SYLVICULTURE IN THE DRY DENSE FOREST OF WESTERN MADAGASCAR

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Résumé: Sylviculture en forêt dense sèche

Cet article synthétise 15 ans d'expériences sylvicoles du Centre de Formation Professionnelle Forestière (CFPF) de Morondava en forêt dense sèche de l'ouest de Madagascar. Les différentes techniques sylvicoles testées et mises au point ont pour but de reconstituer ou d'augmenter le potentiel producteur de bois d'oeuvre. La sylviculture proprement dite, suit l'exploitation et utilise une partie des infrastructures de débardage (layons, places de dépôt, etc.).

Quatre techniques sylvicoles peuvent être utilisées seules ou combinées: la régénération naturelle, la régénération artificielle par plantation, la régénération artificielle par semis direct, et l'amélioration de peuplement.

La régénération naturelle est la technique la plus souhaitée pour des raisons écologiques et économiques. Mais son obtention dépend de la station (notamment du sol et de ses réserves en eau), de la lumière et bien sûr des espèces. Malheureusement, peu d'espèces commerciales se régénèrent bien. D'où la nécessité de recourir à la régénération artificielle pour pallier les déficiences sur certaines stations d'un bon nombre d'essences.

La régénération artificielle par plantation d'espèces autochtones donne de bons résultats avec des plants à racines nues mis en terre en pleine saison sèche (juin-août). Sur les 25 espèces testées, sept sont couramment utilisées en plantation aussi bien dans des layons que dans des trouées (méthode similaire aux placeaux Anderson) et même en plein. D'autres essences pourront s'ajouter progressivement à ces sept espèces quant leurs problèmes spécifiques seront réglés. Malheureusement, la plantation est une technique onéreuse à cause surtout du coût de production des plants et de certains entretiens. La plantation dans des trouées semble la technique la plus prometteuse et peut être vulgarisée.

La régénération artificielle par semis direct n'a été testée qu'avec huit espèces, dont deux donnent des résultats satisfaisants. Elle est en cas de réussite beaucoup moins coûteuse que la plantation.

L'amélioration de peuplements, qui consiste en des éclaircies sélectives pour donner plus de lumière à des tiges d'avenir d'essences recherchées, n'a été testée qu'avec trois espèces. Les Arofy (*Commiphora guillaumini* et *C. mafaidoha*) ont une croissance en diamètre qui double pour les tiges des étages intermédiaires et inférieurs, alors que le Hazomalany (*Hazomalania voyroni*), essence sciaphile, ne réagit pas à l'éclaircie. En extrapolant ces résultats aux essences commerciales, ce type d'intervention ne semble pouvoir s'effectuer malheureusement que dans de rares peuplements particulièrement riches en tiges de diamètres moyens (au moins 100 tiges/ha).

En abrégé, un schéma décisionnel en fonction des stations est proposé pour le choix des techniques sylvicoles à utiliser.

En conclusion, la reconstitution et même l'amélioration de la forêt dense sèche après exploitation semble possible. Certaines interrogations demeurent quant au temps de rotation entre deux coupes d'exploitation qui serait compris entre 60 et 120 ans, ce qui donnerait une productivité de 0,05 à 0,1 m^3/ha/an de bois d'oeuvre.

Un autre problème est l'application de ces résultats dans la pratique des exploitants. Seuls deux exploitants appuyés par le CFPF ont commencé timidement des plantations aprés exploitation. Quelques propositions sont faites pour stimuler la réalisation de travaux sylvicoles en forêt naturelle.

Abstract

Fifteen years of sylviculture in the dry deciduous forest of western Madagascar is summarized, consisting of techniques aimed at restoring or increasing wood production after timber exploitation of the natural forest. Four approaches were taken: natural regeneration, planting, sowing, and improving growth conditions for economically valuable species by clearing or thinning the surrounding vegetation.

Natural regeneration of economically valuable species is too poor to allow sustainable timber exploitation. Artificial regeneration works best with seedlings planted during the dry season (June-August). Seven out of 25 species tested yield satisfying results when planted along logging trails, clearings, or even in the open. Plantation in clearings seems the most promising. Unfortunately the production of saplings and their maintenance after plantation in the forest is time consuming and expensive. Direct sowing has been tried only with eight tree species. Two of them yielded satisfying results at much lower costs than with plantation of saplings. Improving growth conditions by clearing the surrounding vegetation has been assessed with three species. *Commiphora guillaumini* and *C. mafaidoha* of small and intermediate size (< 25 cm diameter at breast height) double their growth rate after clearance of the surrounding vegetation. This, however, has no effect on *Hazomalania voyroni*, a shade-tolerant species. Also, it is economic only in areas with very high densities (> 100 stems/ha) of medium-sized trees.

From a sylvicultural point of view, restoration and improving the timber value of the forest after exploitation seems possible. However, given the time period of 60 to 120 years needed for full restoration between cuts (equivalent to 0.05-0.1 m^3 exploitable timber/ha/year) the question of sustainability remains. Another problem is the application of the sylvicultural knowledge by local concession holders.

1. Introduction

Sylvicultural research on the dry dense indigenous forest on the west coast of Madagascar in the region of Morondava was started according to western standards in 1978 with the creation of the Centre de Formation Professionnelle Forestière (CFPF) at Morondava. Consequently, compared to the dynamics of this type of forest, the results presented in this article cover only a relatively short period of time.

Sylviculture obviously depends on the natural conditions and the way in which the forest is actually exploited. Apart from serving as resource for agricultural land, the natural forests are mainly used for timber exploitation and subsistence alimentation (FAVRE, 1996; GENINI, 1996; RAONINTSOA, 1996). The impact of the latter type of utilization seems negligible in comparison to the deforestation (i.e., irreversible destruction of the natural forest) and the exploitation of timber (selection of only a limited number of tree species and thus modification of the structure and composition of the natural forest). In the present context, sylviculture aims to restore and, if possible, increase the timber after exploitation and is therefore primarily concernde with commercial timber species.

2. Infrastructures for exploitation

Since its creation, the CFPF has exploited more than 60 different tree species with 15 to 25 species per 100 hectare bloc. Only 4 to 15 m^3 (i.e., 6 to 20 trees) are taken per hectare (CFPF, 1978 - 1990). The infrastructure for timber exploitation includes: secondary dirt roads for timber

trucks, forest depots for the round timber before it can be loaded onto the trucks, and hauling tracks and trails to transport the timber from the site of felling to the forest depot.

Two types of exploitation have been applied (Fig. 1; Table 1):

- a semi-mechanized method using a forest tractor equipped with a cable winch that drags out the logs with a cable and then hauls them on a logging road 4 m wide (RAKOTONIRINA, 1987).
- a manual method using logging wheels and four zebus that transport each log from the site of felling to the forest depots. For this, trails 2.5 - 3.5 m wide are cut from the secondary dirt road directly to the felled trees. In contrast to the regular hauling tracks of the former method, non-exploitable big trees are left when cutting the narrower trails for the zebus (WYSS, 1990).

Table 1: Surface requirements (in %) of various infrastructures needed for semi-mechanized and manual timber extraction.

	Semi-mechanized	Manual
Secondary dirt roads (2 x 1000 m x 6 m)	1.2	1.2
Forest depots (20 x 20 m x 20 m)	0.4	0.4
Hauling tracks (40 x 220 m x 4 m)	3.5	
Trails (1-3 m wide, variable length and numbers)		≈ 5.2
Total surface requirements of infrastructures	5.1	6.8

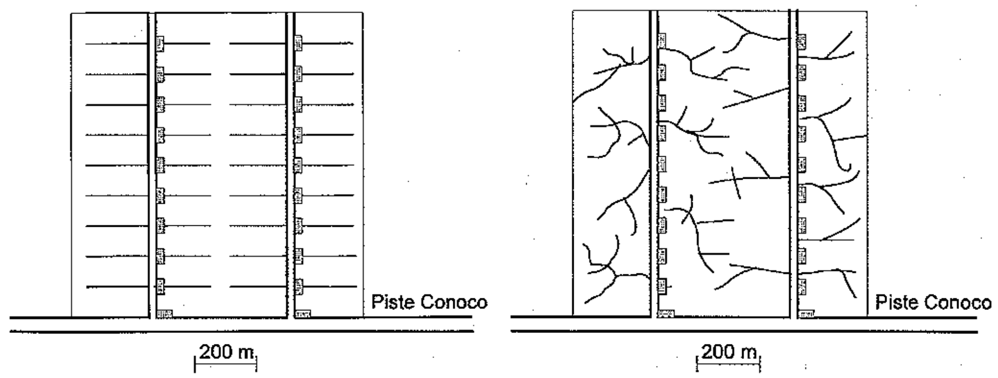

Fig. 1: Infrastructures installed for semi-mechanized and manual logging. The fine line marks the boundary of the forest bloc and does not represent trails. Shaded rectangles = forest depots

Timber extraction with logging wheels and zebus have higher surface requirements, but the trails are narrower than the hauling tracks, therefore less illuminated, and may thus represent smaller lines of disturbance for the forest ecosystem than semi-mechanized logging. The sylvicultural activities applied to restore the forest mainly use these infrastructures created by exploitation. In both methods, the secondary dirt roads are left unchanged for future access and supervision of sylvicultural work. Since manual exploitation only started in 1990, most of the sylvicultural work reported here has been carried out on infrastructures used by semi-mechanized logging.

3. Sylvicultural techniques

Four principal sylvicultural techniques can be applied alone or in combination for the reforestation after exploitation (DELEPORTE, 1989a):

- natural regeneration
- artificial regeneration by planting
- artificial regeneration by sowing
- improving growth conditions for timber species by clearing and thinning of the surrounding vegetation.

3.1 Natural regeneration

Natural regeneration is the most preferable option, because it requires little effort and recreates a rather diverse array of species which are well adapted to the site. Unfortunately many factors which cannot be controlled as yet, limit the economic value of natural regeneration (e.g., low density of economic timber species and economically unfavourable composition of the tree species community). The forest regenerates naturally either through seeds, shoots or even suckers (RAKOTONIRINA and PRELAZ, 1982). We are primarily interested in seeds as the most important method of forest regeneration, keeping in mind, however, that certain species, such as *Cordyla madagascariensis* or *Dalbergia* spp., mainly reproduce asexually.

The main factors influencing natural regeneration by seeds are (HUNZIKER, 1982):

- density of parent trees and their fruit production
- period of germination capacity of the seeds
- seed predators
- potential of seed dispersal
- climatic conditions (primarily the amount of rain required for germination and growth during the first vegetation period)
- soil and its water resources for germination and juvenile growth
- surrounding vegetation competing for water and light.

Some factors such as the density of parent trees, competing vegetation, light (and indirectly the microclimate), and to some extent the soil can be modified artificially. Consequences of such modifications can be complex and may show up only after long periods of time, especially in tropical dry forests (LAMPRECHT, 1986). The CFPF has not yet had the possibility to study all these factors and their interactions systematically. Studies were restricted to seed bearers and seed dispersion, competing vegetation, soil, and light conditions.

3.1.1 The influence of seed bearers

Quality, diversity, and number of seed bearers depend on site characteristics. They are modified primarily by exploitation. In most cases these modifications are rather negative

(LAMPRECHT, 1986), reducing the number, the diversity, and also the quality of the seed bearers by cutting systematically only some species or by choosing only the best individuals. On the other hand, exploitation, particularly creating infrastructures, can also have a positive influence since it enhances sun exposure of seed bearers which then flower and bear more fruit (GANZHORN, 1995b).

Potential or real seed bearers are difficult to identify. Generally, trees of the upper level [diameter at breast height (DBH) > 25 cm] can all be considered as potential seed bearers if they are also female for the dioecious species. Certainly there are also smaller-sized species of commercial interest, such as *Dalbergia* spp., which reach maturity while still belonging to the intermediate stratum.

Regeneration has been studied in relation to the presence of seed bearers within a radius of 25 to 50 m around the area to be regenerated. There are positive correlations between the presence of seed bearers and regenerating seedlings for some species but not for others (RAKOTONIRINA and PRELAZ, 1982; RAVOSOA, 1986). Based on these correlations tree species can be classified in six categories (FELBER, 1984). Some species are assigned to two different categories.

1st category: numerous seed bearers and abundant regeneration:
Dalbergia chlorocarpa, D. greveana, and *Grewia cyclea*

2nd category: species with limited dispersal ability:
Berchemia discolor, Breonia perrieri, Clerodendrum sp., *Commiphora* spp., *Foetidia asymmetrica, Hazomalania voyroni, Poupartia sylvatica,* and *Zanthoxylum* sp.

3rd category: species with far-ranging dispersal ability:
Apaloxylon tuberosum, Colubrina decipiens, Colvillea racemosa, Fernandoa madagascariensis, Givotia madagascariensis, Hymenodictyon decaryanum, Neobeguea mahafaliensis, Stereospermum euphorioides, and *Terminalia mantaliopsis*

4th category: numerous seed bearers, but little regeneration:
Cedrelopsis grevei, C. microfoliolata, Commiphora guillaumini, and *Securinega seyrigii*

5th category: average number of seed bearers but little regeneration:
Capurodendron mandrarense, Cordyla madagascariensis, and *Neobeguea mahafaliensis*

6th category: few seed bearers and little regeneration:
Albizia boivini, A. greveana, A. tulearensis, A. sp., *Broussonetia greveana, Apaloxylon* sp., *Cordia* sp., *Gyrocarpus americanus, Hazomalania voyroni, Quivisianthe papinae, Rhus perrieri, Securinega perrieri, Stadmania oppositifolia, Stereospermum* sp., and *Tetraptrocarpon geayi*

Species of the first category are almost always present and very often those of the third category are also found in natural regeneration. Species of the second category will be present if there are seed bearers close to the area to be regenerated. Those of the categories four and five are rarely present and those of category six are almost always absent.

Exploitation should therefore leave:

- some seed bearers of species belonging to categories one and three per hectare
- about 10 seed bearers of the species of category two per hectare
- for species of the categories four and five regeneration could not be linked to the number of seed bearers; other, unidentified factors intervene. Given their poor regeneration it may be important to keep a large number of seed bearers.
- of the species belonging to category six only fully grown or dying trees should be felled.

3.1.2 Influence of the soil

Water capacity of the soil is among the main factors determining regeneration success (FELBER, 1984; HUGUES, 1986). Well aerated soils with the largest water reserves (well structured, clayey soils) house the densest and most diversified regeneration. Thus it is evident that topography (BOURGEAT, 1990) and even microtopography play an important role in the natural regeneration (ABRAHAM, 1985; RAKOTONIRINA, 1996). The soils at the bottom of a slope and of a ravine are most favourable for high diversity of regenerating species (Table 2).

Table 2: Mean number of stems per hectare of natural regeneration in forest depots in relation to soil and topography. The numbers in brackets are mean number of tree species.

Topography	Soil	Number of 400 m² plots	Number of years since the creation of the infrastructure				
			1	2	3	4	6
Plain	unleached ferruginous red	8			2 100 (13.0)		3 425 (19.0)
Plain	unleached ferruginous yellow	3	2 533 (6.0)	2 125 (6.2)	3 083 (6.0)	3 525 (5.8)	
Plain	leached ferruginous yellow	4	850 (4.5)	1 075 (4.5)	1 725 (5.0)	1 500 (4.5)	
Top of slope	leached ferruginous yellow	4	3 270 (7.3)	4 680 (9.1)	5 275 (8.6)	5 730 (8.6)	
Middle part of slope	ferruginous yellow compressed and deep	3	5920 (10.1)	7764 (11.4)	10090 (11.5)	7782 (11.6)	7546 (10.9)
Foot of slope	ferruginous yellow compressed and deep	3	4 560 (11.3)	5 200 (14.3)	5 147 (13.7)	5 133 (14.3)	4 907 (12.7)
Valley	Poorly developed on recently alluviated uninundated land	5	1 116 (10.3)	1 040 (10.0)	1 153 (10.0)	1 037 (9.0)	1 160 (10.7)
Valley	vertisols	3	1 075 (3.2)	1025 (4.0)		1025 (3.0)	

Based on density as well as the number of regenerating species the different soils can be classified into three categories:

Favourable soils
- ferruginous red soils containing a high proportion of clay
- compact, deep, yellow ferruginous soils
- poorly developed soils on recently alluviated land that is rarely inundated

Average soils
- soils of greenish character and vertisols
- poorly developed soils on recently alluviated land that is often inundated
- ferruginous leached soils
- ferruginous unleached soils

Unfavourable soils
- rankers
- poorly developed podzolic soils
- ferruginous leached podzolic soils

Soils of the first category are often found along watercourses but are rarely inundated. With respect to exploitable timber volume and tree species composition, they contain the commercially most interesting populations. Unfortunately they represent only a small part of the surface area of the CFPF forestry concession (8 to 10 %) as well as of the region in general. Regeneration is assured if other factors like competing vegetation can be controlled. Natural regeneration on these soils is dense and diverse.

The second category of soils covers the largest area of the forestry concession. These forests are exploitable even though the yield is low (4 to 8 m³/ha). Nevertheless they contain many species of commercial interest. Regeneration on these soils is uncertain and not very diverse. Forest on the last soil category is not exploited since it contains only very few economically valuable tree species with very low exploitable timber volume.

Up to now, regeneration patterns on different soils could neither be linked to chemical soil properties such as pH, the amount of organic substances, or nitrogen content (FELBER, 1984; HUGUES, 1986), nor to the depth of litter layer as a potentially inhibiting factor. Also slight scratching of the seed with a hook did not improve germination success (RAKOTONIRINA and PRELAZ, 1982).

3.1.3 Influence of competing vegetation and light

Light has little effect on germination but profound consequences for the survival of seedlings (BEZZOLA, 1984; RAZAFINDRANDIMBY, 1991). The same number of seedlings younger than 1 year (2000 to 3000/ha) has been counted in closed forest as well as on its edge and in full light. But their survival rate in full light or on the forest edge is much higher with 4900 and 4500 seedlings/ha older respectively, than 1 year compared to 900 seedlings/ha in closed forest. Thus, the installation and survival of natural regeneration of commercial species mainly takes place in relatively well illuminated areas. This agrees with observations in the tree nursery which show that the majority of the commercial species is heliophil from their youth on.

The best dimensions of the areas to be regenerated are 5 m wide and east-west oriented (Table 3). Longish areas instead of squares seem to be preferable because they have a relatively larger perimeter which allows a better "interception" of seeds.

Table 3: Effects of the width of dirt roads on the number of stems per hectare, the number of species, and the average growth in length per year measured at the age of six years.

Width of dirt road (m)	Stems/ha	Number of species	Average growth in height (cm) per year
3	20 757	26.5	25.5
5	18 647	23.5	40.0
7	15 519	20.0	39.0

As a rule of thumb, the best regeneration and good growth is obtained if the relative light intensity on the ground in the middle of the regenerating area is between 20 and 40 % of the illumination in full sunlight (CATINOT, 1965). For the best regeneration the shape and dimensions of the openings (forest depots, dirt roads, or gaps in the stand) depend on their direction and on the structure of neighboring stands of trees (height, density of the leaves). These dimensions are estimated as follows:

- 4 to 8 m wide and at least 15 to 25 m long according to the height and the density of the population for gaps that are east-west oriented;

- 5 to 10 m large and at least 20 to 30 m long for north-south oriented openings.

Naturally, i.e., without human intervention, these dimensions are rarely obtained except in areas of larger windfalls or after the fall of a big baobab. The gaps created by felling are equally insufficient because their surface areas rarely exceed 50 m^2 and are more often close to 20 m^2. Only a few seedlings of commercial species grow in these areas.

However, light does not just have positive effects. It provokes the installation and growth of competing vegetation, (bushes, vines, and especially herbs, particularly grass), even more if the spot is rich (many prickly vines or bamboo). These herbs cover the sunny area and can suffocate or prevent the regeneration of the desired species. Especially on rich soil, it is therefore necessary to weed the area during the first years. This is supported by the observation that economically interesting species appear only during the first three years after creation of gaps. Afterwards, few new seedlings are added to the population (Table 2).

3.1.4 Growth of natural regeneration

Depending on light and soil conditions, growth of the same species can differ widely. Interspecific competition within the area of natural regeneration accentuates the difference between species with slow and rapid growth. If sufficiently dense (> 2500 stems/ha, main height: 3 - 6 m), the natural regeneration progressively shows stratification after five years. Table 4 lists the growth of species frequently found in natural regeneration. The growth of *Commiphora guillaumini*, *C. mafaidoha*, and of *Cedrelopsis grevei* is particularly weak. Growth of *Givotia madagascariensis*, *Grewia cyclea*, *Colvillea racemosa*, *Colubrina decipiens,* and *Terminalia mantaliopsis* is high with annual increments in height of more than 1 m.

Table 4: Annual increase in height for some species in natural regeneration and after planting, measured at seven years of age.

Species	Increase in height per year (cm)		Height at 7 years (m)	
	Natural regeneration	Planted	Natural regeneration	Planted
Broussonetia greveana	20 - 60	20 - 60	4.0 - 6.0	4.0 - 6.0
Colubrina decipiens	30 - 100	30 - 70	3.0 - 6.0	3.0 - 5.0
Colvillea racemosa	50 - 150	40 - 150	5.0 - 8.0	5.0 - 7.0
Commiphora guillaumini	0 - 20	20 - 40	0.2 - 1.0	2.0 - 3.0
Commiphora mafaidoha	10 - 50	30 - 50	1.0 - 3.0	3.0 - 4.0
Cedrelopsis grevei	5 - 50		0.5 - 3.0	
Dalbergia spp.	15 - 75		1.0 - 5.0	
Fernandoa madagascariensis	10 - 60		1.0 - 4.0	
Givotia madagascariensis	50 - 150		4.0 - 8.0	
Grewia cyclea	30 - 100		2.0 - 7.0	
Poupartia sylvatica	20 - 75		2.0 - 5.0	
Terminalia mantaliopsis	50 - 100		4.0 - 6.0	
Zanthoxylum sp.	20 - 60		2.0 - 4.5	
Cordyla madagascariensis		25 - 60		3.0 - 4.0
Gyrocarpus americanus		20 - 50		2.5 - 3.5
Hazomalania voyroni		5 - 30		
Neobeguea mahafaliensis		25 - 45		2.5 - 3.5

3.1.5 Work requirements

Work requirements do not account for establishing the infrastructures, since they are required for exploitation. The schedule and time required to promote natural regeneration are listed in Table 5. Widening of dirt roads is most time consuming among the various activities, taking up about 45 % of the total time during the first seven years. The first cleaning operations require a specialised worker who can identify the young seedlings of the desired species.

3.1.6 Conclusions

Since light is one of the prime factors for the installation and growth of commercial species (see 3.1.3), the only method allowing sufficient natural regeneration consists of total clearing of a small forest plot. In order to minimize costs, it is preferable to use the hauling infrastructures (forest depots and dirt roads) instead of clearing new areas around seed bearers.

Soil type and the water supply are also important components. The most promising regenerations are found in the middle and at the foot of slopes and in valleys on uninundated soil. These sites are some of the richest in yield and species diversity. Unfortunately, these favourable sites represent only a small proportion of the surface (about 10 %) of the forest of the CFPF.

Many other factors influence the success of regeneration such as rainfall, the population surrounding the regenerating area (especially the density of the seed bearers) and the fauna which can have positive, but also rather negative effects on natural regeneration (BAUM, 1996; BÖHNING-GAESE et al., 1996; SCHARFE and SCHLUND, 1996; DU PUY, 1996).

Table 5: Number of man-days required for maintenance of a 100-ha plot in order to promote natural regeneration during the first seven years; surface area per 100 ha: 4000 m^2 forest depots; 37000 m^2 hauling tracks.

Operations	Year	Forest depots	Hauling tracks.
Cleaning	1	2.4	22.2
Cleaning	2	2.4	22.2
Widening of dirt roads from 4 to 6 m	3 or 4		122.1
Cleaning: removal of vines	4	4.8	44.4
Cleaning: removal of vines or thinning	7	4.8	44.4
Total per type of infrastructure		14.4	255.3
Total per 100 ha		269.7	

3.2 Planting trees

Planting of saplings has been the main type of afforestation applied since the creation of the CFPF in 1978. It is supposed to compensate for weak natural regeneration and is applied at sites where natural regeneration has little chance of establishing itself, such as on average soils (see 3.1.2), or when two years after exploitation regeneration is considered insufficient. The sites used for plantation are essentially the same infrastructures as used for hauling.

The plantation studies focussed on five main issues:

- choice of species
- period of plantation
- type of plants
- the soil
- light (type of exploitation infrastructure).

Other studies and experiments have been conducted in order to solve specific problems, i.e., protection against predators or the planting of wildlings.

3.2.1 Selection of species

In the beginning, research concentrated on *Commiphora guillaumini* and *C. mafaidoha* because they represent about 80% of the exploited timber volume but show poor natural regeneration. Further experiments focussed on *Cordyla madagascariensis*, *Neobeguea mahafaliensis*, *Gyrocarpus americanus*, *Broussonetia greveana*, and *Hazomalania voyroni*. The latter species is considered to be endangered, even though it is not exploited by the CFPF (RANDRIANASOLO et al., 1996).

Over a total of 13 years, plantation experiments were performed with more than 25 species. Three species were exotic to Madagascar (*Gmelina arborea, Khaya senegalensis,* and *Tectona grandis*) and one exotic to the forest of the CFPF (the Ramy: *Canarium madagascariensis*), though it is found in some riverine forests of the west coast. The exotic species have now been totally abandoned for plantation in natural forest, as they are poorly adapted to local conditions due to their high mortality, weak growth, and being prone to assaults by predators (wild zebu). Exotic species like *Eucalyptus, Cassia,* and *Casuarina* are reserved for plantations outside the forest.

The possibility for plantation of native species evidently depends on the productivity of the nursery even though for some species it is possible to use saplings collected in the forest (RANDRIANASOLO et al., 1996). At present, plantations concentrate on species with high initial growth rates or (and) the species with timber qualities that can not be substituted. Seven species are commonly used in plantation: *Broussonetia greveana, Colvillea racemosa, Commiphora guillaumini, C. mafaidoha, Gyrocarpus americanus, Hazomalania voyroni,* and *Neobeguea mahafaliensis.*

Other species could be planted more often if some specific problems could be solved, such as germination in the nursery, knowledge about the appropriate time of planting, best characteristics of the transplant, or protection against predators in the forest. Among these species are: *Colubrina decipiens, Cordyla madagascariensis, Dalbergia* spp., *Givotia madagascariensis, Poupartia sylvatica, Stereospermum euphorioides, Terminalia mantaliopsis,* and *Zanthoxylum* spp..

3.2.2 The plantation period

Initially, seedlings were planted at the beginning of the rainy season in January. These plantations almost always completely failed. This can now be attributed to several reasons, of which the quality of the transplant and the date of planting are the most important. After a successful test with three species planted in August 1981, plantations were made more and more systematically during the dry season in July and August.

Table 6 shows the survival of some species two or three years after planting. For most species the beginning and the middle of the dry season are the most favourable plantation periods. Also plantating at that time of year achieved the best growth rates. It seems, that some species, like *Commiphora mafaidoha,* can be planted all year round. The period of leaf flush (January-March) is unfavourable for planting. The fact that the majority of the planted species do better in the dry season can be explained by the development of the roots before leaf flush. This insures better balance between water supply and the increased evapotranspiration after leaf flush.

Some species keep their leaves to some extent during the dry season in the nursery, e.g., *Hazomalania voyroni, Capurodendron mandrarense,* or *Poupartia sylvatica.* They do not tolerate transplantation at any time of the year even if the transplant is defoliated. Bare-rooted planting is perhaps not the best method for these species, bag planting should be tried.

Table 6: Survival rate (%) after two or three years in relation to the time of plantation.

Species	Dry season (July - Sept.)	End of dry season/start of rainy season (Oct.-Dec.)	Rainy season (Jan. - Mar.)	End of rainy season/start of dry season (April-June)
Broussonetia greveana	90 - 100		77	
Capurodendron mandrarense	0			
Colubrina decipiens			77	
Colvillea racemosa	80 - 90		37	
Commiphora guillaumini	80 - 90	70	42	
Commiphora mafaidoha	98	97	97	96
Cordyla madagascariensis	80		58	
Gyrocarpus americanus	92	74	83	
Hazomalania voyroni	67		42	
Neobeguea mahafaliensis	70 - 90	66	25	85
Poupartia sylvatica	5		40	

3.2.3 Type of transplant

The quality of the transplants (Table 7) is one of the most important factors for successful plantation. Most of the transplants were bare-rooted. Roots such as of *Commiphora* spp. are generally well developed in comparison to the parts above ground. Certain species even develop tubers or voluminous bulbs (e.g., *Neobeguea mahafalensis*) that hardly fit into the standard plastic bags.

Table 7: Characteristics of good transplants. H = total height of transplant (cm), DGL = diameter at ground level (mm).

Species	H	DGL	Best transplants
Broussonetia greveana	> 60	> 8	H > 100
Colvillea racemosa	> 20	?	?
Commiphora guillaumini	> 50	> 15	100 < H < 125 25 < DGL < 32
Commiphora mafaidoha	> 60	> 7	70 < H < 140 12 < DGL < 25
Cordyla madagascariensis	> 40	?	DGL > 15; H > 125
Gyrocarpus americanus	> 50	> 15	?
Hazomalania voyroni	> 30	> 15	30 < H < 70 15 < DGL <30 1 < H/DGL < 3
Neobeguea mahafaliensis	> 25	?	?

The height of the sapling, its diameter measured at ground level, and the ratio of height to diameter are suitable parameters for the assessment of the quality of a plant. Especially the diameter at ground level is one of the most important parameters because it reflects the condition of the roots. The absorption of water depends on the condition of the roots which is a prepondering factor for the growth of the young transplants. The minimum and optimum dimensions were established on the basis of the growth rate and growth during the first two or three vegetation periods. The characteristics vary between species. For species forming tubercles, one has to make sure that they are turgescent at the time of transplantation.

It is possible to use wildings for some species. *Givotia madagascariensis* which hardly germinates in the nursery can be planted by this method with a success rate of 90 %. On the other hand, *Zanthoxylum* spp. does not grow as well because damaged transplants are attacked by termites.

3.2.4 The soil

Table 8 lists the favourable and unfavourable types of soil for the growth of certain species. Species such as *Commiphora guillaumini*, *C. mafaidoha*, *Cordyla madagascariensis*, and *Givotia madagascariensis* are very flexible, while others, such as *Broussonetia greveana*, *Colubrina decipiens*, *Hazomalania voyroni*, and *Neobeguea mahafaliensis* have more specific requirements. Figure 2 illustrates different growth patterns on different types of soil for two of these species.

Table 8: Favourable and unfavourable types of soil for different species.

Species	Favourable soil	Unfavourable soil
Broussonetia greveana	ferruginous compressed, deep; poorly developed, on recently alluviated land rarely inundated	ferruginous, unleached; podzolic tendance
Colubrina decipiens	inundated, vertisols; ferruginous, red, much clay; ferruginous, compressed, deep; poorly developed on recent alluviations	ferruginous, unleached; podzolic tendance
Colvillea racemosa	ferruginous, unleached, sandy	inundated, vertisols
Commiphora guillaumini	ferruginous, unleached or leached	inundated, vertisols
Commiphora mafaidoha	ferruginous, unleached	inundated, vertisols
Cordyla madagascariensis	ferruginous, unleached or leached	inundated, vertisols
Dalbergia sp.	ferruginous, red, containing clay; ferruginous, compressed, deep	inundated, vertisols; podzolic tendancy;
Givotia madagascariensis	inundated, vertisols; ferruginous, red, containing clay; ferruginous, compressed, deep; poorly developed on recent alluviations	podzolic tendancy

Species	Favourable soil	Unfavourable soil
Gyrocarpus americanus	ferruginous, red, containing clay; ferruginous, compressed, deep; poorly developed on recent alluviations; alluviated land rarely inundated	ferruginous, unleached; podzolic tendance
Hazomalania voyroni	ferruginous, red, containing clay; ferruginous, compressed, deep; poorly developed on recent alluviations; alluviated land rarely inundated	inundated, vertisols; ferruginous, unleached; podzolic tendance
Neobeguea mahafaliensis	ferruginous, unleached	inundated, vertisols; ferruginous, compressed

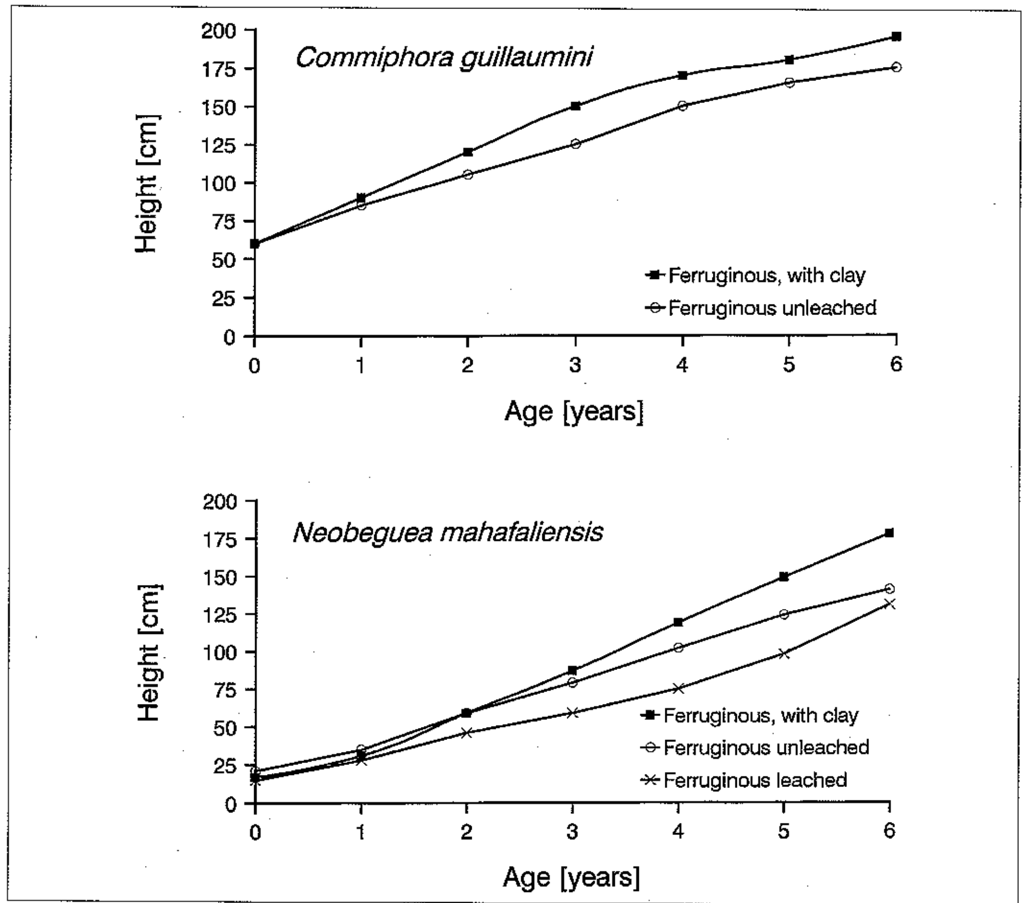

Fig. 2: Growth of planted trees in relation to types of soil; *Commiphora guillaumini*; *Neobeguea mahafaliensis*; three replica per type of soil, 90 plants per replica.

3.2.5 Light

As described above (3.1.3) many of the commercial species are heliophile in the forest as well as in plantations. It is nevertheless possible to plant these species also at sites where they would not apparently regenerate naturally, such as on trails (1-3 m wide and very shady) and in larger treefall gaps. It is also possible to plant certain heliophile species in openings of 5 x 5 m, a method close to the technique of dense spots used by ANDERSON (in CATINOT, 1965). At least for the first five years, this technique does not need any maintenance and plants may grow even better than in hauling tracks (Table 9).

In comparison, *Hazomalania voyroni* only grows well in trails because it is sciaphile (DELEPORTE and RANDRIANASOLO, 1991). It has even been planted under natural forest cover, but this plantation is too recent (3 months; by the time the paper had been written) to be evaluated.

Broussonetia greveana seems to prefer lateral shadow, while *Gyrocarpus americanus* is relatively insensitive to light. Other factors can modify these general findings, such as competition with herbs (none in openings, rather important on dirt roads) and soil disturbance (the soil is little disturbed in treefall gaps, but has very different characteristics on the tracks because of the hauling).

Table 9: Mean increase in height (cm) during two vegetation periods for five tree species planted in tracks and clearings. Light intensity declines from hauling tracks to large to average clearings; 30 to 240 transplants on hauling tracks and 75 transplants by species for each type of clearing.

Species	Hauling track	Large clearing[1]	Average clearing[2]
Broussonetia greveana	39.9	74.2	98.4
Commiphora guillaumini	46.7	62.2	60.3
Commiphora mafaidoha	71.7	90.3	82.8
Gyrocarpus americanus	90.2	83.9	89.1
Neobeguea mahafaliensis	58.4	73.8	70.9

[1]clearing of 5 x 5 m and removal of undergrowth with a diameter ≤ 7 cm on a 5 m large strip surrounding the opening
[2]clearing of 5 x 5 m

3.2.6 Growth of the transplants

The growth of saplings depends on many local factors such as soil, light, or the distribution and quantity of annual rainfall. Favourable rains can double growth while a cyclone or a tropical depression during the period of growth can defoliate the transplants entirely or partially, or even break the young shoots, thus strongly reducing the growth rate of that year even though there was adequate rain. The range of annual increment and the height reached at seven years are listed for some species in Table 4. The table also shows the relatively good growth of two *Commiphora* spp. in plantations compared to their growth in natural regeneration.

3.2.7 Work requirements

As for natural regeneration, work requirements listed here for the planting operations do not include those required for establishing the infrastructures except for clearings. Table 10 lists the amount of work required at different plantation sites. Saplings are planted every 2 m on tracks and at distances of 1 by 1 m in clearings.

Table 10: Number of man-days/1000 m^2 for planting and maintenance for the first seven years at four different types of sites. The production of 1 transplant is equivalent to 0.1 man-days.

Operations	Year	Hauling tracks	Trails	Big clearings	Average clearings
Number of transplants	0	125	500	1000	1000
Preparation of the soil	0	0.0	1.0	15.0	5.0
Cost of transplants	0	12.5	50.0	100.0	100.0
Planting	0	1.4	5.6	11.1	11.1
Cleaning	1	0.3			
Cleaning	2	0.3			
Widening of dirt roads from 4 to 6 m	3 or 4	3.3			
Cleaning: removal of vines	4	0.6			
Cleaning: removal of vines	7	0.6			
Total		21.7	56.6	126.1	116.1

Table 11 compares the manpower required for two types of plantations. With the first method, saplings are planted on 4 m wide hauling tracks. One to seven saplings are planted (average four) for each tree which has been cut. The the second method is only applied in treefall gaps which are easily accessible. Here, about ten saplings are planted for each downed tree.

Table 11: Number of man-days per 100 ha for planting and maintenance operations in two types of plantations during the first seven years. The production of a transplant is equivalent to 0.1 man-days.

Operations	Year	Plantation on hauling tracks	Plantation in treefall gaps
Number of transplants	0	4625	12000
Preparation of the soil	0	0.0	60.0
Cost of transplants	0	462.5	1200.0
Planting	0	51.8	134.4
Cleaning	1	11.1	
Cleaning	2	11.1	
Widening of dirt roads from 4 to 6 m	3 or 4	122.1	
Cleaning: cleaning of vines	4	22.2	
Cleaning: cleaning of vines	7	22.2	
Total		703.0	1394.4

The second technique yields 2.5 times more plants, but it is twice as expensive than the first method due to the cost of the transplants. The first method still is 3.5 times more expensive than natural regeneration, even though planting requires less specialized workers than the maintenance of natural regeneration.

3.2.8 Conclusions

Afforestation by planting is already well established for many species with respect to the type of transplants, period of plantation, station, sites of plantation, and maintenance. Every year, 20 000 to 35 000 transplants have been planted in the forest of the CFPF. Some problems remain such as the protection of the saplings against *Hypogemus antimena* [an endemic rodent of the region, SOMMER, in press) or against wild pigs (*Potamochoerus larvatus*; mainly for *Cordyla madagascariensis*)].

Though planting can compensate for deficiencies of natural regeneration, it is expensive mainly due to the price of the transplants. However, if this method would be applied widely, it should be possible to reduce the cost for sapling production. It is also possible to reduce the number of the transplants needed if they were of good quality.

A problem for the application in traditional exploitations is the type of site or infrastructure to be enriched. Treefall gaps generated during logging seem to be the most convenient sites, especially, since they require no maintenance after planting. The number of transplants could be reduced to nine instead of 25 per opening or by only planting in two or three gaps per hectare.

3.3 Direct sowing

In order to compensate for the deficiencies of natural regeneration, direct sowing has been applied since the beginning of the activities of the CFPF. Sowing is less expensive than planting and therefore should more likely to be within the budget of concession holders or forest services.

Unfortunately, the first experiments undertaken were complete failures. It was only after 1985 that experiments with this technique were resumed after more was known about the various species and forest ecosystems (DELEPORTE, 1989b). Studies on forest composition, phenology, climate, and soil characteristics, as well as more sylvicultural experience (preservation and pretreatment of the seeds, germination, natural regeneration, and planting) enabled improvements in the experimental design for direct sowing to be developed (RANDRIANASOLO et al., 1996; SORG and ROHNER, 1996).

Several problems have been addressed in these experiments:
- the selection of species
- pretreatment of seeds
- date of sowing
- and preparation of soil.

3.3.1 Selection of species

Eight different species have been tested so far: *Berchemia discolor, Colubrina decipiens, Colvillea racemosa, Commiphora guillaumini, C. mafaidoha, Cordyla madagascariensis, Gy-*

rocarpus americanus, and *Neobegua mahafaliensis.* Five of these species have been sown on tracks (Table 12). Except for *Berchemia discolor,* the germination rate was good for the other four species by the end of the wet season. After the following dry season, the number of living transplants declined strongly. Only the survival rate of *Gyrocarpus americanus* was still acceptable (9.0 %)) after two wet seasons. *Cordyla madagascariensis* could also be of interest if the young transplants were not be dug out by wild pigs during the dry season for their highly appreciated tubercules. In general, predation on saplings can be quite high. Of a batch of 1080 *Commiphora* spp. saplings planted in experimental plots only 87 survived for more than two years. The rest had been eaten mainly by rodents, such as *Hypogeomys antimena.*

Table 12: Percentage of seedlings surviving on trails and hauling tracks over time.

Species	Number of seeds	Sowing date	Months after sowing 1	2	3	5	13	15/16	23	28	44
Sown on trails											
Commiphora mafaidoha	329	22 Dec. 1986	21.0	16.1	14.9		1.5	0.6			
Neobeguea mahafaliensis	289	22 Dec. 1986	43.9	33.2	31.5		0.0	0.0			
Berchemia discolor	124	22 Dec. 1986		0.8	0.0		0.0	0.0			
Cordyla madagascariensis	116	22 Dec. 1986		37.9	38.8		0.0	1.7			
Gyrocarpus americanus	239	22 Dec. 1986		42.7	39.3		9.2	9.2			
Sown on hauling tracks											
Commiphora mafaidoha	3950	15 Dec. 1986	11.3	10.1	9.0		4.7	2.5			
Neobeguea mahafaliensis	2470	22 Dec. 1986	32.5	18.4	17.6		0.5	0.4			
Commiphora guillaumini	4795	15 Dec. 1985							13.3	8.0	
Colvillea racemosa	3278	4 Dec 1986	15.1	14.1	13.5	11.2	7.5				12.0

Four species were also used on hauling tracks (Table 12). The germination rate was good for *Neobeguea mahafaliensis* and *Colvillea racemosa,* and fair for *Commiphora* spp.. Survival of *C. racemosa, C. guillaumini,* and to some extent also of *Colubrina decipiens,* were satisfying after the first dry season, though data for the latter are incomplete.

Thus, of the eight species tested, only *Colvillea racemosa* was entirely satisfying. *Gyrocarpus americanus, Colubrina decipiens, Commiphora guillaumini,* and *Cordyla madagascariensis* give average results. Many plants died during the first dry season. Plants too small and

often insufficiently lignified are not resistant to the long dry season. In order to survive, seeds of fast growing species must be directly sown as soon as possible after their development to allow the young plants to profit from the rain.

3.3.2 Treatment of seeds

As shown by experiments in the nursery, certain species, such as *Colvillea racemosa* require special treatment to increase their germination rate (RARIVOSON, unpubl. ms.; RANDRIANASOLO et al., 1996; SORG and ROHNER, 1996). For this species soaking in water of 80°C, followed by maceration for 24 hours greatly improves germination rate and speeds up germination for the first three weeks. In the forest, however, seedlings having germinated earlier suffered increased mortality and after about five months, by the end of the wet season, there was basically no difference in survival and growth between saplings grown from either treated or untreated seeds.

3.3.3 Date of sowing

The date of sowing is important for the success of direct sowing. The best time for sowing is from December to the beginning of January which is the most likely time of regular rainfall (Table 13). If sown too early, the seeds could be destroyed by predators or the young plants die during a dry spell at the beginning of the wet season. Sown too late, the plants are unable to grow enough to resist the dry season.

Table 13: Effects of the date of sowing on growth and survival of *Colvillea racemosa* at the end of the rainy season; seeds sown on hauling tracks.

Date of sowing	Number of seeds	Percentage of living plants 05 Jan. 88	Percentage of living plants 08 Apr. 88	Mean height (cm) 08 Apr. 88
20 Oct. 87	1 340	2.2	0.8	11.4
16 Nov. 87	1 450		10.7	11.3
17 Dec. 87	5 440	34.0	25.1	21.8
06 Jan. 88	5 810		18.5	19.7

3.3.4 Treatment of the soil

Even if the forest soil is sandy and not very compact, exploitation and mainly hauling with machines provokes at least slight superficial compression which could influence water infiltration. Preparation of the seed bed consisted primarily of digging up the soil for a width of 20 cm and a depth of about 10 cm with the "angady" (Malagasy spade). Whenever possible the soil was tilled in a way generating a concave profile to concentrate the rainwater. This improves water permeability and facilitates sowing. Table 14 summarizes the main results obtained with untreated seeds of *Colvillea racemosa.* Tilling greatly improved germination and the number of living plants but did not increase growth.

Table 14: Effects of soil treatment (digging up the soil to a depth of 10 cm in a swathe 20 cm wide) on the survival of plants and mean height at the end of the wet season for *Colvillea racemosa* sown on hauling tracks on December 17, 1987.

	Percentage of plants surviving			Mean height(cm)
Date	**01 Jan. 88**	**25 Feb. 88**	**05 Apr. 88**	**05 Apr. 88**
Months	**0.5**	**1.25**	**3.75**	**3.75**
With treatment	12.5	22.4	20.4	20.5
Without treatment	6.2	10.6	8.4	23.9

3.3.5 Work requirements

As above, work requirements listed here for sowing do not take into account for the establishment of the infrastructures except for the clearings. Table 15 shows the work required for sowing and maintenance on hauling tracks and forest depots. At the forest depots the seeds are sown every 30 cm in a line, with 1 m between the lines. According to these figures, direct sowing is 23 % more expensive than promoting natural regeneration (Table 5), but it is two to three times cheaper than planting (Table 10). Widening the tracks is the most expensive part, requiring 37 % of the work time.

Table 15: Number of man-days per 100-ha plot for maintenance of plots where commercial timber species had been sown during the first seven years; 1000 treated seeds of *Colvillea racemosa* are equivalent to about 0.4 man-days.

Operations	Year	Forest depots	Hauling tracks
Number of seeds	0	13333	30821
Labour	0	8.00	18.50
Cost of seeds	0	5.33	12.21
Sowing	0	3.20	7.40
Cleaning	1	3.20	29.60
Cleaning	2	2.40	22.20
Widening of dirt roads from 4 to 6 m	3 or 4		122.10
Removal of vines	4	4.80	44.40
Removal of vines	7	4.80	44.40
Total number of man-days		31.73	300.81
Total per 100 ha forest		332.54	

3.3.6 Conclusions

Direct sowing is economically interesting because it is two to three times cheaper than planting. Still, it is only applicable to species for which seeds are available in large quantity. In order for direct sowing to be successful, the following points are important:

- to sow as quickly as possible after installation of the infrastructures to avoid invasion of weeds
- to till the seed bed
- to select species adapted to the present soil characteristics (nevertheless, sowing of seemingly well adapted species is not successful on the most permeable soils)
- to sow after the first regular rainfalls (mid-December to the beginning of January) at a depth of at least the size of the seed
- to do the first cleaning shortly after sowing (February - March).

Direct sowing can be considered successful, if 20 % of the seeds germinate after one month and saplings are at least 20 cm high at the end of the first rainy season.

Suitable species are characterized by:

- big seeds which are rarely or never attacked by predators
- rapid germination after sowing, possibly after pretreatment of the seeds
- substantial growth during the first rainy season (heliophile species)
- tolerance towards different soil types.

For the time being, only *Colvillea racemosa* and *Gyrocarpus americanus* meet these requirements. They are used on dry sites (unleached ferruginous soils) and on humid sites on tracks and in forest depots. Direct sowing and planting yield similar results in these both species. Experiments with other species are in progress (DELEPORTE, 1989b).

3.4 Increasing growth by selective thinning

Selective thinning aims at increasing the growth of commercial species in order to reduce the interval between subsequent exploitations. Experimental thinning was carried out to increase sun exposure of the crowns of three important timber species: *Commiphora guillaumini, C. mafaidoha* and *Hazomalania voyroni.*

3.4.1 The case of *Commiphora* spp.

At present *Commiphora* spp. provide the vast majority of native timber used for all kinds of purposes (RAONINTSOA, 1996). Thus, sustainable exploitation of these species seem desireable.

Of 159 *C. guillaumini* and 21 *C. mafaidoha,* 104 trees were thinned and 76 were untreated controls. At the beginning of the experiment, the DBH varied between 1.4 and 48.6 cm ($\bar{x}$ = 17.2 cm) and total height between 2.4 and 22.5 m ($\bar{x}$ = 13.3 m). Trees were assigned to three size classes: understorey (< 6 m high), middle layer (6-15 m), and overstorey (> 15 m).

The main results are (Table 16, Fig. 4, 5):

1. There is no difference between *C. guillaumini* and *C. mafaidoha* with respect to thinning.

2. The experimental treatment (thinning or not) contributes most to the variance in the increase in diameter.

3. Trees immediately show a positive reaction to thinning. The effect lasts for at least five years.

4. DBH is highly correlated with total height (Fig. 3). Increase in height is most pronounced in trees with DBH < 10 cm. These trees have a ratio between height (H) and DBH > 100. Once trees reached the top of the intermediate storey (H > 12 m), they increase in DBH rather than height (H/DBH < 100).

   In accordance with this result, the effect of the thinning is most evident in trees with DBH < 20-25 cm. Here, the increment doubled at least (Fig. 4). Thinning has no effect in overstorey trees as they no longer compete for light. The same effect has been described for the tree community as a whole (GANZHORN, 1995b; GANZHORN and KAPPELER, 1996).

5. The best regressions between the increment in diameter over five years (ID) and the DBH are given by the functions of Gauss:

   Thinned trees:

$$ID = \frac{37.94}{15.82\, x \sqrt{2\pi}}\; x\, e^{-0.5\left(\frac{DBH-14.9}{15.82}\right)^2} ;\ r = 0.91$$

   Untreated controls:

$$ID = \frac{20.21}{14.15\, x \sqrt{2\pi}}\; x\, e^{-0.5\left(\frac{DBH-23.2}{14.15}\right)^2} ;\ r = 0.85$$

6. Based on extrapolation of the regression between the increment in DBH over five years and the DBH for untreated controls, trees reach exploitable size (DBH = 41.3 cm) after 450 years (Fig. 5).

Table 16: Effects of thinning, the DBH at the beginning of the observations, and the stratum of the forest to which the individual tree belonged on the increase in DBH of *Commiphora* spp. over six years; ANCOVA, Type III SS.

Source of variation	df	F	P
Thinning	1	40.93	< 0.001
DBH	1	12.62	< 0.001
Stratum	2	3.86	0.020
Total model	4/169	14.55	< 0.001

Thus, increasing light exposure of the crown via thinning increases growth of *Commiphora guillaumini* and *C. mafaidoha* at DBH < 25 cm. For trees with DBH < 10 cm, thinning provokes twisting. This is not surprising given their growth coefficient H/DBH > 100. Thinning would therefore be economically interesting for trees of DBH between 10 and 25 cm. Unfortunately, there are only 3-8 stems of this sized *C. guillaumini* and *C. mafaidoha* per ha (BURREN, 1990). Low natural regeneration may add to the problem. By accelerating growth and thus reducing the cutting cycle, the time available for natural regeneration is reduced and both *C. guillaumini* and *C. mafaidoha* regenerate in low numbers (see 3.1). Thus, by favouring growth one could observe the gradual reduction and final disappearance of *C. guillaumini* and *C. mafaidoha*.

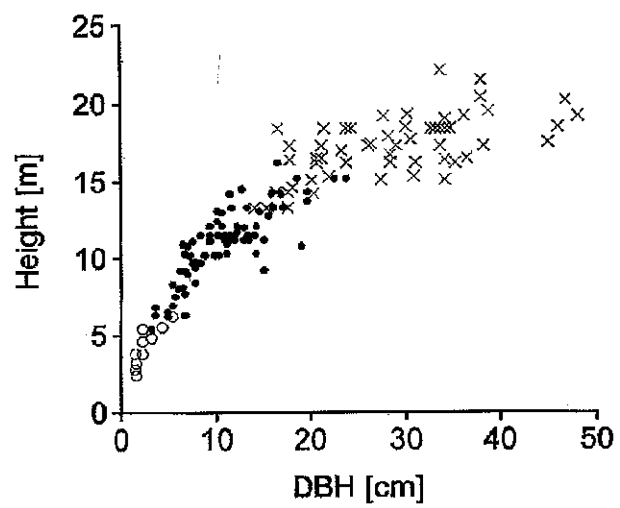

Fig. 3: Height (H) in relation to DBH for *Commiphora guillaumini* and *C. mafaidoha*; $H = 1.18 + 1.47xDBH - 0.057xDBH^2 + 0.001xDBH^3 - 8.745E\text{-}6xDBH^4$; $r = 0.95$; $P < 0.001$.
The different symbols reprsent assigment of the trees to different layers of the forest: circles = under storey; dots = middle layer; crosses = upper storey.

3.4.2 The case of *Hazomalania voyroni*

Hazomalania voyroni, known outside Madagascar as "false campher" is one of the best known tree species from the west coast of Madagascar. Its resistence against termites and suitability for technical processing with simple tools has resulted in the overexploitation of this has species, driving it to the brink of extinction. In unmanaged forests natural regeneration is insufficient to re-establish or even maintain an economic level of exploitation.

A thinning experiment involving 34 controls and 33 experimental trees where the neighboring vegetation had been removed, did not show any treatment effects. Increase in DBH depended primarily on the original height and DBH, and secondarily on the forest stratum. Clearing of the surrounding vegetation had no effect on growth, except that it possibly favoured the growth of trees already larger than 15 cm DBH. Growth could neither be related to crown characteristics nor to the type of soil.

Based on the data collected during this experiment, growth rates of *H. voyroni* could be estimated and extrapolated similarly as for *Commiphora* spp. (Fig. 5). *H. voyroni* grow very slowly until they reach about 10 cm DBH (at about 90 years). Then growth rates increase and remain relatively constant at 3-4 mm/year. Even though *H. voyroni* grows relatively fast in comparison to *Commiphora* spp., it still takes about 190 years for it to grow to the size of 48 cm DBH. But, at least the technical problems of its propagation, plantation and reforestation have been solved.

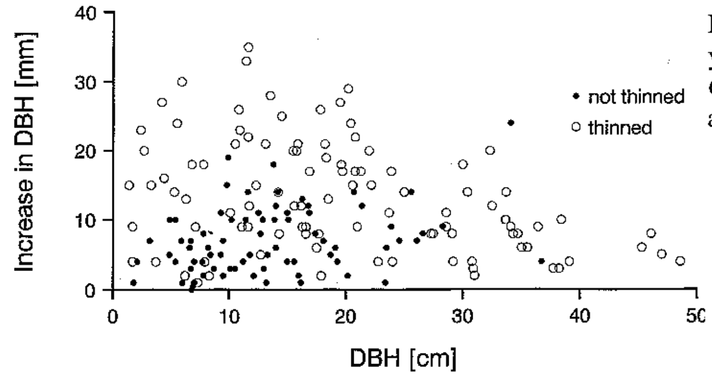

Fig. 4: Increase in DBH in 5 years in relation to DBH for *Commiphora guillaumini* and *C. mafaidoha*.

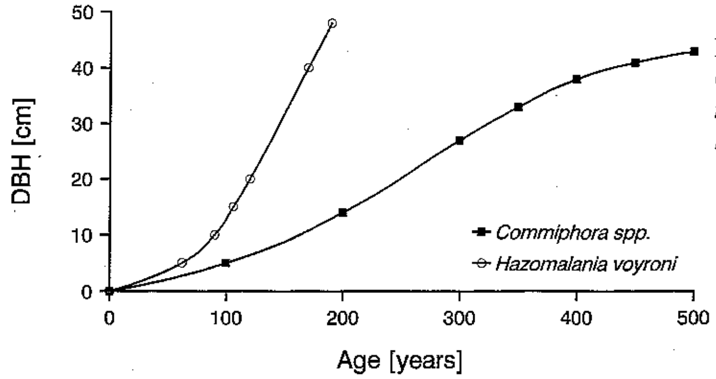

Fig. 5: Extrapolated growth (DBH) for untreated *Commiphora* spp. and *Hazomalania voyroni*.

3.4.3 Conclusions

Most commercial timber species are heliophile. If *Commiphora* spp. can serve as a model for heliophile species, thinning can increase growth and thus yield. According to this example, this technique is applicable to trees between 10 and 25 cm DBH. Only 20 to 100 stems per hectare

of commercial timber species match this criteria (BURREN, 1989). For this, about 100 man-days of logging and 33 man-days for maintenance are needed per 100 ha. This is very expensive with unclear long-term effects. In addition, as suggested for *Commiphora* spp., accelerating growth (and thus reducing the time available for reproduction) might have disasterous long-term effects for species with poor or very episodic regeneration, provoking their progressive disappearance.

4. Global sylvicultural strategy

Sylviculture aims at restoring or even increasing timber production before or after exploitation. Thus, it is primarily interested in commercial species. However, sylviculture has not only to assure long-term sustainable utilization of the dry dense forest, but should also allow perpetuation of natural processes, thus facilitating conservation of biodiversity and maintaining ecosystem functions. Due to these ecological considerations as well as for economic reasons, natural regeneration has first priority among sylvicultural activities. However, natural regeneration is rather poor and within the human (and thus economic) time scale is only satisfying under certain conditions of soil, light, and density of the seed bearers (see 3.1). Direct sowing has second priority for economic reasons. Unfortunately, for the time being, this is possible with only two species. Planting has lowest priority, although it is best known. In populations rich in commercial species of average diameter, improvement by selective thinning could be considered. These considerations resulted in a decision tree for sylvicultural activities in the dry deciduous forest of western Madagascar (see below).

Decision tree for sylvicultural activities in the dry deciduous forest of western Madagascar

1. Favourable sites for natural regeneration
- ferruginous red clayey soils
- deep, yellow ferruginous soils
- poorly developed soils on recently alluviated land, rarely inundated
- foot of a ravine and uninundated valleys

1.1 Natural regeneration (see 3.1)

If two years after opening of the forest (forest depots, tracks or treefall gaps) natural regenation is insufficient: number of stems of commercial species < 1000/ha, or number of commercial species < 5/200 m^2, or dominant height < 1 m

then:

1.2 Planting or supplementary planting (see 3.2)

2. Unfavourable sites for natural regeneration and favourable for direct sowing
- ferruginous leached soils
- ferruginous unleached soils with little clay
- top of a ravine and plateau

2.1 Direct sowing (see 3.3)
- ferruginous yellow unleached soils: *Colvillea racemosa*
- ferruginous leached soils on top of a ravine: *Gyrocarpus americanus*

If at the end of the first rainy season (April), direct sowing is judged insufficient: Percentage of living plants < 15 %, or average height < 20 cm

2.2 Planting or additional planting (see 3.2)

3. Other sites, unfavourable for natural regeneration and for direct sowing
- greenish soils and vertisols
- poorly developed soils on recently alluviated land frequently inundated
- ferruginous leached sandy soils
- ferruginous unleached sandy soils
- ferruginous leached podzolic soils
- periodically inundated valleys
- top of a ravine
- plateau and summits

3.1 Planting (see 3.2)
If after two years planting is judged insufficient (survival rate < 50 %)

3.2 Additional planting with another species (see 3.2)

4. Rich populations
- more than 100 stems of 10 to 25 cm per ha
- smallest surface to be treated > 10 ha
- ferruginous red soil containing much clay
- concretioned, deep yellow ferruginous soils
- poorly developed soils on recently alluviated land, rarely inundated
- foot of a ravine and uninundated valleys

4.1 Improvement of the populations by selective thinning

5. Summary

This article has illustrated different ways of afforestation after exploitation of the dry dense forest on the west coast of Madagascar. Sylvicultural applications included: natural regeneration, direct sowing, and planting. These techniques still have to be improved but they can be implemented already successfully even if growth is sometimes slow. Thus, despite considerable environmental constraints (especially rainfall pattern and soil conditions) sustainable forest management seems possible in the region of Morondava, at least from the technical point of view. Further improvements of sylvicultural techniques have to aim at greater economy (e.g., by reducing the number of plants per area of reforestation), at a reduction in the time needed for maintenance, and at simplifying the operations to match the regional possibilities in terms of financial means and man-power. Some fundamental studies are needed such as determination of the dimensions and conditions under which a tree can be considered a seed bearer.

In conjunction with socio-economic activities, education programs, and enforcement of existing laws, sylvicultural operations in natural forests can help to preserve the forest and can reduce the deforestation by a growing human population.

Since 1978 the CFPF has realized using different sylvicultural techniques:

- natural regeneration on forest depots, hauling tracks, and old small deforestations inside the forest on a surface of about 200 ha;
- planting of about 200 000 tree saplings on hauling tracks, forest depots, trails, and treefall gaps on an exploited surface of 4 000 ha, equivalent to 160 ha of forest clearing;
- direct sowing of 150 000 seeds on hauling tracks and forest depots on an exploited surface of about 500 ha, equivalent to 20 ha of forest clearing;
- improvement of the timber on about 50 ha.

Of the 4500 ha exploited for the first time, representing about 55 000 felled trees, about 380 ha (mainly exploitation infrastructures: i.e., 8.4 % of the surface) have been restored and even strongly enriched. Afforestation on the hauling infrastructures alone amounts to three to four plants (by natural regeneration, direct sowing, or transplants) for every logged tree. The rest of the exploited area (about 4100 ha) follow their own dynamics. Permanent observation plots established in 1989 (BURREN, 1989) do not yet allow conclusive interpretation of the development and evolution of the natural regeneration. Timber stands in these areas could be enriched after subsequent exploitation by creating new exploitation infrastructures complementary to the existing ones.

Unfortunately the rotation period between the first and second felling is not yet as well known yet. According to a first estimate based on inventories and the growth of the *Commiphora* spp. (80 % of the exploited volume), about 100 to 120 years have to pass before the same timber volume as in the first felling can be harvested again (WALKER, 1989). This, however, may overestimate the rotation period. Logging overstorey trees during the first exploitation can be considered as thinning which should stimulate the growth of the trees of the intermediate storey close to the treefall gaps. Secondly openings created by infrastructures should certainly provoke edge effects favouring growth (BURREN, 1990) and thirdly, species other than *Commiphora* spp. grow more rapidly.

Despite these considerations it is very unlikely that the rotation period will be below 60 years, which corresponds to timber production of about 0.1 m^3/ha/year. Thanks to the enrichments which could progressively be exploited, the rotation period between the 2nd and 3rd felling should decline and the harvested volume should increase.

The sylviculture practiced by the CFPF can be considered as a low impact activity. Only 10 to 15 % of the forest cover is affected by exploitation and creation of infrastructures. The sylvicultural operations are linked to the exploitation since they only use the infrastructures needed for logging.

Traditional logging in this region does not open similar infrastructures. Firstly, because they are very expensive, and secondly, the timber is carried on the back out to the next road on small footpaths. These paths are unfavourable for reforestation because they are narrow and shady. Only *Hazomalania voyroni* can be planted under these conditions. Thus, paradoxically, reforestation and natural regeneration is not at all guaranteed after traditional exploitation, even though the forest structure has only been slightly modified.

Official contracts with concession holders request afforestation after exploitation. However, contracts are very often formulated in a very general way, difficult to implement and to control. In addition, the concession holders prefer to pay a relatively small amount to the Forest Service which should be used for the afforestation of an area equivalent to the exploited one rather than to restore their own concession which would be much more expensive and require specialized workers. Thus, though many of the technical problems are solved and the know-how for sustainable timber exploitation is available, the present political and socio-economic situation seems unfavourable for long-term sustained forest utilization (CUVELIER, 1996; CUVELIER and RAONINTSOA, 1996)

LOCAL TREE SPECIES IN THE TREE NURSERY

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Résumé: Essences locales en pépinière

Durant les 15 dernières années, le CFPF a réalisé environ 200 essais de germination en pépinière avec des essences locales. La plupart de ces essences ont germé et ont été produites avec succès en pépinière. Cependant, seules les essences présentant une valeur économique sont reproduites en pépinière dans le but de fournir des plants pour l'enrichissement de la forêt après exploitation. Les essais entrepris avec certaines essences (*Hazomalania voyroni, Colvillea racemosa, Commiphora* spp.) sont décrits plus en détail. *H. voyroni*, l'essence jadis la plus utilisée sur la côte Ouest en raison de sa résistance aux termites et de son aptitude à être travaillée avec des outils simples, a été surexploitée et pratiquement éliminée d'une grande partie de son aire. Le faible potentiel de dispersion et une régénération naturelle peu abondante expliquent que les populations de cette essence ne peuvent pas se reconstituer sans assistance. Les problèmes techniques liés à la germination, à la production en pépinière et à la plantation de *H. voyroni* en forêt sont actuellement résolus et sa survie relève maintenant de l'aménagement des forêts et de considérations politiques. *C. racemosa* est l'une des essences à croissance très rapide de la forêt dense sèche de l'Ouest malgache. Son aptitude colonisatrice est élevée. Des traditions locales expliquent pourquoi cette essence n'a pas encore été exploitée commercialement. Son bois se prête à la transformation et possède des propriétés permettant d'envisager un usage commercial. Le semis direct et la plantation ne posent pas de problèmes. Différentes espèces du genre *Commiphora* remplacent actuellement *H. voyroni* sur le marché et fournissent la plus grande partie du bois utilisé dans la région. Elles peuvent être élevées facilement en pépinière et ont été employées avec succès dans les plantations d'enrichissement après exploitation. Si les techniques de propagation de ces essences, et d'autres encore, sont maîtrisées, leur application pratique hors de la concession du CFPF est encore très insuffisante, bien que le reboisement après exploitation de la forêt soit maintenant devenu une obligation légale.

Abstract

During the last 15 years the CFPF has performed some 200 germination experiments with local tree species in a tree nursery. Most tree species germinated and could be grown successfully. Today only economically valuable species are being retained in the tree nursery to provide 40 000 saplings for replantation after logging operations. Experiments with some tree species (*Hazomalania voyroni*, *Commiphora* spp., and *Colvillea racemosa*) are described in more detail. *H. voyroni* used to be the main timber species along the west coast of Madagascar due to its resistence against termites and its suitability for processing with simple tools. This has resulted in the overexploitation and elimination of the species from most parts of its former range. Due to its low dispersal potential and poor natural regeneration, *H. voyroni* populations may not recover without help. As the technical problems of its germination, plantation, and reforestation have been now solved, it is just a question of forest management and politics whether or not this species will survive. *Commiphora* spp. are now the main timber trees of the area, replacing *H. voyroni* on the market. These species can be grown readily in tree nurseries and have been used