# Tree Monitoring and Growth Analysis at Cloudbridge Nature Reserve, Costa Rica

## Comparison of the growth of tropical tree species in the first three years of growth

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**Summary of Thesis**
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## Introduction

The clearing of forests on the earth's surface remains alarming[1]. However, the pace of the worldwide forest loss has decreased. As the forest areas still decreased by 8.9 million hectares worldwide between 1990 and 2000, this amount has increased in the renewal years until 2005 to 7.3 million hectares[2]. The total forest decrease is calculated by the sum of the lost areas (e.g. by clearings) and the already reforested areas. The losses by clearings amount to 13 million hectares per year. These areas are partly offset by reforestation projects so that there remains a loss of 7.3 hectares a year. From these facts the significance of reforestation projects becomes apparent.

Although Costa Rica is often considered as a Hispanic prototype country for political, social, economic and ecological reasons, even here the decline of the forests is terrifying. In the year 1990 – according to evaluations of the FAO - only 28% of Costa Rica was still forested[3]. Figure 1 shows the progress of forest destruction from 1940 to 1987.

[1] FAO-WALDBERICHT (state of the world´s forest) of 14.11.2005
[2] Ibid.
[3] FEDLMEIER, 1996

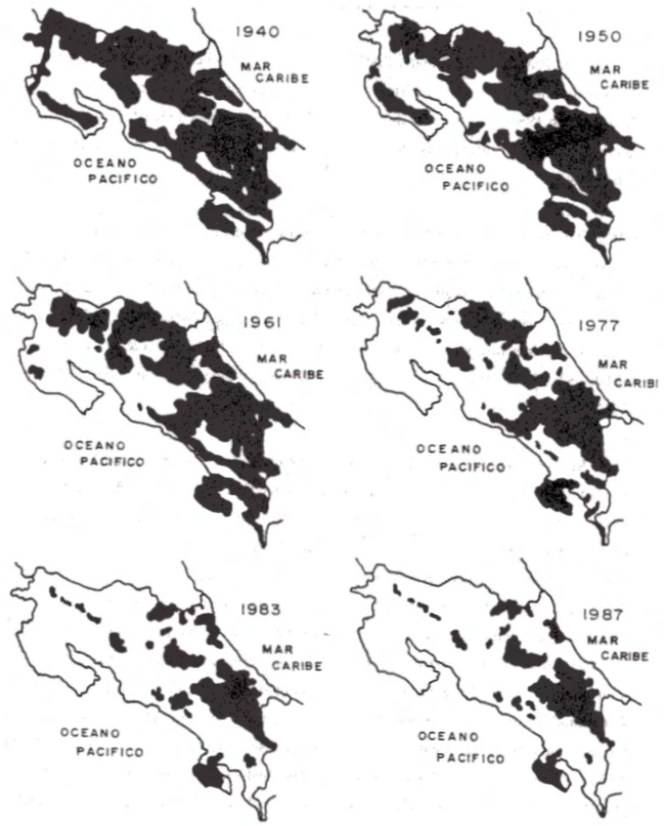


**Figure. 1:** Closed forest areas in Costa Rica, in the years 1940, 1950, 1961, 1977, 1983 and 1987 (Feldmeier 1996)

About 70 % of the wooded areas are national parks and biological reserves. Thanks to international support for private and public reforestation it became possible to reforest 1% of Costa Rica's land area in the last 15 years. But for the most part non-native forest species were used (e.g. *Tectona grandis* [L.], *Gmelina arborea*[4], *Eucalyptus deglupta*[5] and *Pinus caribaea* [L.])[6]. In a few cases attempts have been made to plant native forest species and reto generate natural forest. One opportunity to reform a nature-orientated forest is certainly to traverse the natural succession till the climax phase. However, the time period of succession is long and indefinite. Another possibility to deliberately interfere into the reforestation process and hence more rapidly reach the desired result, is

[4] ROXB.
[5] BLUME
[6] FELDMEIER, 1996

the use of reforestation plantations[7]. Native forest species are actively integrated in the disturbed areas while the natural succession takes place passively – i.e. without additional intervention. It is possible to reestablish the desired forest species with the protection of a nurse or pioneer crop.

The objective of this thesis is to examine the applicability of certain native forest species, namely *Alnus acuminata*, *Cedrela tonduzii*, *Citharexylum donnell-smithii*, *Cupressus lusitanica*, *Quercus copeyensis*, *Sapium pachystachys*, *Tecoma stans* and *Ulmus mexicana*, to regenerate of natural forests by means of plantations. For this it is essential to gain extensive knowledge about the analyzed species in regard to their growth and development. In the thesis on hand the first three growth years are examined. The analysis took place in the "Cloudbridge Nature Reserve" in the south of Costa Rica. As the revenues of harvested wood of the planted species *Alnus acuminata* and *Cupressus lusitanica* shall be used for the sourcing of the plant and maintenance of the reforestation plantations in the "Cloudbridge Nature Reserve", it will be furthermore verified if these species are appropriate to revenue-oriented cultivation in the investigation area.

The following questions arise from the thesis objective:

- Which factors have a effect on the growth and the development of the forest species?
- Are there differences regarding the growth behavior of the species with reference to the location?
- Are the forest species *Alnus acuminata* and *Cupressus lusitanica* practical for profit orientated cultivation in the investigation area? How can the growth behavior of the two species be evaluated?
- Which forest species are suitable for the predisposition of reforestation plantations in the investigation area?
- Is it possible to derive advice for new reforestation plantations from the findings of this thesis?

The above-mentioned questions give rise to the following tasks:

[7] See chapter 2.4 of Thesis

- Determination of the forest species
- Demonstration of the tree allocation of a selected area
- Recording of forest growth and yield parameters
- Acquisition of further data of the location, vitality of the trees and of collateral vegetation
- Interpretation and comparison of the recorded parameters and data with the help of statistical methods
- Categorization (site class determination) of the forest species *Alnus acuminata* and *Cupressus lusitanica*
- Suggestions for the future predisposition of reforestation plantations in the investigation area

The findings of the thesis should help to show how the choice of the location, the choice of the forest species, and or their location affects the outcome, and should as well offer some ideas for new reforestation plantations in the investigation area.

## Sites and Methods

The area of investigation was four reforestation plantation areas established in May/June 2002. On these, a full survey of the stock of trees was executed. The data basis of this thesis were the 8 tree species to be found the most often in the investigation area and identified after the stock inventory. These species are: *Alnus acuminata*, *Cedrela tonduzii*, *Citharexylum donnell-smithii*, *Cupressus lusitanica*, *Quercus copeyensis, Sapium pachystachys*, *Tecoma stans* and *Ulmus mexicana*. The basic population of the investigation amounted totally to 553 individuals.

For the estimation of the applicability of the species

for the installation of reforestation plantations the following growth parameters were determined: diameter (diameter at breast height, diameter at 65 cm tree height, diameter at stembase), tree height, crown radius and crown-commence-height. (See table below) Additionally, the ground cover surrounding the tree bole, the crown competition, the vitality of the trees, damage to the trees, the associated vegetation for which the relation to the diameter and tree height was analysed, and the inclination (slope) were recorded. After having inspected all parameters and their relation to each other, the applicability of the respective species for reforestation plantations could be clearly identified. An evaluation of the applicability of *Alnus acuminata* and respectively *Cupressus lusitanica* for an economically oriented silviculture in the investigation area was also done.

The conclusions and parameter relations were supported by regression and other statistical tests, such as analysis of variance.

| | | | | | | | | | | crown diameter: | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No.** | **Tree code** | **slope** | **ground coverage** | **competition** | **soil quality** | **drainage** | **height** | **whd** | **bhd** | **north** | **west** | **south** | **east** | **vitality** | **plantyear** |
| **1** | cl | 12.5 | 2gr | 2tr - poro | 5 | 4.5 | 4.2 | | 5.5 | 1.8 | 1.6 | 1.8 | 1.3 | 4 | 2002 |
| **2** | cl | 15 | 1gr | 1tr | 4.5 | 4.5 | 3.5 | | 5.6 | 1.1 | 1.2 | 1.4 | 1.4 | 4 | 2002 |
| **3** | cl | 20 | 1fb | 5tr - poro | 4.5 | 4.5 | 1.85 | 3 | 0.2 | 0.55 | 0.55 | 0.4 | 0.5 | 3 | 2002 |
| **4** | cl | 25 | 1fb | 5tr - poro | 4.5 | 4.5 | 2.8 | | 2.2 | 0.45 | 0.8 | 0.5 | 0.4 | 3 | 2002 |
| **5** | cl | 40 | 1fb | 5tr - poro | 4.5 | 5 | 1.5 | 1.6 | 0.5 | 0.3 | 0.2 | 0.2 | 0.15 | 2 | 2002 |
| **6** | cl | 10 | 1fb | 5tr - poro | 4.5 | 4.5 | 1.85 | | 2.6 | 0.9 | 0.9 | 0.4 | 0.7 | 3 | 2002 |
| **7** | cl | 2.5 | 2fb | 3,5tr - poro | 4.5 | 4.5 | 2.25 | | 1.6 | 0.5 | 0.4 | 0.3 | 0.25 | 3 | 2002 |
| **8** | cl | 2.5 | 1fb | 5tr - poro | 4.5 | 4.5 | 1.2 | 2.4 | 0.1 | 0.2 | 0.2 | 0.15 | 0.4 | 1 | 2002 |
| **9** | cl | 10 | 1gr,1fb | 3tr - poro | 4.5 | 4.5 | 3.4 | | 3.2 | 1.2 | 0.85 | 1.05 | 1.1 | 3.5 | 2002 |
| **10** | cl | 2.5 | 1fb | 1tr - poro | 4.5 | 4.5 | 1.7 | | 1.6 | 0.2 | 0.35 | 0.3 | 0.4 | 2 | 2002 |
| **11** | cl | 30 | 1gr | 2tr - cy | 4.5 | 4.5 | 3.2 | | 4 | 1.1 | 0.75 | 0.7 | 0.4 | 4 | 2002 |
| **12** | new tree need to be planted | | | | 4.5 | 4.5 | | | | | | | | | 2002 |
| **13** | cl | 7.5 | 1fb | 0 | 4.5 | 4.5 | 1.9 | | 2 | 0.4 | 0.5 | 0.3 | 0.35 | 3.4 | 2002 |
| **14** | cl | 2.5 | 1fb | 2tr - cy | 4.5 | 4.5 | 4.5 | | 3.8 | 1.1 | 1 | 0.7 | 1 | 4.5 | 2002 |
| **15** | cl | 2.5 | 1gr | 1tr - cy | 4.5 | 4.5 | 3.1 | | 2.9 | 0.4 | 0.45 | 0.35 | 0.1 | 4 | 2002 |
| **16** | cl | 0 | 1fb | 5tr - poro | 4.5 | 4.5 | 1.6 | 2.5 | 0.7 | 0.25 | 0.3 | 0.2 | 0.3 | 2 | 2002 |
| **17** | qc | 2.5 | 1fb | 3tr - poro | 4.5 | 4.5 | 0.19 | | | | | | | 1 | 2003 |
| **18** | cl | 2.5 | 1fb | 4tr - poro | 4.5 | 4.5 | 0.38 | 1.3 | | 0.2 | 0.2 | 0.15 | 0.15 | 2 | 2002 |
| **19** | cl | 2.5 | 1fb | 1tr - poro | 4.5 | 4.5 | 1.95 | | 1.6 | 0.6 | 0.6 | 0.4 | 0.5 | 3 | 2002 |
| **20** | new tree need to be planted | | | | | | | | | | | | | | 2002 |
| **21** | cl | 7.5 | 1fb | 4 - 5tr | 4.5 | 4.5 | 2.9 | | 2.1 | 0.8 | 0.65 | 0.3 | 0.6 | 3 | 2002 |
| **22** | new tree need to be planted | | | | | | | | | | | | | | 2002 |
| **23** | cl | 40 | 1fb | 3tr | 4.5 | 4.5 | 1.6 | | 1.6 | 0.4 | 0.3 | 0.15 | 0.25 | 2.5 | 2002 |
| **24** | cl | 10 | 0 | 3tr | 4.5 | 4.5 | 2.9 | | 2.4 | 0.9 | 0.5 | 0.55 | 0.45 | 2.5 | 2002 |
| **25** | cl | 40 | 2fb | 1 - 2tr | 4.5 | 4.5 | 2 | | 1.5 | 0.45 | 0.45 | 0.4 | 0.4 | 3 | 2002 |
| **26** | inga spp. | 7.5 | 1fb | 0 | 4.5 | 4.5 | 1.2 | 1.6 | | 0.15 | 0.2 | 0.3 | 0.25 | 3 | 2003 |
| **27** | cl | 20 | 1fb | 0 | 4.5 | 4.5 | 2.1 | | 2.2 | 0.9 | 0.8 | 0.75 | 0.9 | 4.5 | 2002 |

| | | | | | | | | | | crown diameter: | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No.** | **Tree code** | **slope** | **ground coverage** | **competition** | **soil quality** | **drainage** | **height** | **whd** | **bhd** | **north** | **west** | **south** | **east** | **vitality** | **plantyear** |
| **28** | cl | 13.599 | 2gr | 2tr - poro | 4.46081456 | 4.479845 | 1.6798 | | 1.6 | 0.44050072 | 0.34 | 0.233 | 0.3285 | 2.8835 | 2002.2023 |
| **29** | cl | 13.632 | 1gr | 1tr | 4.45674962 | 4.477087 | 1.6412 | | 1.6 | 0.42649928 | 0.32 | 0.214 | 0.3145 | 2.8786 | 2002.2114 |
| **30** | cl | 13.665 | 1fb | 5tr - poro | 4.45268469 | 4.474329 | 1.6025 | 1.49 | 1.5 | 0.41249785 | 0.3 | 0.195 | 0.3006 | 2.8737 | 2002.2206 |
| **31** | cl | 13.698 | 1fb | 5tr - poro | 4.44861975 | 4.471572 | 1.5638 | | 1.5 | 0.39849641 | 0.29 | 0.176 | 0.2867 | 2.8688 | 2002.2298 |
| **32** | cl | 13.73 | 1fb | 5tr - poro | 4.44455482 | 4.468814 | 1.5252 | 1.4 | 1.5 | 0.38449498 | 0.27 | 0.157 | 0.2727 | 2.864 | 2002.2389 |
| **33** | cl | 13.763 | 1fb | 5tr - poro | 4.44048988 | 4.466056 | 1.4865 | 1.36 | 1.4 | 0.37049354 | 0.25 | 0.138 | 0.2588 | 2.8591 | 2002.2481 |
| **34** | cl | 13.796 | 2fb | 3,5tr - poro | 4.43642495 | 4.463298 | 1.4479 | 1.32 | 1.4 | 0.35649211 | 0.23 | 0.119 | 0.2449 | 2.8542 | 2002.2572 |

## Summary and Conclusions

In this chapter the questions posed in the preamble are renewed and some conclusions are provided. In addition, several suggestions are offered for the further cultivation of the trees.

### Which forest species are suitable for the predisposition of reforestation plantations in the investigation area?

From the examination of the first three years of growth it appears that all observed species (with the exception of the species *Cupressus lusitanica* and *Tecoma stans*) turn out to be qualified for reforestation plantations in the investigation area. As the species *Cupressus lusitanica* and *Tecoma stans* are not originally native in the investigation area, planting these two species for the purpose of new reforestation plantations is discouraged.

However, the basically qualification does not state anything regarding the actual development of the forest species. The findings[8] permit conclusions on the status of development of different species and suggestions for future cultivation. The growth conditions for the species *Alnus acuminata* and *Ulmus mexicana* as well as for *Sapium pachystachys* with few exceptions attend to be optimal at present. *Sapium pachystachys* seem to be less well developed at periodically poor water-provided locations. The substandard height growth[9] for the majority of the individuals of *Sapium pachystachys* is no indication for non-optimal growth conditions due to good to very good vitality of this species.

The rest of the forest species qualified for cultivation are subject to high fluctuations concerning their growth parameters[10] and have lower vitality average values so that the growth conditions only tend to be partially suitable.

Since the majority of the trees undergo intensive insolation, and the water supply increases with raised irradiance, which is very important particularly for small plants[11], the insolation and the water supply constitute the primarily growth regulating factor.

[8] See chapter 4 of thesis
[9] Shown in chapter 4.1.2 of thesis
[10] See variation coefficient Table 8

Out of the previous findings we know that an additional amount of shade of the less well developed species benefits their growth. To create an optimal sun and shade situation, the planting of a nurse crop consisting of *Alnus acuminata* with some addition of *Sapium pachystachys* are especially practical (see more below: "Is it possible to derive advice for new reforestation plantations from the these observations?").

**Which factors have a constitutive effect on the growth and the development of the forest species?**

**Inclination (Slope)**

The inclination influences the value of the width of the crown radii for the species *Cupressus lusitanica*, *Ulmus mexicana* and *Alnus acuminata*. The crown radii of the above mentioned forest species on the north slope are the widest in a northern direction. Slower growing species do not show any connection between the crown radius and the inclination. As *Cupressus lusitanica*, *Ulmus mexicana* and *Alnus acuminata* have a relatively rapid growth, it has to be analysed in the future if there is a dependency of the inclination on the crown radius at height growth of the slower-growing species. Further findings regarding the influence of the inclination are explained in more detail in the paragraph "Are there differences regarding the growth behavior of the species with reference to the location?"

**Ground cover**

Here the arguments regarding the influence of the ground cover on the development are only significant for the individuals of the species *Alnus acuminata* and *Cupressus lusitanica* on which the ground vegetation is not removed any longer due to an increased tree height. For *Alnus acuminata*, increasing amount of ground cover has a negative influence on growth. Since there is a connection between the extent of ground cover and diameter growth, ground clearing for *Alnus acuminata* individuals higher than 2.5 meters will help achieve optimal growth results. The ground cover of *Cupressus lusitanica* needs

[11] WALDARBEITSSCHULEN DER BUNDESREPUBLIK DEUTSCHLAND, 2000

not to be removed on the predominant conditions at the investigation time. However, as LAMPRECHT (1989) states that *Cupressus lusitanica* reacts in a very sensitive way to ground covering plants and thus a removal of the ground cover in this case study would be necessary, this item should be observed further on.

**Competition in the crown**

As the tree species studied here react differently to competition in the crown, a height-based and temporal coordinated plantation of the different species should be undertaken for a new plant of reforestation plantations in the investigation area. This could be put into execution by planting a nurse crop consisting of *Alnus acuminata* with a low mixed rate of *Sapium pachystachys*.

**Damages**

Among the multiplicity of damages, the following deserve special attention: (1) the withering phenomenon of *Citharexylum donnell-smithii*, *Quercus copeyensis* and *Tecoma stans*, and (2) the impact of wind on *Cupressus lusitanica*. The first phenomenon could be ameliorated by the planting of a nurse crop. No practical measures can be taken to prevent the wind damaging of *Cupressus lusitanica*.

A third damaging factor is the infestation of *Hypsipyla grandella* and its effect the vitality and the growth of *Cedrela tonduzii*. If this is observed, the use of natural predators *Braconidae* and *Ichneumonidae* should be taken into consideration[12]. Those are already utilized successfully on pineapple and banana plantations in Costa Rica[13]. An alternative to that would be the liming of the individuals of *Cedrela tonduzii* during planting. According to NEWTON et al. (1998) the infestation by *Hypsipyla grandella* declined with increasing content of basic acting minerals in the soil.

Should the infestation of the plantation trees by leaf cutter ants (*Acromyrmex spp*., *Atta spp*.) exceed the tolerable extent of damages, according to SPEIGHT/WYLIE (2001) the only solution is seeking and destroying of the ant hives.

[12] NEWTON et al.,1993
[13] NEUES DEUTSCHLAND, 2. May 2006

An reduction of leaf fungi seems not to be efficient without the use of fungicides.

**Are there differences regarding the growth behavior of the species with reference to the location?**

In spite of a lower average rate ground cover and crown competition and less insect damages, individuals of the species *Citharexylum donnell-smithii*, *Cedrela tonduzii* and *Quercus copeyensis* planted on the slope feature a slower growth and a higher mortality rate than the individuals in the valley. All this and the additional stronger damage by insolation (withering, dry up) on the slope and the partially observed dehydration from the topsoil to the Ah-soil horizon detected during the recording of the soil profiles[14], indicate a – at least seasonal – inadequate water supply to the plants on the slopes. The shade bearing tree *Quercus copeyensis* seems to be especially susceptible to water deficiency as the vitality and the diameter increment and height increment on the slope are significantly worse on the slope than in the level areas. Therefore it is important to create a soggier microclimate especially on the slopes and to decrease the insolation intensity. This could be effected by plantating of a nurse crop on a long term basis and short-term by not cutting of shady bushes and trees of the nearby vegetation. However, an "overgrowing" of the plants, i. e. an extreme contention in the crown especially caused by the gramineous and ferns, has to be avoided.

**Are the forest species Alnus acuminata and Cupressus lusitanica practical for profit oriented cultivation in the investigation area? How is the growth behavior of the two species to be evaluated?**

Regarding their growth activities both species, *Alnus acuminata* and *Cupressus lusitanica*, would be practicable for a profit orientated cultivation in the Cloudbridge Reserve. This becomes particularly apparent during the species comparison of the basal

[14] Anlage 2 - Bodenprofil 1

area values per tree where both species by far reach the highest basal area values (see Chapter 4.1.5).

However, the damages caused by wind impact are very high for *Cupressus lusitanica*. For this reason a cultivation of this species cannot be recommended. The top height site class of IS 19 (CATIE, 1991) belongs additionally to the site classes with a moderate growth only. That is an additional reason why a cultivation of *Cupressus lusitanica* for wood production should not be attempted. The remaining individuals of *Cupressus lusitanica* should be further on cultivated and used. The cultivation of the two species consists of (1) continuing the "Plantation Monitoring Project" to be able to detect damages in sufficient time, and (2) direct silviculture measures, i.e. pruning and thinning.

As the natural self-pruning at the time of recording for *Alnus acuminata* and *Cupressus lusitanica* was not sufficient, it will be necessary to make prunings for an economically orientated cultivation of these species. For *Alnus acuminata* this is done after five to seven years according to MEZA (1971). The pruning height is 5/9 of the trees' height (MEZA, 1971) which would be an average pruning height of 4.5 m at a current mean height of 8 m. According to CATIE (1995) pruning should be adopted for *Alnus acuminata* reaching a top height diameter of 10 to 12 cm together with the first thinning. According to CATIE (1995) the pruning height should reach 40 % of the tree height, i.e. less than MEZA (1971) states. The top height diameter of individuals of the species *Alnus acuminata* examined in this thesis amounts to 12.6 cm. Thus the present pruning height of *Alnus acuminata* is ca. 3.5 m. The ultimate pruning height is about 7 m after two prunings (CATIE, 1995).

LAMPRECHT (1986) indicates that *Cupressus lusitanica* can be pruned every three years up to one third of the tree height without affecting growth. According to this basic principle a pruning should be executed at an average tree height of 6 m with an average pruning height of 2 m. The pruning is done by individual tree, in other words the pruning can only be made for individuals which reached the appropriate tree height. According to GROENENDIJK (1983) the pruning heights for *Cupressus lusitanica* at different tree heights turn out to be as follows:

**Figure 2:** Pruning heights for *Cupressus lusitanica*; Quelle: GROENENDIJK (1983)

| TREE HEIGHT [m] | PRUNING HEIGHT [m] |
|---|---|
| **5,0** | **1,5 (UP TO 1/3 OF THE TREE HEIGHT)** |
| **7,0** | **3,5 (UP TO 1/2 OF THE TREE HEIGHT)** |
| **10,0** | **5,0 (UP TO 1/2 OF THE TREE HEIGHT)** |
| **12,0 – 15,0** | **7,0 (UP TO 11 CM DIAMETER)** |
| **17,0** | **11,0 – 13,0 (UP TO 11 CM DIAMETER)** |

Thinnings have to be made for *Alnus acuminata* and for the here detected top height site class of IS 20 after four, nine and 13 years (CATIE, 1995). The thinnings constitute a mixture of quality and high thinning (CATIE, 1995). According to CATIE (1995) at the first thinning about 50 % of the individuals have to be removed.

According to CATIE (1991), for *Cupressus lusitanica* the first thinning is to be executed at an age of seven to nine years. Oppressed, badly shaped (eg twin stems[15]) or damaged individuals with a breast height diameter (DBH) of 8 to 15 cm will be removed . At age eleven to thirteen years, the second thinning takes place, where the best trees will be exposed or an unique individual allocation will be created in the area. With the latter one stems with at least a tree height diameter (DBH) of 15 cm will be removed. According to CATIE (1991), this will be repeated at tree age of 15 to 16 years (cutting cycle of 25 to 30 years). The top height site class IS 23 of CHINCHILLA (1989) forms the basis of these data.

As a result of the above set statements it can be reasoned for the further cultivation in the Cloudbridge Reserve that thinnings for *Alnus acuminata* have to be realised in 2006 for the first time and for *Cupressus lusitanica* in 2009. At this point, it has to be pointed out that both species are not closed stands but plantations with 3 rows each and a row distance of 3 m and the light competition has less influence than in other plantations. For this reason the extent of thinnings for this species should turn out minor. The main focus should be on the prunings of *Cupressus lusitanica* and *Alnus acuminata*. These prunings should be done according to the above-mentioned methods.

[15] see chapter 4.2.4 of thesis

A practicable alternative to *Cupressus lusitanica* for wood production is the cultivation of the species *Ulmus mexicana*. This one even has a faster tree height growth in the first three years than *Cupressus lusitanica* and is generally less damaged. The individuals of *Ulmus mexicana* in the Cloudbridge Reserve have a higher homogeneity concerning the height and diameter increment. The coefficient of variation of the tree height of *Ulmus mexicana* is the smallest of the whole study and amounts to 28.6 %. As the individuals of *Ulmus mexicana* partly tend to twin stem generation, "quality" thinning should be done even in the youth phase of the trees.

**Is it possible to derive suggestions for new reforestation plantations from the results of this study?**

Due to the fact that – except for the light demanders –overshading has a positive (or at least no negative) impact on the growth in the first three years, it is recommended to fall back on establishing a nurse crop with the forest species *Alnus acuminata* and *Sapium pachystachys* to regenerate the original vegetation on a reforestation plantation. The species *Alnus acuminata* has already been used several times for reforestation and regeneration of damaged forests[16]. In the Colombian Andes an attempt was made to retransform demoted areas to tropical cloud forest with the help of the forest species *Alnus acuminata*[17]. In these cases *Alnus acuminata* had a nurse crop character.

A nurse crop is defined as a former forest clearing on which fast growing pioneer tree species are cultivated[18]. The principal tree species are grown later under the protection of the pioneer tree species. As soon as the principal tree species have been regenerated safely, the nurse crop – in this case *Alnus acuminata* and *Sapium pachystachys* – will be removed bit by bit[19].

For the installation of a nurse crop on the Cloudbridge Reserve the individuals of *Alnus acuminata* with continuation of the current 3 * 3 m tree-to-tree distance and a small part of *Sapium pachystachys* in a 6 * 6 m distance could be planted. After ca. 3 years – when

[16] SCHULTE et al., 1992; CAVELIER, 1995
[17] MURCIA, 1997
[18] WALDARBEITSSCHULEN DER BUNDESREPUBLIK DEUTSCHLAND, 2000
[19] Ibid.

the nurse crop offers shade – the principal species can be planted at a distance of 6 * 6 m between the trees.

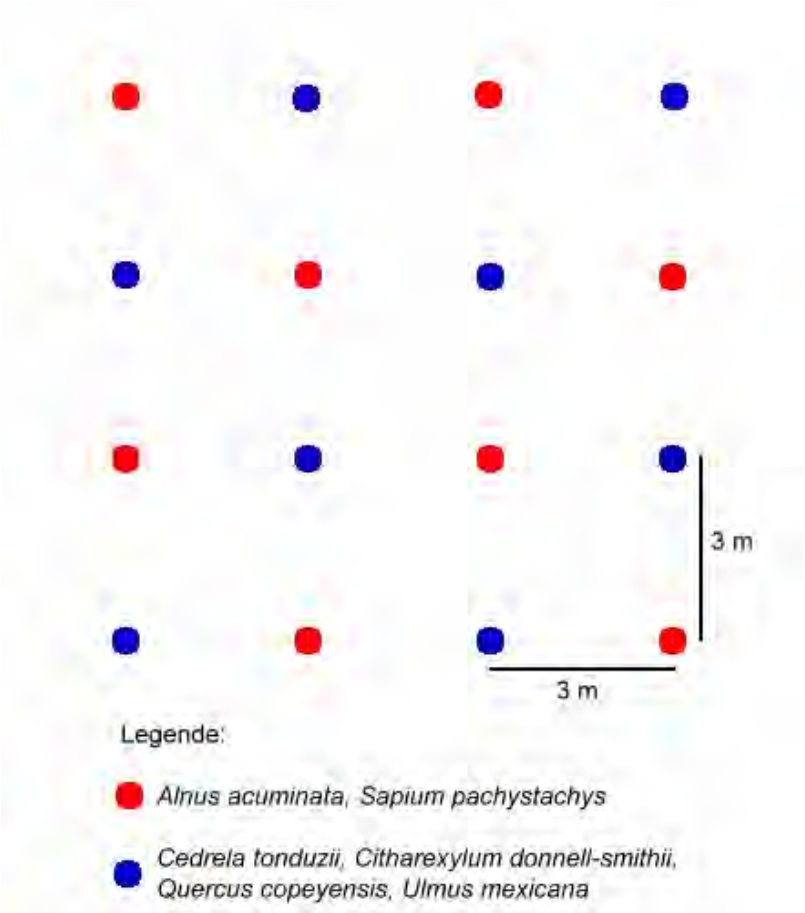


**Figure 3:** Proposal for a future species allocation on reforestation plantations in the investigation area. Red nurse crop species; Blue= principal tree species

The nurse crop will create a favorable microclimate for the principal trees. Dehydration will be reduced, especially on the slopes, and the nurse crop will protect the principal trees against heat[20]. One can expect that the decreased "dry stress" will improve the growth activities of the remaining species. Better soil conditions may result from the nitrogen fixing effects of *Alnus acuminata* [21] and the risk of slope sliding will decrease due to the increasing rooting of the soil. MURCIA (1997) as well as CAVELIER (1995)

[20] WALDARBEITSSCHULEN DER BUNDESREPUBLIK DEUTSCHLAND, 2000
[21] SCHULTE et al., 1992; CAVELIER, 1995

stated that in contrast to self-developing areas the biodiversity of the nurse crop consisting of *Alnus acuminata* is lower and the composition is different. For instance, 15% of the species of the nurse crop consisting of *Alnus acuminata* cannot be found in naturally regenerated areas. This supports MURCIA`s statement (1997) that a combination of nurse crop areas and self-generating areas (as in the Cloudbridge Reserve) brings about the highest biodiversity.

As noted, the nurse crop tree species have to be extracted after the regeneration of the principal tree species (*Quercus copeyensis*, *Ulmus mexicana*, etc.). Continued growth of the nurse crop could even have negative effects on the biodiversity as *Alnus acuminata* can have allelopathic impact on several species of the undercrop (CAVELIER, 1995). For this reason, the removal of the nurse crop tree species in sufficient time is important.

After the successful regeneration of the principal tree species the cultivation and protection measures should also be stopped, so that species typical for the habitat can establish themselves on the plantation and this way the biodiversity required for the natural habitat “cloud forest” will be achieved.

**Author's Comments**

I hope that with the help of this thesis I can contribute a part to the protection and reforestation of the last relic of "cloud forest" in Costa Rica. Active protection and reforestation constitute two important factors for the preservation of this unique forest type which is habitat to a multitude of animal and plant species. The value of preservation is not only defined by the uniqueness of this area of unspoiled nature, it is also basis for the eco-tourism which is an important economic factor in Costa Rica -- and particularly in the region of San Gerardo de Rivas, serving as a major part of the residents' income. Reforestation efforts are gaining a wide base of support among the inhabitants in Costa Rica – perhaps a sign of a reversal of the trend toward the destruction of the tropical forest. Tropical forest protection is only meaningful if – like occurred in this case study – the protection of the forest accompanies with the maintenance and amelioration of the living standards, e.g. by providing employment.

**About the Author**

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