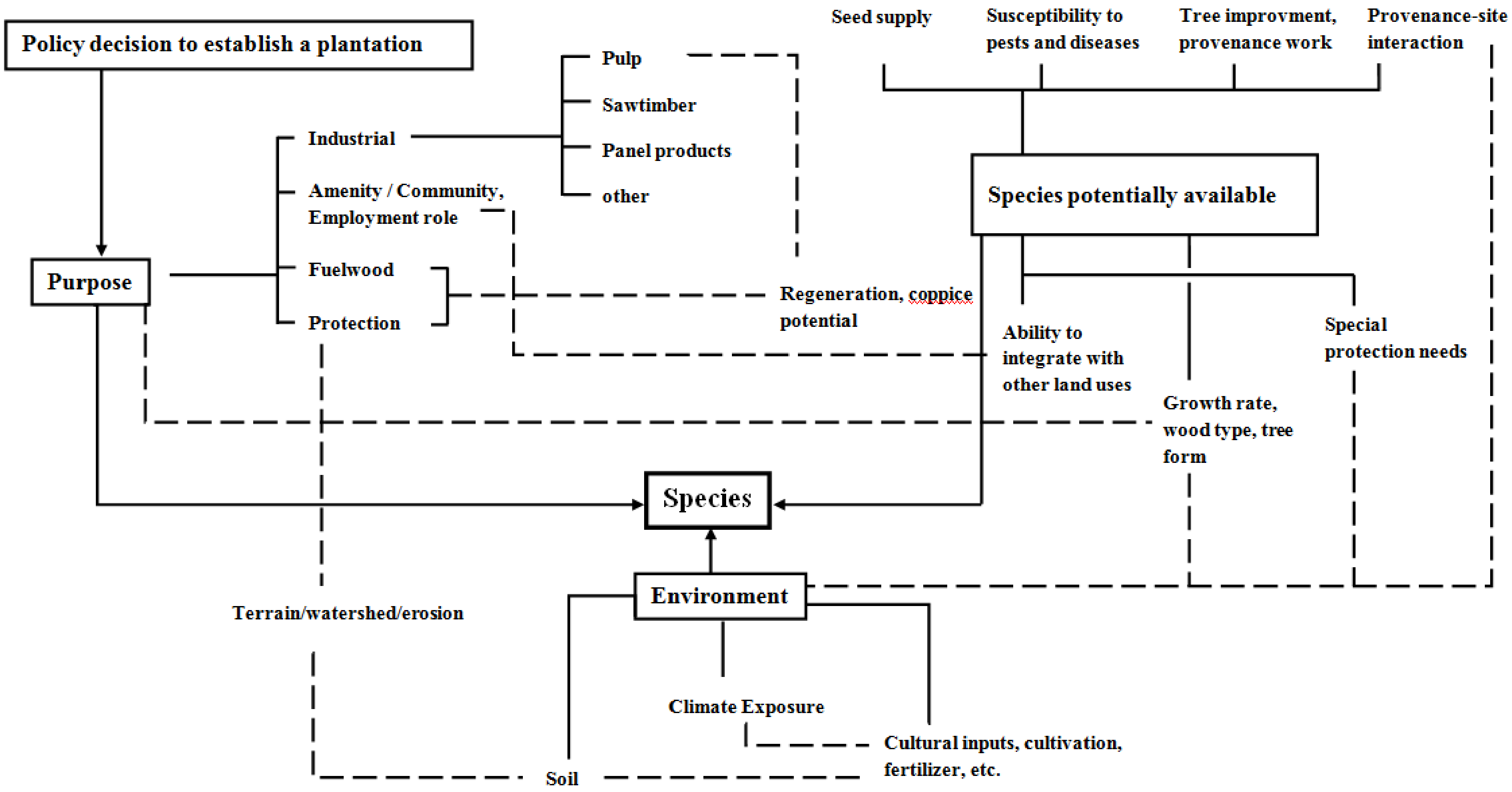

Figure 8: Factors influencing choice of species (Evans 1992)

Ad 1: What is the purpose of the intended plantation?

The operators of the Tropenstation state that the planted species are used for reforestation (also along rivers) as well as for the cultivation of fruits, for fodder, fibres and construction purposes (unpublished).

The point „reforestation' is therefore important. E.g. SÁNCHEZ AZOFEIFA *et al* (2002) state, that an "increasing isolation of protected areas may prevent them from functioning as an effective network". The building of biological corridors is indeed one of the goals of "Regenwald der Österreicher", a corresponding organisation to the Tropenstation (VEREIN REGENWALD DER ÖSTERREICHER, n.d.).

To achieve a "new forest" it seems to be necessary to plant, because a natural regeneration of the volitional range of species is difficult to arise. EVANS (1992) suggests a planting in lines or groups to get the desired species and in the same time to protect the natural forest structure and cover. He refers to it as "enrichment planting" which can also be found as one goal of the Tropenstation. Important appears to be the awareness that plantations are a sufficient way to ensure the increasing wood demand (EVANS 1992).

On the contrary, RICHARDS (1996) states, that a secondary forest might have a greater range of species per unit area than primary forests. The problem seems to be the lack of data. The species richness may depend on age and other factors.

HAGGAR *et al*. (1998) assert that planting in degraded tropical landscapes such as pastures can have positive effects on soil conditions. Therefore a plantation is not only utilized for the forest regeneration but also for the soil fertility and furthermore contributes to the protection of the people from floods and other calamities.

Another point which cannot be neglected is of an economic nature: MONTAGNINI *et al* (1995) ascertained that a mixed plantation has a much more diverse array of products which can be sold by the farmers then monospecific stands. This protects the people from uncertain and unexpected market performances. Additionally, the diversification of species diminishes the risk of losing plants by unforeseeable incidents such as species performance, scarcity of seedlings, or pest damage. A last point worth mentioning here is that the costs of establishing slow growing species is lower in a mixture than in monospecific stands (MONTAGNINI *et al*. 1995).

Ad 2: Which species are potentially available for planting?

The answer for this question is not easy, since RICHARDS (1996) states that about breeding systems, information is just available for few species. Conclusions are only possible with care. He states that most of the species reproduce by seed.

Hence the Tropenstation raises seeds, which are collected in the primary forests by the gardeners.

Additionally, some of the seedlings are raised by the farmers themselves against money and a small part is bought from nursery gardens.

An important point is pursuant to RICHARDS (1996) that there is also little information about genetic diversity below the species level. This fact has to be considered by buying plants.

Most of the seedlings, which are planted in the project, are raised by the Tropenstation itself.

Ad 3: What will grow on the sites available?

First and above all the information has to be provided that little is known regarding the performance of species in reforestation projects (WISHNIE *et al*. 2007).

RICHARDS (1996) mentions that pioneer species, the first ones on deforested areas, are dominant in the early and middle stages of secondary succession and differ in ecological requirements, vegetative features and reproductive strategies from those of mature rain forest.

It can be presumed that in general secondary forest species are more commonly distributed than those of primary forests; taxa of the more mature rain forests often have very small and disjunct areas of their distribution. RICHARDS (1996) also names some genera and families of this pioneer species, from which some are planted in the investigated areas or are incoming by themselves. These genera or families are: *Inga, Ochroma, Melastomaceae, Sterculia, Terminalia, Cecropia, and Heliconia.*

FISHER (1995) states, that most of the soil problems in degraded areas are due to aluminium toxicity, low pH and phosphorous fixation. This makes the choice of species a bit more complicated, but HAGGAR *et al*. (1998) and CARNEVALE and MONTAGNINI (2002) are giving a solution. They quote some studies made in Costa Rica, that have shown, that species such as *Vochysia ferruginea* and *Hyeronima alchorneoides* can aid nutrient cycling and encourage land restoration, but also have good growth performance and high quality wood. CARPENTER *et al*. (2004) add, areas having suffered less extreme erosion could be restored, eventually in a mixture with the native species *Vochysia* ssp., *Terminalia amazonia* and *Calophyllum brasiliensis*, *Cedrela odorata*. Also BUTTERFIELD and FISHER (1994) argue that tropical hardwoods in general are found on every type of soil. Of course there are some limitations. For instance *Cedrela odorata* prefers fertile soils. *Vochysia guatemalensis* and *Vochysia ferruginea* accept acid soils with high aluminium saturation; but they come to the conclusion that exotic genera are sensitive to a lack of nutrients.

WISHNIE *et al*. (2007) supposed that due to all the studies it is difficult to extrapolate the results of many of these studies to areas with different climates or soil conditions. This is another issue that makes it difficult to decide which species to plant. Therefore the results of BUTTERFIELD and FISHER (1994) have to be evaluated with caution. They argue that all of their data, collected thus far, prove, that native species can be competitive with fast-growing exotic species, but the data they refer to are all collected in La Selva in the middle of Costa Rica and therefore in a different kind of climate and soil. Nevertheless, of the 26 tested species, only 2 proved difficult to germinate. This result is not indicating problems of seed breeding. A lack of information about the growth potential leads to an insufficient evaluation.

Although BUTTERFIELD and FISHER (1994) found out that lots of species can survive in low light situations, many of them would benefit from more light than is available at the forest floor.

RICHARDS (1996) affirms this by saying that height growth of all the species he investigated was greater in gaps. He even confirms that gaps are not only important for the reproduction of the more light-demanding species but also for the relatively shade-tolerant species which are not able to regenerate successfully without them. Some of the species even seem to be light demanding and intolerant of shade, especially when young.

All of those species mentioned above are planted in the investigated areas, and are a good choice. For all these arguments, different opinions and the lack of data it is obvious that more research have to be done. The choice of various taxa is often nothing more than a matter of applied research, which does not exclude wrong decisions. Every gathering of information can help to reforest the degenerated land more effectively.

4.1.2 Short portrait of the three most common species

Since for some of the species information is hardly available and some appear in the data just once, the short characterisation will have its main focus on the three species that are most common in the data. Tab. 6 lists all species but only the last three are described in this Chapter. For more detailed information about the species with n ≥ 10 in Tab. 6 see Appendix C.

A classification into groups according to (1) the wood density as cited in the literature and to (2) the shadow tolerance, a more ecological point of view, was tried but it turns out, that there is not enough information about wood density and shadow tolerance of all species in the literature. For this reason the analysis of the data was restricted to the three most common species *Terminalia amazonia* (J.F. GMEL.) EXELL, *Carapa guianensis* AUBL., *Cedrela odorata* L. The data of these three species can be found in Appendix D.

Scientific Name	Family	n
Anacardium occidental L.	Anacardiaceae	1
Andira inermis (W. WRIGHT) DC.	Fabaceae	1
Caryocar costaricense DONN. SM.	Caryocaraceae	1
Cecropia ssp.	Cecropiaceae	1
Chrysophyllum cainito L.	Sapotaceae	1
Citrus ssp.	Rutaceae	1
Cojoba arborea L.	Fabaceae	1
Heliocarpus ssp.	Tiliaceae	1
Licania platypus (HEMSL.) FRITSCH	Chrysobalanaceae	1
Ochroma pyramidale (CAV. EX LAM.) URB.	Bombacaceae	1
Pentagonia tinajita SEEM.	Rubiaceae	1
Theobroma cacao L.	Sterculiaceae	1
Vochysia guatemalensis DONN. SM.	Vochysiaceae	1
Dilodendron costaricense (RADLK.) A.H. GENTRY & STEYERM.	Sapindaceae	2
Ficus ssp.	Moraceae	2
Nephelium lappaceum L.	Sapindaceae	2
Ocotea ssp.	Lauraceae	2
Pouteria ssp.	Sapotaceae	2
Psidium guajava L.	Myrtaceae	2
Terminalia bucidoides STANDL. & L.O. WILLIAMS	Combretaceae	3
Terminalia catappa L.	Combretaceae	3
Theobroma simiarum DONN. SM.	Sterculiaceae	3
Vochysia ferruginea MART.	Vochysiaceae	3
Annonaceae JUSS.	Annonaceae	4
Pourouma bicolor MART., (BENOIST) C.C. BERG & HEUSDEN	Cecropiaceae	5
Sterculia recordiana STANDL.	Sterculiaceae	4
Syzygium malaccense (L.) MERR. & L.M. PERRY	Myrtaceae	4
Hyeronima alchorneoides ALLEMÃO	Euphorbiaceae	5

Virola koschnyi WARB.	Myristicaceae	5
Anacardium excelsum (BERTERO & BALB. EX KUNTH) SKEELS	Anacardiaceae	6
Spondias mombin L.	Anacardiaceae	6
Vitex cooperi STANDL.	Verbenaceae	7
Luehea seemannii TRIANA & PLANCH.	Tiliaceae	8
Symphonia globulifera L. F.	Clusiaceae	8
Artocarpus altilis (PARKINSON) FOSBERG	Moraceae	9
Brosimum utile (KUNTH) PITTIER	Moraceae	9
Tabebuia chrysantha (JACQ.) G. NICHOLSON	Bignoniaceae	9
Aspidosperma spruceanum BENTH. EX MÜLL. ARG.	Apocynaceae	10
Croton schiedeanus SCHLTDL.	Euphorbiaceae	10
Inga ssp.	Fabaceae	10
Pseudobombax septenatum (JACQ.) DUGAND	Bombacaceae	10
Zygia ssp.	Fabaceae	19
Samanea saman (JACQ.) MERR.	Fabaceae	14
Virola sebifera AUBL.	Myristicaceae	14
Platymiscium curuense N. ZAMORA & KLITGAARD	Fabaceae	15
Astronium graveolens JACQ.	Anacardiaceae	17
Minquartia guianensis AUBL.	Olacaceae	17
Calophyllum brasiliense CAMBESS.	Clusiaceae	21
Schizolobium parahyba (VELL.) S.F. BLAKE	Fabaceae	25
Peltogyne purpurea PITTIER	Fabaceae	29
***Terminalia amazonia* (J.F. GMEL.) EXELL**	**Combretaceae**	**42**
***Carapa guianensis* AUBL.**	**Meliaceae**	**48**
***Cedrela odorata* L.**	**Meliaceae**	**56**
Not identified		22
	Σ	**505**

Table 6: Species which are in the data plot. Species in bold are used for analysis.

4.1.2.1 *Terminalia amazonia* (J.F. GMEL.) EXELL

The natural distribution of this species is from Mexico to South America. In Costa Rica the tree can be found on both sides and in elevations from 30 to 1000 m sea level (INBIO 2011).

T. amazonia is a component of the rainforest in every part of its distribution and sometimes in gallery forests on the river shore (BOSHIER, D. and CORDERO, J. 2010). It is common in evergreen lowland to montane forests (WEISSENHOFER, A. and HUBER, W. 2001).

The height can reach 50 m, but typical are 20 to 35 m and 1.5 m in diameter. The old trees have huge buttresses. The growth in plantations is moderate, although this varies from site to site (BOSHIER, D. and CORDERO, J. 2010).

PIOTTO *et al*. (2003) recommends *T. amazonia* as very promising species for reforestation in Costa Rica lowland region due to the species' good growth in volume, form, and adaptability to very different site conditions. Additionally, CUSACK (2004) found out that rare species were more prominent in plantations of *T. amazonia* than in other plantations.

Normally, *T. amazonia* does not seem to have a problem in pure stands according to plagues or illness. The biggest problem is probably the leaf cutter ant, but there are various others: *Cossula* spp., *Exophthalmus* spp.; fungi, which cause wounds (BOSHIER, D. and CORDERO, J. 2010).

T. amazonia is highly valued for its high quality wood (BOSHIER, D. and CORDERO, J. 2010). The bulk density is 0.769 g/cm³. The wood is used among others for boat building, bridge construction, construction in general, decorative veneer, furniture, joinery, plywood (TWE 2008).

4.1.2.2 *Carapa guianensis* AUBL.

The natural distribution of *C. guianensis* is Belize over Costa Rica to French Guyana, Peru, Martinique and Trinidad and Tobago (STRI 2011). The tree is deciduous or evergreen due to the site and can reach 60 (normal: 25 to 40) with a diameter up to 2 m. It is part of the overstory in wet and very wet forests (precipitation 1900 - 3500 mm) between 0 and 800 m above sea level. If possible *C. guianensis* forms pure stands.

The wood is one of the most used in the region for interior or exterior construction. The quality is variable due to the site, where the tree grew (BOSHIER, D. and CORDERO, J. 2010).

TWE (2008) enumerates among others: boat building, building construction, construction, decorative plywood and veneer, external joinery with ground contact, musical instruments, and pulp and paper products. The bulk density is 0.64g/cm³.

4.1.2.3 *Cedrela odorata* L.

The natural distribution of this species is from Mexico to South America and the Antilles (INBIO 2011). The tree reaches a height of 30 to 40 m with a diameter of 100-300cm (BOSHIER, D. and CORDERO, J. 2010).The habitat is in dry forests of the pacific coast and in humid forests on both sides between 0 to 1200 m above sea level (INBIO 2011).

The tree needs light (BOSHIER, D. and CORDERO, J. 2010); therefore it grows well on pastures and cultivated land (INBIO 2011).

The regeneration is poor, because of the attack by *Hypsiphyla grandella* (which might have been a problem in the investigated area, because there were several *C. odorata* affected by a not identified larva). In the south pacific region it is associating with *Schizolobium parahyba* and *Spondias mombin* (both planted in the investigated areas) (INBIO 2011).

BOSHIER, D. and CORDERO, J. (2010) also mention that a mixture between 10 to 15 species per ha are recommendable, for instance *Leucaena* ssp., *Enterolobium cyclocarpum*, *Tectona grandis* or *Samanea saman*. This can reduce the *Hypsiphyla grandella* problem.

C. odorata is mentioned in Appendix III of the CITES list with the comment, that logs, sawn wood and veneer sheets are in Brazil and the Plurinational State of Bolivia are concerned. In addition, the following countries have listed their national populations: Colombia, Guatemala and Peru (CITES 2011).

INBIO 2011 says that it is an endangered species, which is actually much exploited. There exist various protection areas in Costa Rica.

Nevertheless its fine wood is one of the most utilized in the present. Its prize is one of the highest in the market in Central America (BOSHIER, D. and CORDERO, J. 2010).

The bulk density (12 % moisture) is 0.448 g/cm³. It is used for various purposes: boat building, heavy and light construction, decorative plywood and veneer, furniture, flooring, joinery, musical instruments (TWE 2008).

4.1.3 Difference in growth of planted trees according to both treatments

4.1.3.1 *Terminalia amazonia* (J.F. GMEL.) EXELL

Fig. 9 and Fig. 10 are illustrating the growth of *T. amazonia* in diameter and accordingly height on the y-axis. On the x-axis the year of plantation is plotted. Evidently, the data for „Group 2' are rare (cf. Appendix D). The literature states, that *T. amazonia* in general has a rapid growth (MONTAGNINI, F. *et al.* 1995, PIOTTO, D., *et al*. 2004). A difference between the two treatment types is not recognisable.

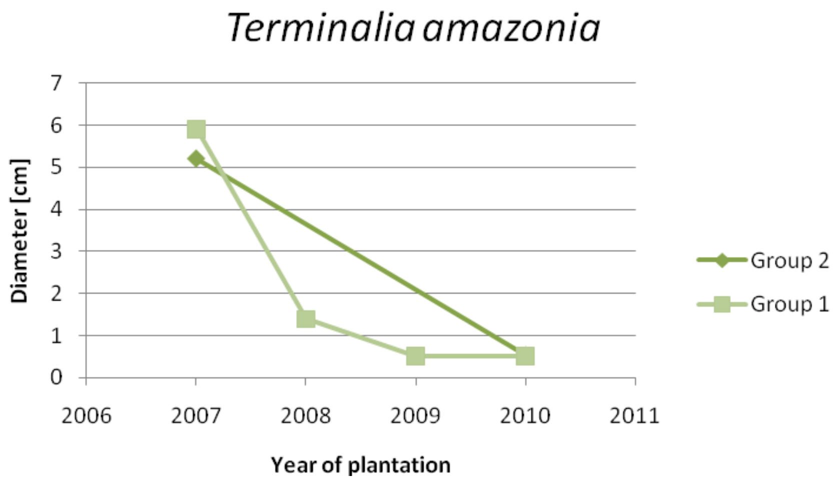

Figure 9: Growth in diameter [cm] of *T. amazonia*

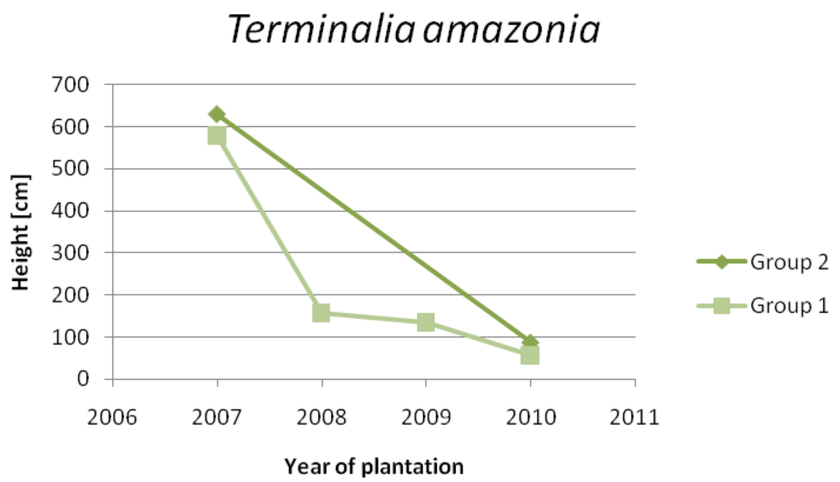

Figure 10: Growth in height [cm] of T. amazonia

In Fig. 11 and the growth tendencies of *T. amazonia* are illustrated. The diameter is plotted on the x-axis, the height on the y-axis is [both in cm]. If calculating a tendency the r^2 of the „Group 1' amounts 0.93 and of „Group 2' 0.99. Both values are indicating a trustworthy result.

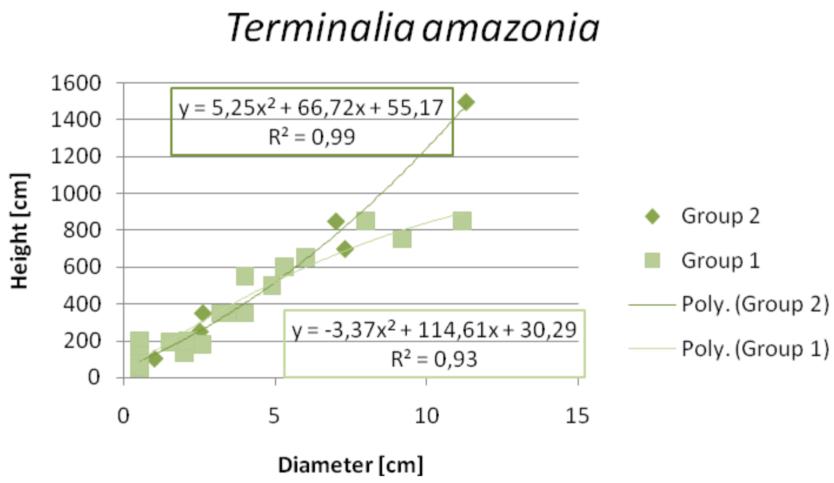

Figure 11: Growth tendencies of *T. amazonia*

By mere looking at Fig. 11 a more rapid growth of the not freed plants can be deduced. Statistical testing of significance does not seem to make sense due to the lacking data.

4.1.3.2 *Carapa guianensis* AUBL.

Fig. 12 and Fig. 13 are displaying the growth of *C. guianensis* in diameter and the according height on the y-axis and the year of plantation on the x-axis. The lack of data is again apparent, but in this case the freed plants are always smaller. A statistical proof is not appropriate.

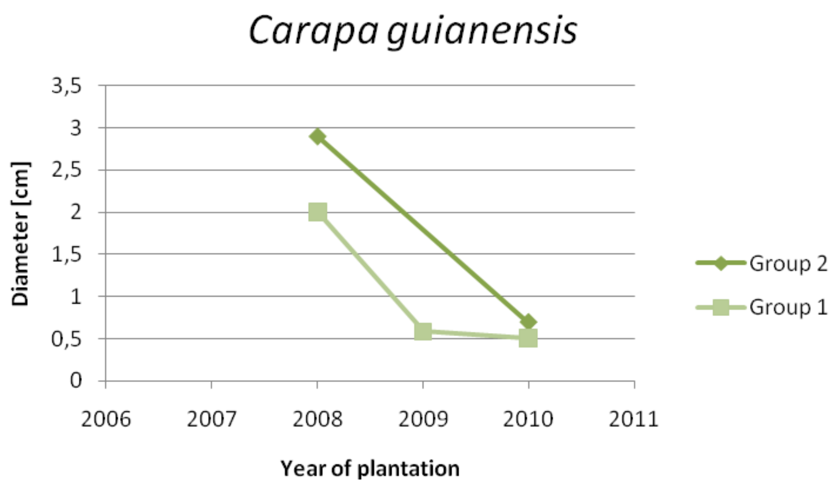

Figure 12: Growth in diameter [cm] of *C. guianensis*

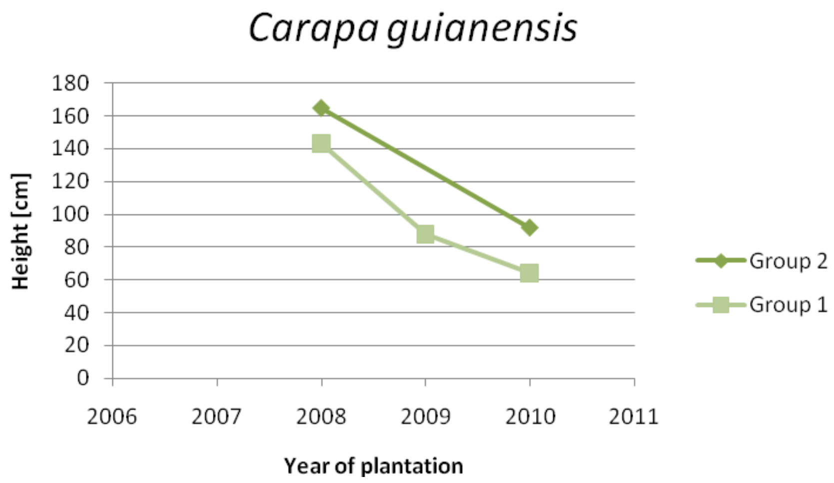

Figure 13: Growth in height [cm] of *C. guianensis*

In Fig. 14 the diameter [cm] on the x-axis is plotted against the height [cm] on the y-axis. The r^2 for „Group 1' is 0.80, for „Group 2' the value is 0.92. Both values are indicating a trustworthy result.

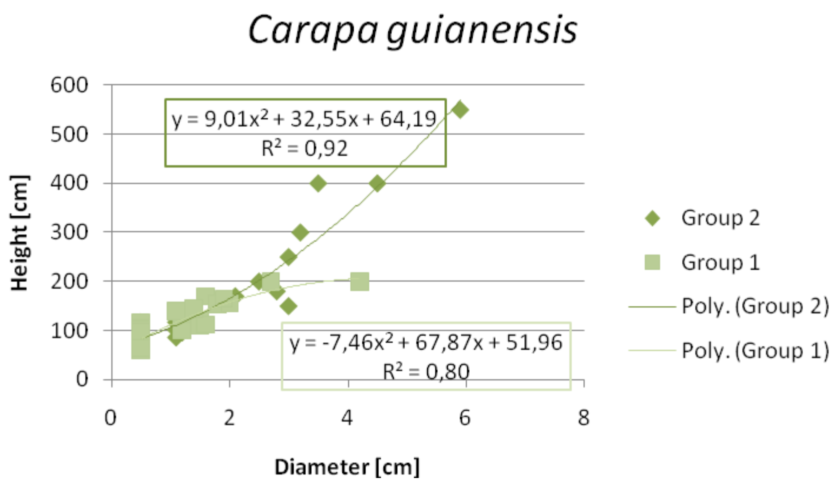

Figure 14: Growth tendencies of *C. guianensis*

Similar to the growth tendencies of *T. amazonia* a more rapid growth of the not treated individuals can be stated. Moreover with further testing a better statistical result is not expected.

4.1.3.3 *Cedrela odorata* L.

According to the figures above in Fig. 15 and Fig. 16 the growth of *C. odorata* is illustrated. On the x-axis the year of plantation is plotted against the diameter [cm] and accordingly the height [cm] on the y-axis.

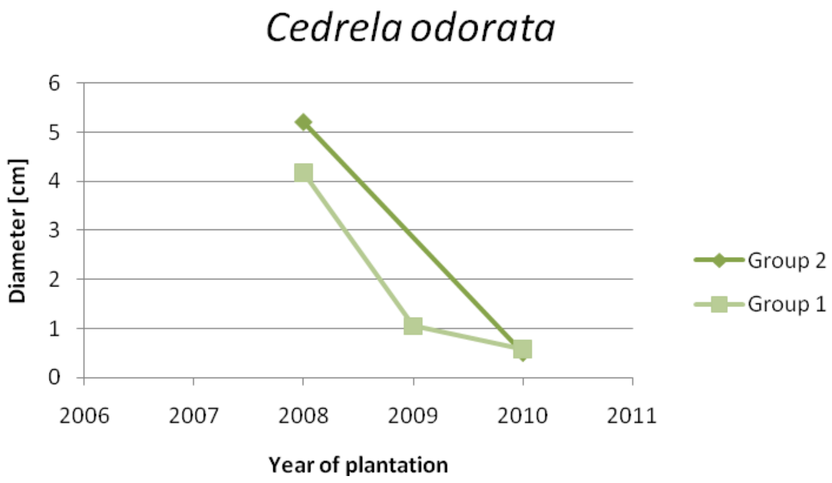

Figure 15: Growth in diameter [cm] of *C. odorata*

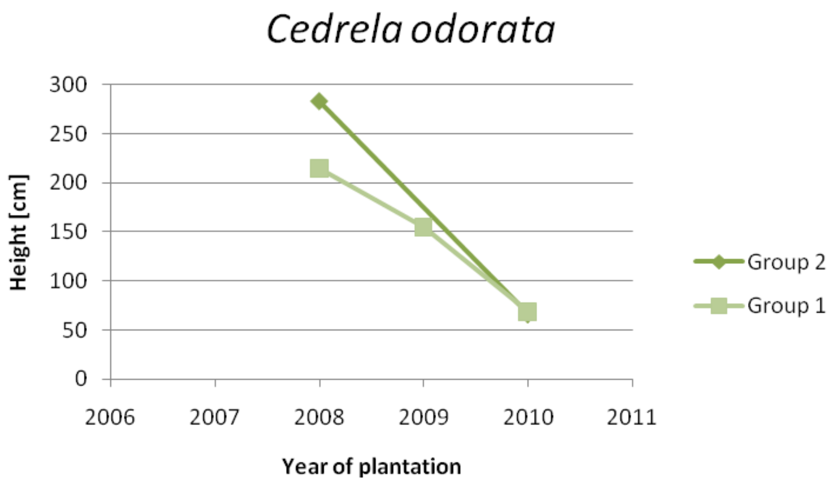

Figure 16: Growth in height [cm] of *C. odorata*

A slight difference in treatment is recognisable in both cases. The not freed group shows a slower growth than the freed group. In literature a regular to good growth is reported by PIOTTO, D., *et al*. (2004).

The tendency of slower growth of the freed group is also apparent in Fig. 17, where the growth tendencies of *C. odorata* are illustrated. The graphic shows on the x-axis the diameter [cm] and on the y-axis the height [cm]. The r^2 for „Group 1' is 0.67 and for „Group 2' 0.54.

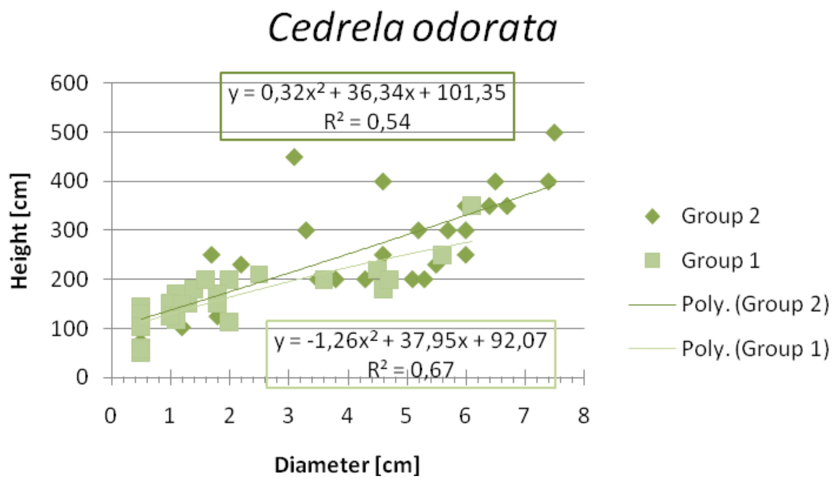

Figure 17: Growth tendencies of *C. odorata*

4.2 Natural regeneration

4.2.1 Difference in natural regeneration according to forests neighbourhood

4.2.1.1 Basic influence of forests

The amount of areas with a forest neighbourhood was six, without a forest neighbourhood the amount was four. In this way every plant was "blown-up" to the represented number per hectare.

Fig. 18 shows the regeneration of woody plants. Column one shows with 359 plants per hectare about five times the amount of woody plants than on the areas without forest neighbourhood with only 67 woody plants per hectare.

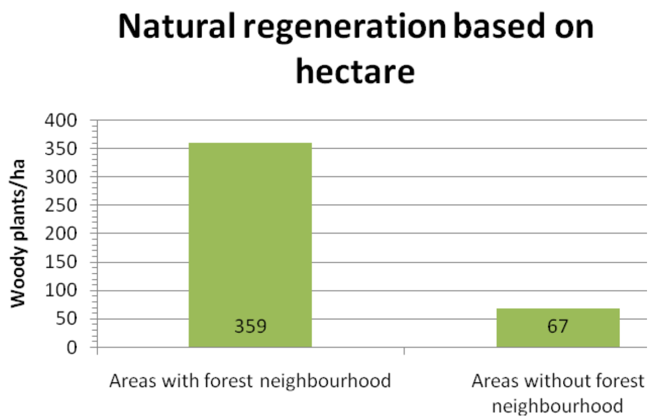

Figure 18: Natural regeneration based on hectare

The first results can be derived without any further statistical operation. The coherence between a higher amount of woody plants in areas with forest neighbourhood and without is obvious. Besides the total amount of plants, the diversity of plants has to be considered. For this reason the two values Simpson index and Simpson evenness as explained in Chapter 3.3.2 are calculated. For the validity of these indices the not identified species were included by classifying them into separate families.

Fig. 19 illustrates the ratio between natural regeneration of the two kinds of areas. Only 16 % of the incoming woody plants were found in the areas without a forest neighbourhood, but 84 % of the species grew on the areas with a forest nearby.

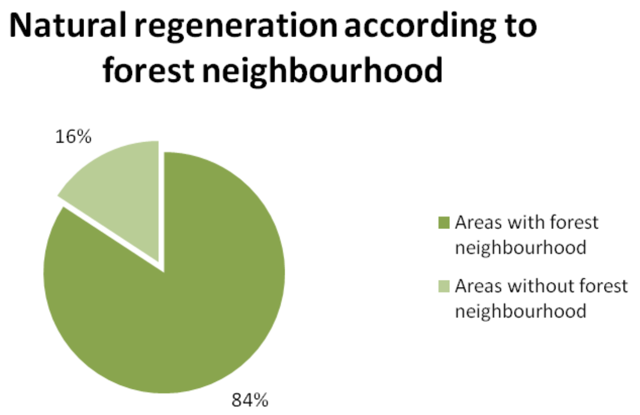

Figure 19: Amount of species in areas with or without forest neighbourhood in [%] to the total amount of natural incoming species

4.2.1.2 Simpson index and evenness

The Simpson index of the clustered areas is illustrated in Fig. 20. With an amount of 0.87 (with forest neighbourhood) and 0.81 (without forest neighbourhood) a difference is perceptible, but not severe. With 0.87 and 0.81 the diversity is located at the higher end of the scale. In the thesis of PRADER, W (2008) the Simpson index of the very same region, but in an undisturbed part of the forest, was calculated with 0.965. The dissertation of HORCHLER, P.J. (2007) quantifies Simpson indices for a primary forest in southern Venezuela with values around 0.98. Both of these values are apparently higher than the ones calculated in this thesis.

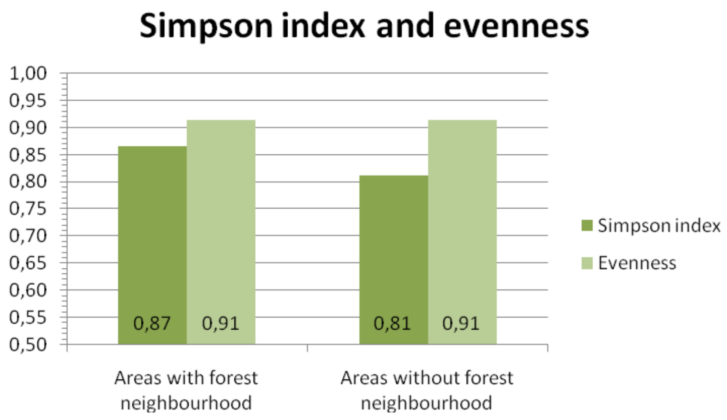

Figure 20: Simpson Index and Evenness of the areas clustered in areas with and without a forest (primary and secondary) neighbourhood

The calculated evenness allows the conclusion that the evaluated woody plants were allocated equally. There is not much variation. With 0.91 the variation of species in the areas with forest neighbourhood is equal to the evenness in the areas without a forest neighbourhood. The evenness in the southern Venezuelan forest HORCHLER, P.J. (2007) investigated in his doctoral thesis, lays around 0.15 to 0.5, so the variation of species in an undisturbed tropical forest is clearly higher than the areas discussed in the in this thesis.

4.2.1.3 Allocation of families

For a more specific analysis it is helpful to separate into two kinds of areas as illustrated in Fig. 21 and Fig. 22. Some plants were only identified down to the family, so every plant only was taken to the family for easing. In case of a gain of information the exact species, if known, are discussed in the text below. A complete overview of the families is listed in Appendix E. For reasons of clarity families that appear less than 2% were summarised in „others' in the following figures. This includes the not identified plants.

The evenness that was discussed above can be explained by looking at the occurring families. Melastomaceae were by far the most dominant species, followed by Piperaceae. These results are supported by various observations (CUSACK, D. and MONTAGNINI, F. 2004, RICHARDS 1996, POWERS, J.S. *et al*. 1997).

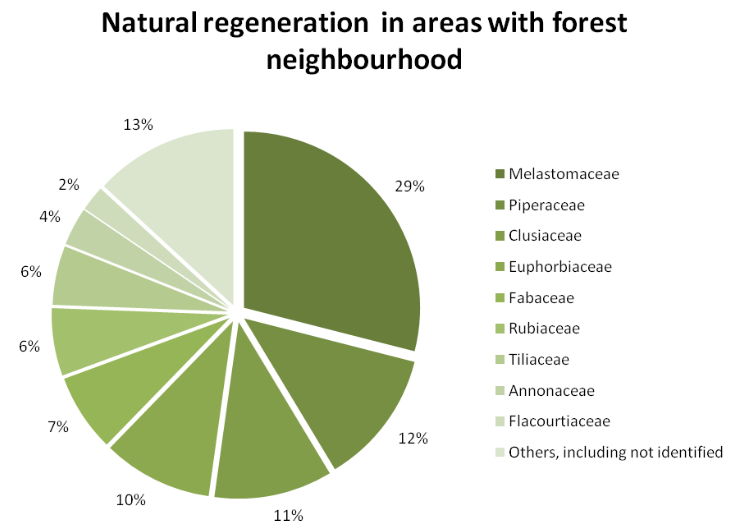

Figure 21: Natural regeneration with a forest neighbourhood in [%] to the total amount of species found in these areas

Most natural income was found in area F1, which can be explained with the history of the area, which was not used for years before the plantation began.

Areas F5, F7, and F26 are more or less equal in their natural regeneration according to the number of incoming species. Area F7 has an income of some economically interesting species like *Cedrela odorata* L.(*Meliaceae*), *Aspidosperma spruceanum* BENTH. EX MÜLL. ARG. (*Apocynaceae*), *Peltogyne purpurea* PITTIER (*Fabaceae*), *Luehea seemannii* TRIANA AND PLANCH. (*Tiliaceae*), *Croton schiedeanus* SCHLTDL. (*Euphorbiaceae*) and *Ochroma pyramidale* (CAV. EX LAM.) URB. (*Bombacaceae*). The proximity to the primary forest might be a reason. Additionally, the forest is situated on the top of the slope on which the area is also situated. This circumstance may influence the seed income positively.

The biggest difference to other areas shows area F18, which has nearly no natural income of seed. Two facts may explain this. In area F18 grass expands problematically. According to the staff the grass is *Brachiaria brizantha* (HOCHST. EX A. RICH.) STAPF. This species impedes a natural regeneration strongly. The second point which may influence a bad regeneration is the situation on the higher end of a slope. For this reason the seed income may be limited.

The four areas with no forest in the neighbourhood (F3, F10, F12, F15) have a clearly different natural regeneration (Fig. 22). With 35.4% the *Fabaceae* dominate the natural generation, but it has to be mentioned, that nearly all of them were *Senna reticulata* (WILLD.) H.S. IRWIN AND BARNEBY. The *Euphorbiaceae* were mainly *Croton schiedeanus* SCHLTDL. in area F3.

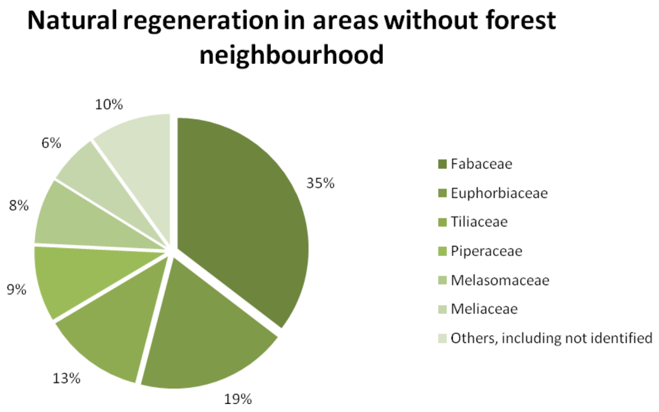

Figure 22: Natural regeneration without a forest in [%] to the total amount of species found in these areas

The lack of natural income makes the necessity of planting, especially in areas with a distance from forests, obvious. This requirement is already evident by comparing the total amount of natural income of the two types of areas as illustrated in Fig. 19 above.

4.2.2 Difference in natural regeneration according to different treatments

4.2.2.1 Basic influence of treatments

The difference between the two groups as clustered in Chapter 3.1.1 is clearly shown in Fig. 23 below.

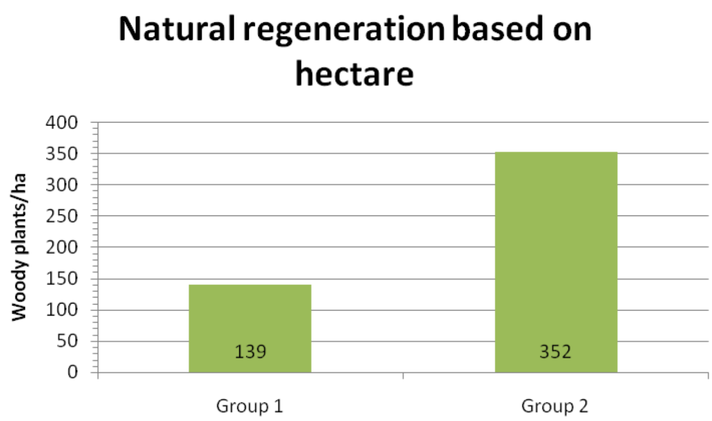

Figure 23: Natural regeneration of 'Group1' and 'Group 2' based on hectare

With about 352 plants/ha the group which were not completely freed had a higher amount of species than the group with a total freeing, which quantifies with 139 plants/ha. This is 2.5 times the amount of „Group 1'.

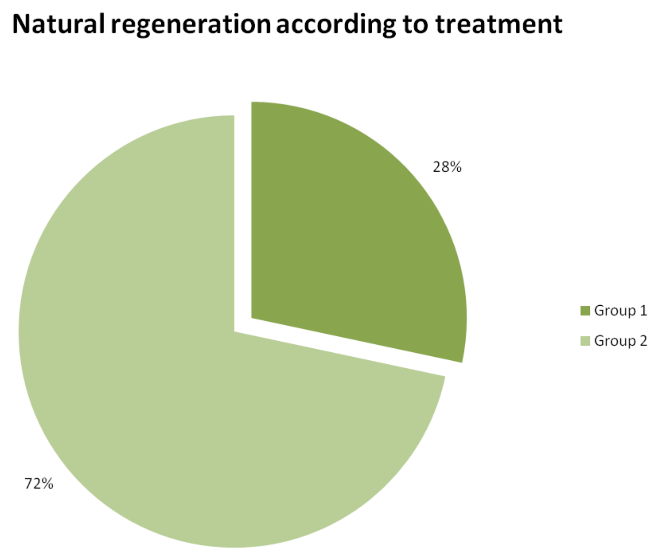

Figure 24: Amount of species in the clustered areas in [%] to the total amount of natural incoming species

Fig. 24 illustrates the percentage of incoming species in relation to the total amount of species. The total amount of incoming species which were found on treated amply areas, is 28% of the total amount of incoming species. In contrast the difference of 72% to the whole part of the species was found in areas untreated or hardly treated.

4.2.2.2 Simpson index and evenness

Furthermore the Simpson index and the Evenness (Fig. 25) are calculated. The results are similar to the results above, if clustered in neighbourhoods.

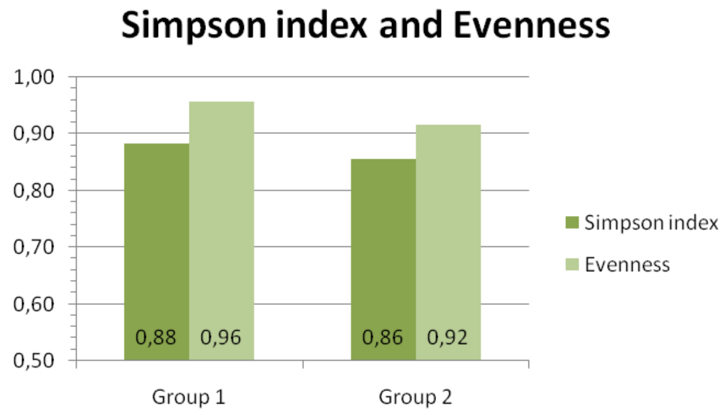

Figure 25: Simpson index and evenness according to treatment

With a value of 0.88 in „Group 1' and 0.86 in „Group2' the Simpson index is again on the higher end of the scale, and indicating a huge biodiversity.

With an evenness of 0.96 the value of the first group is hardly higher than the one in areas which were completely freed with an amount of 0.92. This again indicates a small number of families occurring.

4.2.2.3 Allocation of families

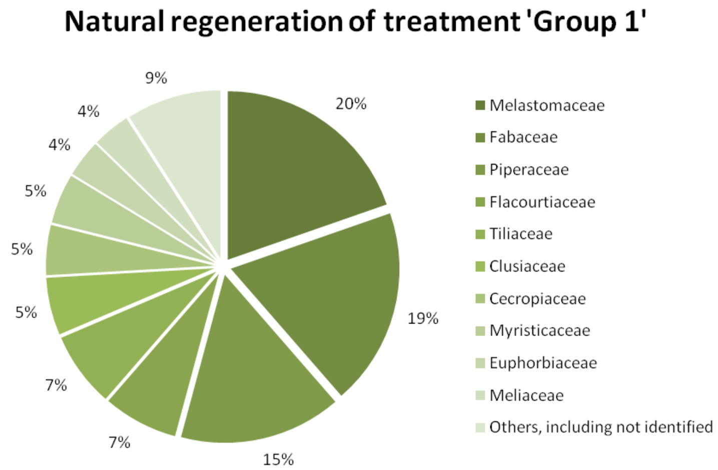

Figure 26: Natural regeneration of the 'treated' group

In „Group 1' the *Melastomaceae* and *Fabaceae* are the most common families, followed by the *Piperaceae* (Fig. 26). In general, we can detect that more than a half of the natural regeneration was built by these three groups. The half of the regeneration of the second group (Fig. 27) is also built by three families, but in this case the *Melastomaceae* on its own is already dominating one third of the regeneration.

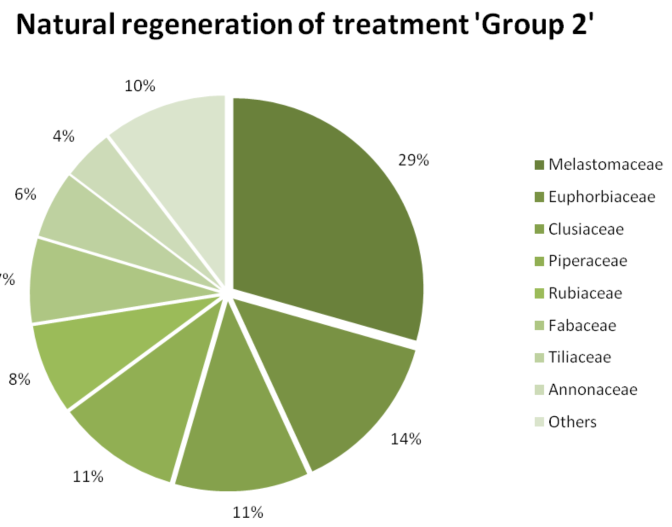

Figure 27: Natural regeneration of the 'untreated' group

The next three important families are *Euphorbiaceae*, *Clusiaceae*, and again *Piperaceae*. We can observe that the species of *Euporbiaceae* are *Hyeronima alchorneoides* ALLEMÃO and *Croton schiedeanus* SCHLTDL can be found as natural incoming plants because these two species are planted as well as desirable woody plants. Especially *Hyeronima alchorneoides* is remarkable because it is planted only five times, although it is recommended as a good species for reforestation because of its ability to grow on acidic soils (BOSHIER, D. and CORDERO, J. 2010).

5 Discussion

5.1 Planted trees

The question asked in this part of the thesis was, if there is a difference in growth between the two types of treatment:

On the one hand there were areas, where the plants are freed amply or where freeing wasn`t necessary. This was called „Group 1'. On the other hand there were areas, where competitors for the newly planted individuals were left. This was called „Group 2'.

The analysis was made for the three most common species: *Terminalia amazonia* (J.F. GMEL.) EXELL, *Carapa guianensis* AUBL., *Cedrela odorata* L. due to the lack of data for the other species. Nevertheless, the interpretation of the data is difficult and only possible by mere looking. Due to this fact, the results have to be considered carefully. Also the time of the first planting was only three years ago, so the differentiation might not be noticeable if existent.

Nevertheless, mere looking at the graphics as shown in Chapter 4.1.3 leads to the conclusion, that there might be a distinction.

This dissimilarity between the graphs can lead to the conclusion, that without treatment the growth seems to be faster. This is surprising because the existence of competitors diminishes the nutrient content and is shadowing the planted species.

It needs to be taken into account, that the data are sparse. Accordingly, the areas are not perfect replicates to each other. So there are surly variables, which are not considered.

Thus, we are far from advising a certain kind of treatment. It is unsure if a ceasing of freeing would be a good advice, because the kinds of competitor species growing on the site are disregarded. There are areas with an aggressive grass (as I mentioned shortly above in Chapter 4.2.1.3 in context to the natural regeneration). On these areas it might be careless to leave the freeing undone as all of the planted individuals might get lost.

For better results with more validity a rerun of the investigation seems reasonable. The research of WISHNIE *et al* (2007) confirms this by relativising their results "as they are just based on the first 24 months of growth". Other researches were also conducted with more and longer data samplings, for instance the paper of CUSACK, D. and MONTAGNINI, F. (2004) with 9-10 years old plantations.

RICHARDS (1996) writes that at first some species in rainforests grow rapidly but after a couple of years their growth slows down. This proves evidence of the necessity to repeat the investigation.

The idealised area as illustrated in Fig. 7 does not exist. Steep slopes and slim forms of areas for instance lead to slight modifications of the experimental design for example the plots were not in a square but in a row. Of course the adherence of randomness was preserved.

For a repetition of research this has to be kept in mind. For validation more sample plots are recommended, which are accompanied with a greater time frame for data collecting.

In future researches it would be interesting to focus attention also on some soil ameliorating species (cf. HAGGAR, R.P. *et al*. 1998; CARNEVALE, N.J. and MONTAGNINI, F. 2002). *Vochysia ferruginea* and *Hyeronima alchorneoides* for instance are both recommended as aid for land restoration. For *H. alchorneoides* only data from 2010 is available in this thesis.

Furthermore POWERS, J.S *et al*. (1997) give the hint that *Vochysia* ssp. shades out grass understory, which again influences the necessity of treatment.

In summary, a possible additional question that could be investigated in future is, if those species influence the growth of natural regeneration and economically valuable planted species. If this is the case, an increasing amount of planting this species may be an advantage. This point of view is supported by PIOTTO, D. *et al*. (2004) who states that with improved planning at the establishment stages, especially concerning the choice of species and further investigations regarding the ecology of plantations, the risk of investment in small farms would be minimised.

A practical suggestion for the plantation on the topic of treatment as defined above is in my opinion not possible without further investigations.

5.2 Natural regeneration

This part of the thesis handled the question of influences to natural regeneration. On the one hand the influence of a forest neighbourhood was analysed and on the other hand the influence of the treatments. Since we did no test of significance in any case due to the little data the results might be coincidence, but in our opinion some conclusions may be drawn, supported by cited literature.

That there is a prominent disparity in the total amount of natural regeneration according to forests nearby is not very surprising, but the lack of dissimilarity concerning the Simpson index and evenness is noticeable. So the forest does not seem to have an influence on the allocation and spectrum of plant families. Confirmed by other studies (e.g. CUSACK, D. and MONTAGNINI, F. 2004, RICHARDS 1996, POWERS, J.S. *et al*. 1997) the dominance of *Melastomaceae* and *Piperaceae* is normal. On areas without a forest nearby *Fabaceae* and *Euphorbiaceae* are also growing. If this is a coincidence or not has to be found out in future studies.

Also a remarkable disparity can be found in the total amount of natural regeneration according to the treatments. The areas, which are not freed, have much more natural regeneration than the others. This again is not surprising, but the missing dissimilarity concerning Simpson index and evenness is noteworthy. The treatment has apparently no influence in allocation and spectrum of the plant families. Once more *Melastomaceae* and *Piperaceae* are the dominant species. Nevertheless, RICHARDS (1996) states, that, "if undisturbed by grazing, tree felling and frequent fires, this secondary vegetation is slowly invaded by primary forest trees and can eventually develop into community similar to that which originally occupied the site".

In summary, the influences of the neighbourhood and the treatment can be approved concerning the amount of natural regeneration, but not concerning the allocation and spectrum of the woody plant families.

In fact, the absence of some variables in this thesis concerning the natural regeneration does not allow a final conclusion. The microclimates, e.g. if a slope is northwards or southwards, the light conditions, etc. of the areas are not considered. The areas are -as mentioned before- not perfect replicates of each other. Moreover, aspects like different kinds of seed dispersal distance to the next seed source are missing. The lacking of these aspects shall not be underestimated.

Longer observation times are necessary to find out more, as also depicted by Cusack, D., and MONTAGNINI, F. (2004) for their study in Costa Rica. In fact, a longer observation time or a re-investigation could lead to interesting results.

Additionally, in future studies a more differentiated identifying of the woody income might be sensible. Although other studies (e.g. POWERS, J.S. *et al*. 1997) only identify to the families, in our opinion a further identification might improve the reliability.

Some studies (CUSACK, D., and MONTAGNINI, F. 2004; POWERS, J.S. *et al*. 1997) found out that there is interdependency between the planted species and the natural income of species. The consideration of the planted species while investigating the natural regeneration seems to be reasonable.

Since the idealised area as illustrated in Fig. 7 does not exist, in reality sometimes adaption had to be made. Steep slopes and slim forms of areas for instance lead to slight modifications, e.g. the plots were not in a square but in a row. Of course the adherence of randomness was preserved.

For improvement of the investigation of these areas a newly research is desirable. A repetition in another thesis in some years is recommended. In this thesis some of the aspects mentioned above could be integrated. A more detailed look at the seed dispersal and the distance to forests is suggested.

For practical purposes it can be determined, that despite the fact that the treatment does not seem to have an influence, an omission should be well thought. The treatment in areas without any problems of grass can be ceased or at least constricted.

POWERS, J.S. *et al*. (1997) found out that *Vochysia* ssp. shades out grass understory so an increasing planting of this species can have the same effect like freeing. In succession a natural income may be possible. Perhaps agroforestry, like already done by some farmers also can curtail the problem with grass, if the farmers agree with the regeneration below their useful plants. A rising of acceptance can be achieved be planting economically valuable trees.

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7 List of figures

8 List of tables

9 List of formulas

10 List of Abbreviations and Spanish expressions

Abbreviations

FAO	Food and Agriculture Organization of the United Nations
ha	hectare
r^2	coefficient of determination
m	moisture

Spanish Expressions

Quebrada	Small River
Rio	River
Piedras blancas	literally “white stones”

Appendix A: Pictures of devastated land in the concerned region

Artificial pasture in the concerned area.

Some lone trees on pastureland with cattle.

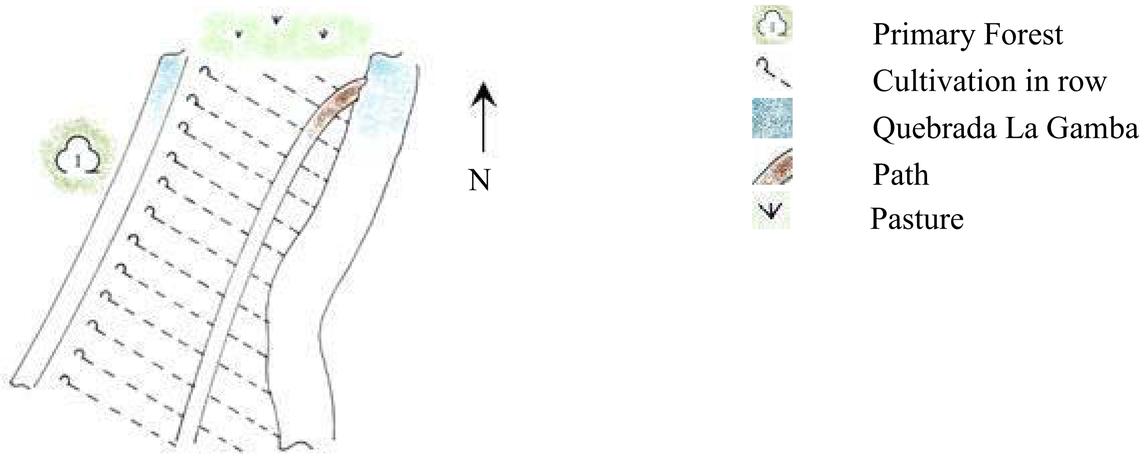
Palm oil plantation characterised by extremely low biodiversity.

Agricultural area

Appendix B: Sketches of the areas and photos

North arrow estimated as well as shape and size of areas.

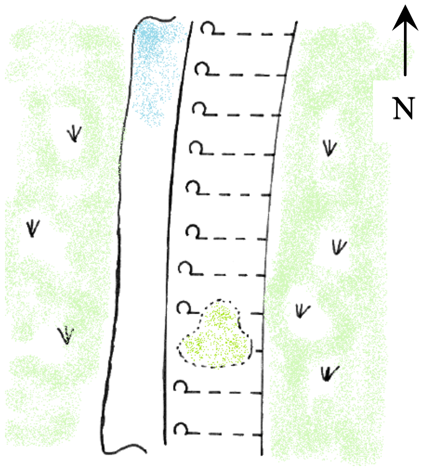
Area F1



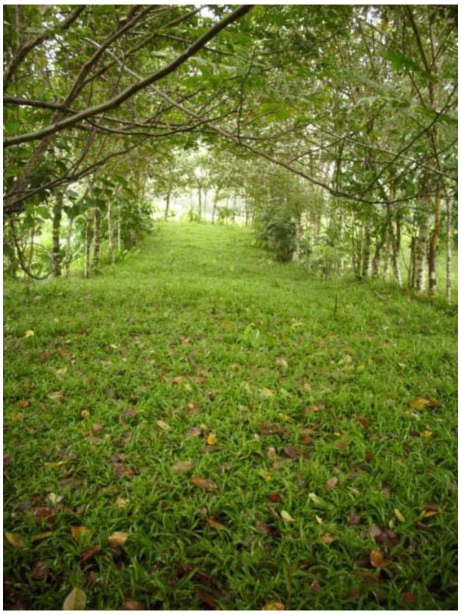
View along the path. Cultivation rows are situated more or less right-angled to the path.

View from the path in one cultivation row. Remarkable is the remaining natural regeneration between the rows.

Area F3



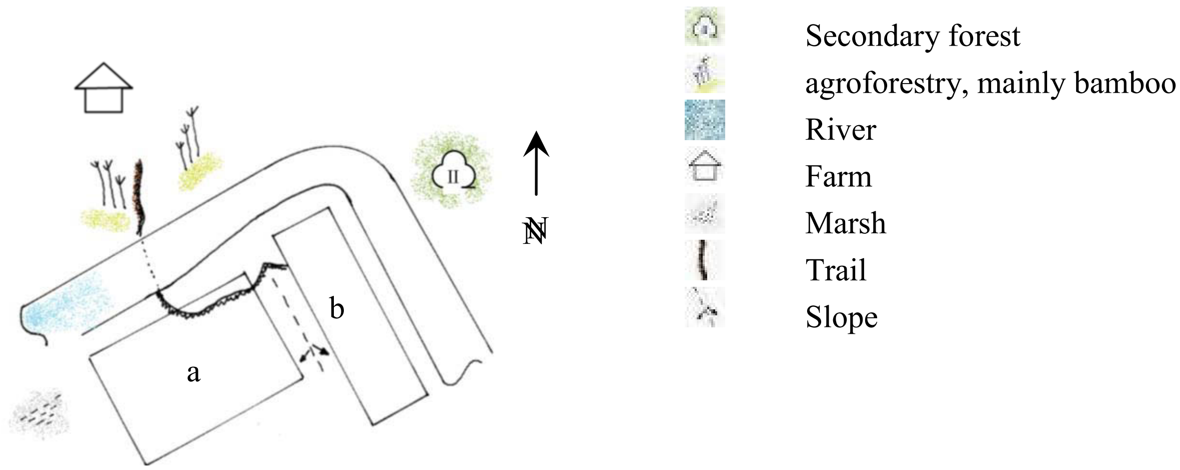
Pasture
Cultivation in row
Quebrada Bolsa
Natural regeneration



View from south to north. The short grass makes a treatment unnecessary

View from the north to the south. The natural regeneration can be seen

Area F5



5a: High grass growing in this area, with a strongly cut back, so the newly planted trees are free.

5b: More shadowy part of the area with short grass.

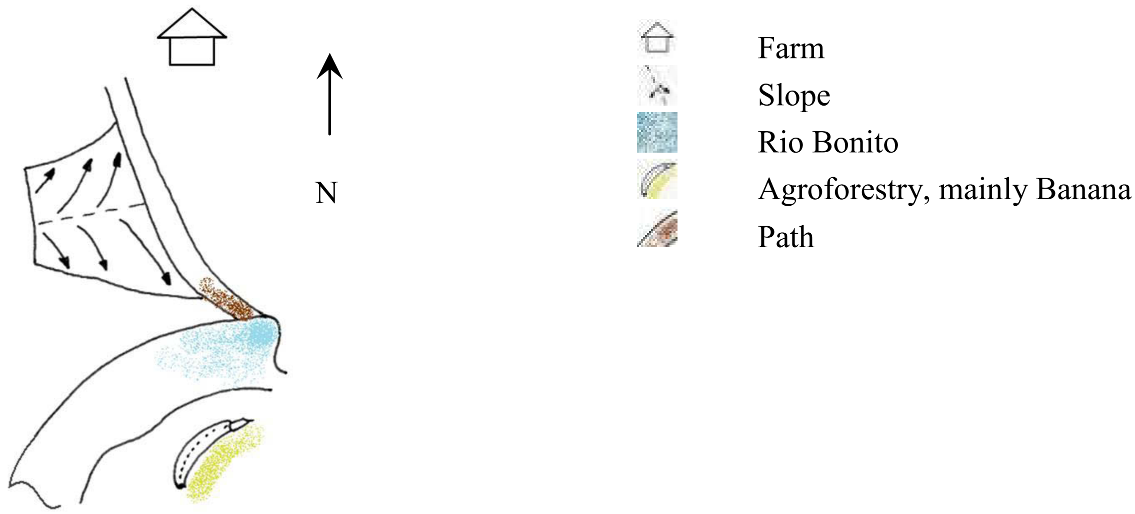
Area F7

Primary forest
Secondary forest
Agroforestry, mainly cacao
Path
Slope

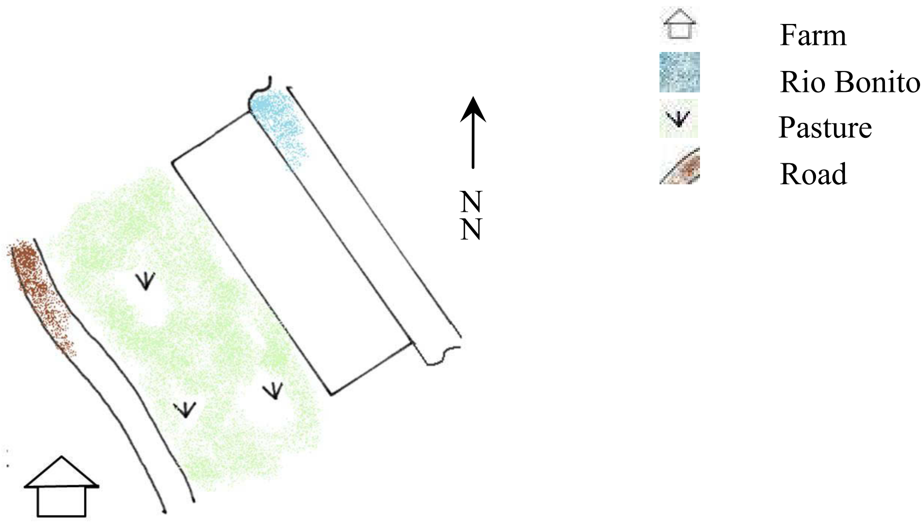
View of the slope

View of the plateau on top of the slope. In the foreground a Melastomaceae

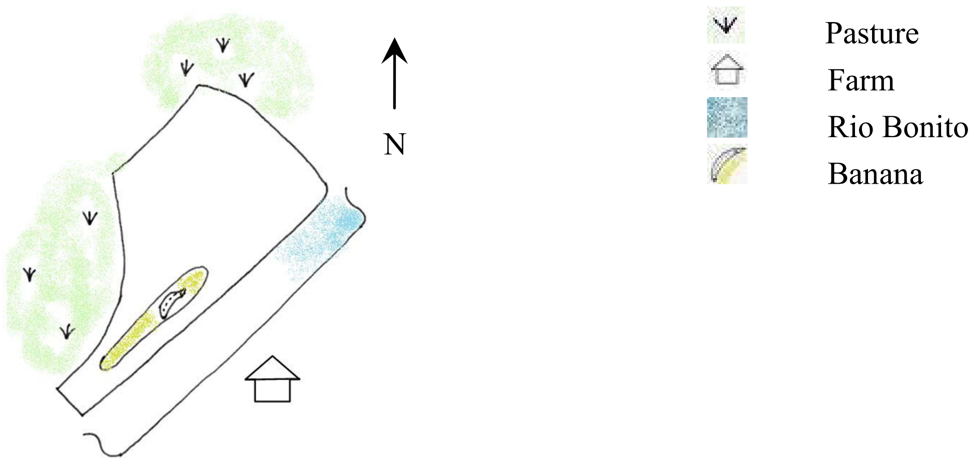
Area F10



Area F12



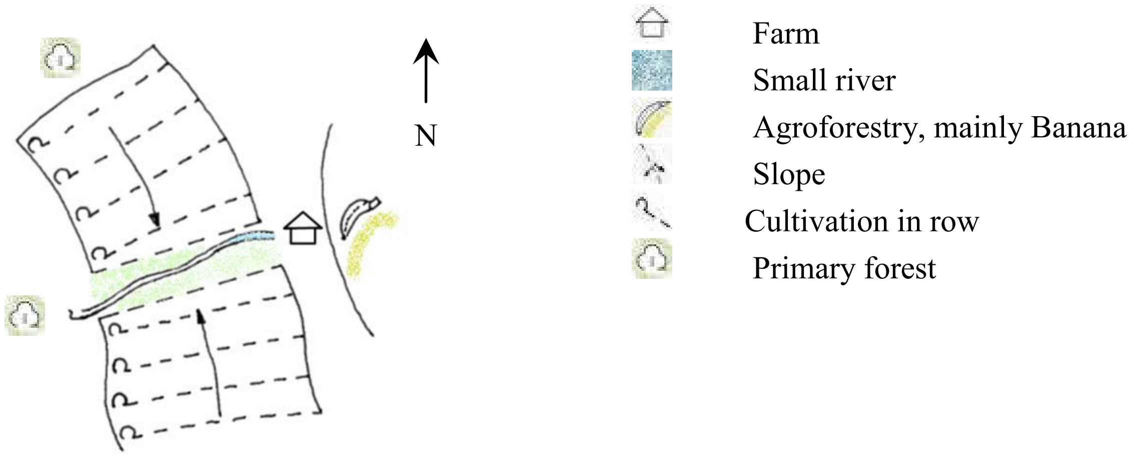
Area F15



High grass competes strongly with the new plantation

Two *Schizolobium parahyba* (VELL.) S.F. BLAKE in the foreground.

Area F26


N
Farm
Small river
Agroforestry, mainly Banana
Slope
Cultivation in row
Primary forest

Appendix C: Information about the planted species with n ≥ 10

In the following the species which are equal or more than ten times found in the areas are introduced. The cited literature is listed in Chapter 6 of the thesis.

Aspidosperma spruceanum Benth. ex Müll. Arg.

In Costa Rica, it is distributed from the central pacific to the south, including the hilly coasts, up to a height of 1000 m. Outside of Costa Rica the species spreads from Mexico to Brasilia, Peru and Bolivia (INBIO 2011).

A. *spruceanum* grows to a tree with heights from 20 to 45 m and has a broad variety concerning the size and the form of leafs (INBIO 2011). It is a common representative of the overstory in forests on well drained hill-tops and ridges (WEISSENHOFER, A. and HUBER, W. 2001).

A. spruceanum prefers very wet forests (INBIO 2011) of the lower tropics. The species covers well drained sites and grows as well on nutrient-poor sandy soils as on heavy clayey red soils (JANZEN, 1983 after GTZ 1997). *A. spruceanum* is also a prominent species in forests with well-drained slopes. Furthermore it can be found in mountain or upland forest (WEISSENHOFER, A. and HUBER, W. 2001).

A. spruceanum belongs to the canopy cover. Natural regeneration is always available, but middle aged and old trees are found less often. *A. spruceanum* has a huge tolerance regarding light conditions. The seedlings grow in dense forests as well as on open space. The species adapts well to changing soil conditions. A numerous seed production, flying seeds and a fast germination are useful against pests and for finding a light gap, but the seedlings can also wait for light. If the usage continues to be carefully and mother trees remain, the existence of the species is secure (GTZ 1997). After A. WEISSENHOFER they use *A. spruceanum* for reforestation and it is a common tree.

The wood is very dense and heavy-weight, but in the same time very elastic (LAMB, 1946 after GTZ 1997). The bulk density (moisture 12 %) is 0.95 g/cm³ (GROSSER, 1993 after GTZ 1997).

A. spruceanum is from the economical point of view valuable. It is used for diverse purposes: construction in general, fences, poles, furniture, parquet, handicraft, fuel wood, ship construction and others (GTZ 1997, STRI 2011, INBIO 2011).

Croton schiedeanus Schltdl.

The natural habitat of *C. schiedeanus* is found from Mexico over Costa Rica to Peru and French Guiana (STRI 2011). In Costa Rica it occurs on both coasts in elevations between 20 y 850 m (INBIO 2011). The species accomplishes its zenith of growth between 8 and 15 (24) m in height (INBIO 2011). *C. schiedeanus* prefers wet forests (INBIO 2011) and lowland evergreen and partly deciduous forests (WEISSENHOFER, A. and HUBER, W. 2001).

M.F. GUERRERO *et al.* (2001) have described the antihypertensive and vasorelaxant effects of an extract from *C. schiedeanus*. Therefore a pharmacological usage is considered possible in the future. After A. WEISSENHOFER (unpublished) *C. schiedeanus* is used for reforestation and a widely spread tree.

Inga ssp.

There are about 350 *Inga* ssp. species in the world, in Costa Rica WEISSENHOFER, A. and HUBER, W. 2001 counted 66, and in the area concerned in this thesis 35 species are native. Some of the species are very similar so making a distinction sometimes very difficult, particularly if fruits and flowers are missing. According to RICHARDS (1996) and LAMPRECHT (1986) *Inga* ssp. is a pioneer tree or shrub. Inga ssp. is for its nitrogen accumulation a valuable small tree (LAMPRECHT 1986).

RICHARDS (1996) states that the abundance of *Inga* ssp. and other trees (such as *Goupia glabra* AUBL. *Visio guianensis* AUBL., species of *Ionia*) is generally an indication for secondary forests.

Pseudobombax septenatum (JACQ.) DUGAND

P. septenatum has its distribution between Belize and the north of South America (STRI 2011; INBIO 2011). In Costa Rica it is a common species in some parts of the Pacific coast. There it can even be a dominant species in the floodplain forest. It can also be found on the Atlantic coast, but more rarely (INBIO 2011). *P. septenatum* is a tree up to 20 m tall (WEISSENHOFER, A. and HUBER, W. 2001) with typical bellied or flattened trunk with numerous green branches (INBIO 2011).

Its habitat is the wet to dry forest, forests of the coast and in sandy dunes. The elevation goes from 0 to 600 m (INBIO 2011).

P. septenatum is used for wood and ornamental purposes (STRI 2011). The seed is edible, but this usage is not very common. In former times the hair of the seeds were used for the contents of pillows (INBIO 2011).

Zygia ssp.

Six of the found *Zygia* ssp. were *Z. longifolia*, which is a tree. Its natural distribution is from Mexico to Brazil (STRI 2011). (WEISSENHOFER, A. and HUBER, W. 2001) describe the genera as trees or shrubs sometimes scandent. They have cauliflory and ramiflory.

The usage of *Z. longifolia* is mainly handicraft (STRI 2011).

Samanea saman (JACQ.) MERR.

S. saman is native from Mexico to Brasilia and including the Antilles (INBIO 2011). The tree is up to 25 m high and has its habitat on both coasts, but more on the pacific side with an elevation between 0 to 800 m (INBio 2011). It grows usually along rivers in rather dry, deciduous forests (WEISSENHOFER, A. and HUBER, W. 2001).

The species favours light, which makes it positive for planting in pasture where planting of 10 to 20 trees/ha is recommended (BOSHIER, D. and CORDERO, J. 2010).

The bulk density (m=12 %) is 0.45 to 0.6 g/cm³ (RICHTER, H.G. and DALLWITZ, M.J. 2000). The wood is medium heavy and because of contorted growing hard to handle. The sapwood differs notable from the heartwood, dries in the air with moderate rapidity but the cracks of drying are remarkable. Nevertheless, the wood is used for construction in general, furniture, interior, parquet, etc. (INBIO 2011). In addition, the species is used for food and ornamental purposes (STRI 2011). The leaves and pods fruits are used for fodder but this is risky because the fruits contain an alkaloid, which is toxic and can lead to abortion. Furthermore the fruit is used against head ache and diarrhoea. The tree is often planted because of its appearance and for shadow spending habit (INBIO 2011).

Virola sebifera AUBL.

The natural distribution of this species is from Nicaragua to Peru, Bolivia and Brasilia (WEISSENHOFER, A. und HUBER, W. 2001). *V. sebifera* can grow up to 30 - 40 m (TWE

2008). It is common in forests on well-drained slopes as well as the genera *Virola* general grows in riverine forests (WEISSENHOFER, A. und HUBER, W. 2001).

The bulk density (m = 12%) is 0.4–0.65 g/cm³ (RICHTER, H.G. and DALLWITZ, M.J. 2000). The species is used for example for handicraft, furniture, boxes and crates, light construction and plywood (STRI 2011; TWE 2008).

Platymiscium curuense N. ZAMORA & KLITGAARD

P. curuense is endemic to the Peninsula de Osa (WEISSENHOFER, A. und HUBER, W. 2001) and grows in an elevation from 0 to 400 m with a dramatically decreasing population, because of the exploitation of the forest. Some programmes for the conservation are successfully conducted (INBIO 2011). *P. curuense* is a large tree up to 30 m tall (WEISSENHOFER, A. und HUBER, W. 2001). It may easily confound with *P. pinnatum* (JACQ.) DUGAND (INBio 2011).

Astronium graveolens JACQ.

The species is widely distributed from southern Mexico to Paraguay (WEISSENHOFER, A. und HUBER, W. 2001). It can be found on the pacific side and rarely in the Peninsula de Osa (INBIO 2011). The tree is up to 35 m tall (WEISSENHOFER, A. and HUBER, W. 2001). The diameter can be up to 80 cm. Small buttress roots reach no more than one meter.

A. graveolens grows in Costa Rica in lower to middle elevations (0 – 900 m), in dry to humid climates with an annual precipitation between 1500-3500 mm. The species adapts its growth to stony soil and bad drained sites as well as rich and well drained sites, but with a slope no more than 30 % (INBIO 2011). It is a species with slow to medium growth. In Honduras this 7 species is used for the enrichment of natural forests, if high value species are missing. In this way they enlarge the biodiversity and the actual value of the forest (BOSHIER, D. und CORDERO, J. 2010).

A. graveolens is a heliophilous plant and deciduous at the beginning of the dry season, which brings the ability to grow in dry and humid forests. It is a species of primary, secondary forests as well as fallow lands. Its regeneration ability is relatively good. In dry forests *A. graveolens* associates with *Dalbergia retusa*, *Tabebuia ochracea*, *Anacardium excelsum* (which is planted in the investigated areas), *Simarouba glauca* and others (INBIO 2011).

The bulk density (m = 12 %) is 0.69 to 0.95 g/cm³ (RICHTER, H.G. and DALLWITZ, M.J. 2000). The wood is durable and resistant against putridity. It can be wood with the highest quality and with a lovely surface, which makes it a favourable wood for furniture, posts, sport products and more.

The species is endangered and could use more protection although it can be found on different conservation areas (INBIO 2011).

Minquartia guianensis AUBL.

The natural distribution of *M. guianensis* is Central America and northern South America (WEISSENHOFER, A. and HUBER, W. 2001). It is common in elevations from 30 to 350 m (STRI 2011). In Costa Rica it can be found in the North, the atlantic side and more rarely in the south (INBIO 2011).

According to the description height and diameter is diverse. BOSHIER, D. and CORDERO, J. (2010) explicate that the tree can reach 70 m or more in height and a diameter of 1.8 m. On the contrary, INBIO 2011 state that it is a small to large tree with a maximum height of 40 m and a diameter of 90 cm.

Single trees grow in mountains or upland forests but mainly can be found "in non-inundated as well as seasonally inundated tropical lowland forests and gallery forests on clayic or sandy soil" (WEISSENHOFER, A. and HUBER, W. 2001). The slope *M. guianensis* prefers is between 20 -40 % and the annual precipitation may not be less than 3500 mm.

The species is characteristic for primary forests, where it reaches the overstory. In the atlantic zones it can be found in patches of the original forts or remaining as a solitary tree. It seems to be a shade tolerant tree with a very good regeneration ability, but poor survivance of the seedlings. Hardly any are trees are in the middle age. It associates with *Carapa guianensis*, *Virola koschnyi* (which both are planted in the investigated areas) and *Pentaclethra macroloba* (INBIO 2011). The investigation experience is lacking (BOSHIER, D. and CORDERO, J. 2010).

The bulk density (m = 12 %) is 0.85 to 1.0 g/cm³ (RICHTER, H.G. and DALLWITZ, M.J. 2000).

Boat building, bridge construction, flooring, furniture, heavy construction, joinery, light construction, railroad ties, vehicle parts, decorative veneer are only some of the various usages (TWE 2008).The wood is difficult to dry and hard to handle but possesses a resistance against fungi, termites and putridity.

The species is endangered and actually much exploited (INBIO 2011).

Calophyllum brasiliense CAMBESS.

The natural distribution of this species goes from Mexico to Costa Rica (WEISSENHOFER, A. and HUBER, W. 2001). In Costa Rica the distribution is on the atlantic as well as on the pacific side in very wet forests. It is common on the Peninsula de Osa where plantations are done (INBIO 2011).

This species reaches a height of 40 to 45 m and a diameter of 1.8 m. *C. brasiliense* is a typical representative of the overstory (GTZ 1997) in forests on well-drained hill-tops and ridges (WEISSENHOFER, A. and HUBER, W. 2001). Usual elevations go from 300 to 900 m (STRI 2011).

The bulk density (m = 12 %) is 0.64 g/cm³ and the wood is used for boat building, construction, chemical derivatives, decorative plywood and veneer, domestic flooring, exterior uses, furniture and joinery (TWE 2008).

Schizolobium parahyba (VELL.) S.F. BLAKE

The natural distribution of this species is from Mexico to Brasilia (WEISSENHOFER, A., HUBER, W. 2001). In Costa Rica the distribution is on the pacific side and in the middle. The elevation reaches 50 to 900 m (INBIO 2011).

The tree can reach a height of 35 m, but more common is 10 to 20 m, with a diameter of 30 to 60 (100) cm. In Costa Rica a plantation of CATIE, Turrialba, has quiet good results with a planting of 4 x 5 m (BOSHIER, D. and CORDERO, J. 2010).

The habitat is coastal forests in which S. parahyba is the most conspicuous canopy tree. Additionally, it grows in lowland forests and is frequently found in secondary forests (WEISSENHOFER, A. and HUBER, W. 2001). INBIO 2011 states that its habitat is humid and dry forests. LAMPRECHT (1986) depicts that this species is an aggressive pioneer.

Its usage is diverse. Besides ornamental purposes (STRI 2011), boat building, boxes and crates, concrete formwork, furniture, heavy construction, external joinery, plywood, pulp and paper products, veneer are some fields of usage. The bulk density (m = 12 %) is 0.37 g/cm³ (TWE 2008)

Peltogyne purpurea PITTIER

The prevalence of this species is only Costa Rica and Panama, on the pacific side. The core area is the peninsula de Osa (INBIO 2011).

The tree has up to 50 m in height and one meter in diameter. The trunk is straight and cylindrical. It possesses narrow buttresses (INBIO 2011; BOSHIER, D. and CORDERO, J. 2010).

The preferred habitats are wet and very wet forest between 50 - 500 m elevation and an annual precipitation more than 3000 mm. Normally, the site should be plain and well drained, but slopes until 35 % and poor soil are possible (INBIO 2011). *P. purpurea* is a species of the overstory, although it is often topped. It can be found mainly in primary and undisturbed forests.

The tree has a very good regeneration underneath the mother tree, but the survival of the middle aged trees is poor. The species is medium shadow tolerant in the first phase but grows well in open areas and on the border of forests. Normally, lot of the seedlings die in the following years, if the site is to shadowy. It associates with *Caryocar costaricense*, *Brosimum utile* (both planted on the investigated areas) and *Couratari guianensis* (INBIO 2011).

Experience with this species in plantation is lacking, in experimental patches P. purpurea shows a very slow growth in the first two years. The cultivation with fast growing species is not recommendable (BOSHIER, D. and CORDERO, J. 2010).

The species is endangered and part of the list of rare and endangered species in Costa Rica.

The bulk density is 0.8 to 1.0 g/cm³, which is quite heavy. It is one of the most valuable woods in Costa Rica because of its colour (trade name: Purple Heart). For its good quality it is used as parquet, furniture, handicraft, construction of boats, bridges and more (INBIO 2011).

Appendix D: Data of the three analysed trees

Terminalia amazonia (J.F. GMEL.) EXELL

Group 1		
Year of plantation	**Diameter [cm]**	**Height [cm]**
2007	4.9	500
2007	3.4	350
2007	4	350
2007	5.3	600
2007	11.2	850
2007	3.2	350
2007	9.2	750
2007	8	850
2007	6	650
2007	4	550
2008	0.5	53
2008	2	135
2008	0.5	145
2008	2.1	200
2008	2.6	180
2008	0.5	190
2008	1.5	195
2009	0.5	200
2009	0.5	125
2009	0.5	78
2010	0.5	57
2010	0.5	54
2010	0.5	57

Group 2		
Year of plantation	**Diameter [cm]**	**Height [cm]**
2007	2.6	350
2007	7	850
2007	7.3	700
2007	2.5	250
2007	0.5	130
2007	11.3	1500
2010	0.5	80
2010	0.5	78
2010	0.5	79
2010	0.5	103
2010	0.5	90
2010	0.5	96
2010	0.5	92
2010	0.5	92
2010	0.5	74
2010	1	103
2010	0.5	93
2010	0.5	57
2010	0.5	79

	Year of plantation	n	max. Diameter [cm]	min. Diameter [cm]	mean Diameter [cm]	max. Height [cm]	min. Height [cm]	mean Height [cm]
Group 1	2007	10	11.2	3.2	5.9	850.0	350.0	580.0
	2008	7	2.6	0.5	1.4	200.0	53.0	156.9
	2009	3	0.5	0.5	0.5	200.0	78.0	134.3
	2010	3	0.5	0.5	0.5	57.0	54.0	56.0
Group 2	2007	6	11.3	0.5	5.2	1500.0	130.0	630.0
	2010	13	1.0	0.5	0.5	103.0	57.0	85.8

Carapa guianensis AUBL.

Group 1			Group 2		
Year of plantation	Diameter [cm]	Height [cm]	Year of plantation	Diameter [cm]	Height [cm]
2008	1.5	120	2007	5.9	550
2008	4.2	200	2007	3.5	400
2008	1.5	110	2007	4.5	400
2008	1.2	115	2007	2.5	200
2008	1.6	170	2007	2.1	170
2009	0.5	79	2007	3.2	300
2009	0.5	75	2007	3	250
2009	0.5	80	2008	2.8	180
2009	0.5	116	2008	3	150
2009	0.5	60	2010	0.5	82
2009	0.5	105	2010	0.5	72
2009	0.5	69	2010	0.5	117
2009	0.5	87	2010	0.5	107
2009	1.2	120	2010	0.5	85
2010	0.5	64	2010	1.1	117
			2010	1.1	101
			2010	0.5	85
			2010	0.5	93
			2010	1.1	86
			2010	1.2	96
			2010	0.5	78
			2010	0.5	73

	Year of plantation	n	max. Diameter [cm]	min. Diameter [cm]	mean Diameter [cm]	max. Height [cm]	min. Height [cm]	mean Height [cm]
Group 1	2008	5	4.2	1.2	2.0	200.0	110	143.0
	2009	9	1.2	0.5	0.6	120.0	60	87.9
	2010	1	0.5	0.5	0.5	64.0	64	64.0
Group 2	2007	7	5.9	2.1	3.5	550.0	170	324.3
	2008	2	3.0	2.8	2.9	180.0	150	165.0
	2010	13	1.2	0.5	0.7	117.0	72	91.7

Cedrela odorata L.

Group 1		
Year of plantation	**Diameter [cm]**	**Height [cm]**
2008	2	200
2008	1.1	117
2008	2.5	210
2008	6.1	350
2008	3.6	200
2008	2	114
2008	4.5	220
2008	4.6	180
2008	5.6	250
2008	4.7	200
2009	1.3	150
2009	0.5	140
2009	0.5	145
2009	1.1	150
2009	1.4	180
2009	1.8	170
2009	0.5	120
2009	1.1	170
2009	0.5	130
2009	1	152
2009	1.6	200
2009	1.2	150
2010	0.5	61
2010	1.8	150
2010	0.5	51
2010	0.5	61
2010	1	126
2010	0.5	58
2010	0.5	104

Group 2		
Year of plantation	**Diameter [cm]**	**Height [cm]**
2007	0.5	72
2007	1.7	250
2007	1.2	102
2007	1.2	160
2007	1.8	124
2007	4.6	400
2007	5.1	200
2007	7.5	500
2007	3.1	450
2008	5.5	230
2008	6	300
2008	6.7	350
2008	3.3	300
2008	5.3	200
2008	6	350
2008	5.7	300
2008	7.4	400
2008	6	250
2008	6.5	400
2008	6.4	350
2008	3.8	200
2008	2.2	230
2008	3.5	200
2008	4.6	250
2008	4.3	200
2008	5.2	300
2010	0.5	66

	Year of plantation	n	max. Diameter [cm]	min. Diameter [cm]	mean Diameter [cm]	max. Height [cm]	min. Height [cm]	mean Height [cm]
Group 1	2008	10	6.1	1.1	4.2	350	114	214.8
	2009	12	1.8	0.5	1.0	200	120	154.8
	2010	7	1.8	0.5	0.6	150	51	68.1
Group 2	2007	9	7.5	0.5	3.0	500	72	250.9
	2008	17	7.4	2.2	5.2	400	200	282.9
	2010	1	0.5	0.5	0.5	66	66	66.0

Appendix E: Complete overview of the incoming species

	F1	F3	F5a	F5b	F7	F10	F12	F15	F18	F22	F26	Σ
Annonaceae	3											**3**
Apocynaceae					1							**1**
Asteraceae											1	**1**
Bombacaceae					1							**1**
Cecropiaceae			1									**1**
Clusiaceae	2	1	1		3					1	3	**11**
Euphorbiaceae	6	5			2			1				**14**
Fabaceae	2	4	1		1	1	1	1	1	1	1	**14**
Flacourtiaceae			1	1						1		**3**
Melastomaceae	10	1		4	2	1			2	1	12	**33**
Meliaceae					1	1						**2**
Mimosaceae											1	**1**
Moraceae	1											**1**
Muntingiaceae	1											**1**
Myristicaceae			1									**1**
Piperaceae	6	5	1	3						1	2	**18**
Rubiaceae	4				1							**5**
Solanaceae		1								1		**2**
Tiliaceae				1	3		1					**5**
Unidentified			1			1						**2**
Σ	**35**	**17**	**7**	**9**	**15**	**4**	**2**	**2**	**3**	**6**	**20**	**120**