Chapter 6.5
Results from Ten Years of Restoration Experiments in the Southeastern Littoral Forests of Madagascar

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Abstract

This chapter summarizes the results of various trials to restore littoral forest in the southeast of Madagascar. Native trees were removed from sites where the sand had been demineralized and redeposited at sites where the sand had not been demineralized. Native tree species were planted exclusively or mixed with introduced *Acacia mangium* and *Eucalyptus robusta*. These introduced trees were transplanted to provide shade for the slower–growing, native tree species. A 20 cm layer of topsoil was applied to the immediate vicinity of each sapling or spread over the entire plantation area. There was no difference in growth rates between sites where topsoil was restricted to the planting holes and those where it was spread over the entire plantation area. Survival rates of native tree species did not differ between the demineralized and the non-demineralized sites, but growth rates were notably slower at the demineralized sites. Survival and growth rates of native tree species were reduced significantly when they were planted in combination with exotic tree species. Native species assigned to different successional stages did not differ in their survival or growth rates. On demineralized soil, tree species with ectomycorrhiza or nitrogen fixing bacteria grew much faster than species without or with different forms of symbiotic microorganisms.

Résumé

Résultats de dix années d'expériences de restauration de la forêt littorale du sud-est de Madagascar. Ce chapitre résume les résultats de divers essais menés pour restaurer une forêt littorale du sud-est de Madagascar. Des arbres indigènes ont été plantés dans des stations où le sable avait été déminéralisé et redéposé. Dans ces stations, la plantation pouvait se limiter à des espèces d'arbres indigènes ou alors concerner aussi des plantations mixtes d'espèces indigènes avec les arbres allogènes *Acacia mangium* et *Eucalyptus robusta*. Ces arbres allogènes ont été plantés pour fournir l'ombrage aux espèces indigènes à croissance plus lente. Une couche de 20 cm de terreau a été apportée juste autour de chaque plant ou alors épandue sur l'ensemble de la zone de plantation. Le taux de croissance des plants ne différait pas selon ces deux techniques d'apport. Les taux de survie des espèces d'arbres indigènes ne différaient pas entre les stations au sable déminéralisé et celles au sable non déminéralisé mais les taux de croissance étaient nettement plus bas dans les stations déminéralisées. Les taux de survie et de croissance des espèces d'arbres indigènes étaient significativement réduits lorsque les espèces indigènes étaient plantées en combinaison avec des arbres allogènes. Les espèces indigènes assignées aux différentes successions de la végétation ne différaient ni dans leur taux de survie ni leur taux de croissance. Dans les sols déminéralisés, les espèces d'arbres à ectomycorhizes ou à bactéries fixant l'azote avaient une croissance plus rapide que les espèces qui en sont dépourvues ou qui présentent des formes différentes de microorganismes symbiotiques.

Introduction

Restoration of natural forests has become an important issue in Madagascar's forestry and conservation activities. Native trees are being planted as buffer zones around natural forests and as corridors to provide continuity of forest habitats and to restore natural forests after exploitation or complete destruction

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(Styger 1999, Holloway 2003). Natural forest restoration trials have been concentrated at humid forest sites on lateritic soil in the east, and on sandy soils with dry deciduous forests in the west (Deleporte *et al*. 1996, Randrianasolo *et al*. 1996, Sorg *et al.* 2003, Sorg 2006). Restoration trials of evergreen littoral forest have been restricted to mostly exotic tree species at the forestry station at Tampolo north of Toamasina (reviewed by Ratsirarson and Goodman 1998).

One of the obligations of the mining permit for QIT Madagascar Minerals' (QMM) Environmental Management Plan is restoration of natural forest after mining. The plan is to double the surface area of the existing conservation zone at Mandena and to plant about 200 ha of natural forest after mining (QMM 2001,Vincelette *et al.* 2006). Restoration of littoral forests in Madagascar might be more difficult than restoring forests of other ecosystems for the following reasons:

1. The coastal littoral forests are growing on nutrient poor sands. Most plants growing under these conditions are likely to rely on fungi and other microbes for symbiotic interactions (Ducousso *et al*. 2004).
2. The sand will be removed and the minerals will be extracted before it will be redeposited. Mineral extraction per se does not seem relevant as the extracted ilmenite is very stable, resistant to chemical attack, and not available to plants as nutrients through weathering (Bormann *et al*. 1998). However, sands from many different layers are mixed during the extraction and re-deposition process, and most living materials (symbiotic bacteria, mycorrhiza, etc.) are unlikely to be available after the extraction process.
3. Natural forest cover is restricted to one large and several small remnants of degraded natural forest, which covers less than 10% of the project area. Thus, regeneration from natural seed dispersal into the plantations from the existing forest is limited.
4. The microclimate in the open, outside the forested zones, differs markedly from the microclimate within the closed littoral forest. Therefore, it seemed necessary to install crops that would provide shade for the young, native forest trees, and create a microclimate that would allow the survival of microorganisms in the topsoil.
5. The recent wave of deforestation of the littoral forest prior to mining (see Vincelette *et al.* Chapter 2.4) destroyed most of the topsoil which would have otherwise been available as additional seed bank and source of microbes for the new plantations.
6. The littoral forests have relatively high species diversity with endemics occurring at low densities (see Rabenantoandro *et al.* Chapter 3.1). This makes it difficult to collect seeds or seedlings to be planted in the tree nursery or transplanted directly.

We only recently became aware of several of these issues and they were not addressed during the original restoration experiments reported on here. Other aspects have been taken into consideration but could not be analyzed in this current chapter because of the slow growth of the trees. Additional, fundamental aspects of forest restoration, such as data on phenology, seed collection, seed storage, and seed germination, are described elsewhere in this book.

In the present chapter, we summarize the following experiments: 1) Restoration trials on demineralized sand, 2) Restoration trials on non-demineralized sand, including a) plantations with different amounts of topsoil, b) plantations on the edge of natural forest, and c) plantations away from natural forests. 3) restoration trials on non-demineralized sand with and without fast–growing, exotic tree species for shade.

Methods

The first qualitative data collection and experiments started in 1992. At that time, growth characteristics of the saplings of several species collected in the littoral forest were observed and described qualitatively. One experimental treatment was to plant the saplings using different amounts of topsoil. The qualitative observations indicated that the depth of the topsoil had a major influence on the growth of the plants. Best results were achieved with plants growing on 10 - 20 cm of topsoil. Since the availability of topsoil is limited in and around these sites, one research priority was to define the depth of the layer of topsoil required for the plantations. All the quantitative experiments reported here with topsoil added are based on a layer of 20 cm. Subsequent experiments applied only 10 cm of topsoil, but these plantations are too young to be evaluated here. The observations listed above also enabled us to categorize the saplings as sun or shade-loving, and thus, to select species which might represent early successional stages. The sun-loving species might be suitable pioneers for reforestation.

Choice of species

The objective of the first stage of the plantation program was to actively install a vegetation formation which could serve as the starting point for a natural or facilitated succession towards restoration of the desired forest components (Vallauri *et al*. 2005). For this, the species were categorized according to their tolerance to sun exposure, high evaporation, and poor soil conditions, and their capacity to rapidly develop an extensive and dense root system. This classification was developed independently from the assignment of species to successional stages (Clements 1916).

Sun-loving (S) and pioneer (P) species

This category contains species that grow best in full sunlight. These are the pioneer species of the littoral forest such as *Vernoniopsis caudata* (Asteraceae), *Campylospermum obtusifolium* (Ochnaceae), *Dodonaea viscosa* (Sapindaceae), *Aphloia theiformis* (Aphloiaceae), *Scutia myrtina* (Rhamnaceae), and *Cerbera manghas* (Apocynaceae). In addition, several true forest species were also assigned to this category. These are also species which require light to become established in the otherwise closed forest. Species belonging to this category were identified by Rajoelison (1997) and supplemented by our own observations; they include *Canarium bullatum* inedit (Burseraceae), *Eugenia cloiselii* (Myrtaceae), and *Rhopalocarpus coriaceus* (Sphaerosepalaceae). We also include species from families known to develop mycorrhiza and bacterial interactions quickly, including Sarcolaenaceae, Myricaceae, and Fabaceae.

Intermediate species (I)

These species cannot be assigned to the categories of sun-loving or shade-loving species. Under unshaded tree nursery conditions, their germination rate is mediocre (see Randriatafika *et al*. Chapter 3.3). Species of this category include *Tambourissa castri-delphinii* (Monimiaceae), *Vepris elliottii* (Rutaceae), *Dracaena bakeri* (Convallariaceae), *Psorospermum revolutum* (Clusiaceae), *Eugenia* sp. (Myrtaceae), and *Ophiocolea delphinensis* (Bignoniaceae).

Climax and shade-loving species (C)

This category consists of forest species, which require shade for optimal growth. It includes *Dypsis prestoniana* and *D. lutescens* (Arecaceae), *Pandanus dauphinensis* (Pandanaceae), *Podocarpus madagascariensis* (Podocarpaceae), *Diospyros gracilipes* (Ebenaceae), *Apodytes bebile* (Icacinaceae), and *Dombeya mandenense* (Malvaceae).

In Brazil, at the Trombetras bauxite mine site (Parotta and Knowles 1999), mixtures of species of different successional stages were used for restoration trials. Following this example, we tried to optimize the reforestation trials by planting 50% sun-loving and pioneer species, 40% species of the intermediate type, and 10% climax species.

Prior to the restoration experiments, the phenology of native plants had to be established to determine the time of seed collection, and fruit and seed preparation. Based on this research, saplings were produced in the tree nursery at Mandena (M15) and planted at 2 m intervals in the sand after removal of the heath vegetation dominated by *Erica floribunda* (Ericaceae). Topsoil was collected from nearby natural littoral forests. Site descriptions, incentives for the design of the plantation, and technical details are listed in Table 1.

Plantations on demineralized sand and without soil humus: native species

The objective of this trial was to test restoration and succession in an experiment that simulates post-mining soil conditions. At Site 4, the process mimicked the actual extraction procedure. For this, an area of 70 x 35 m was demineralized to a depth of 2 m. The demineralized sand was redeposited in the excavation to simulate the conditions after mining (Fig. 1). In Block R, the topsoil was removed to a depth of 40 cm over an area of 1 x 1 m at each planting location. This was done to mimic the removal of humus after exploitation, but complete demineralization, as at Site 4, was not conducted. The hole was then covered with a 20 cm layer of topsoil.

Plantation on non-demineralized sand: native species

These trials included only plantations with native tree species. The plantations of Blocks G-extension and K were used to test whether localized topsoil concentrated around the sapling had different consequences for growth and survival than topsoil spread over the entire area. Block G served as a corridor between the natural forest and an artificial swamp (see Randratafika *et al*. Chapter 6.6) in addition to containing test plantations of *Crataeva obovata*

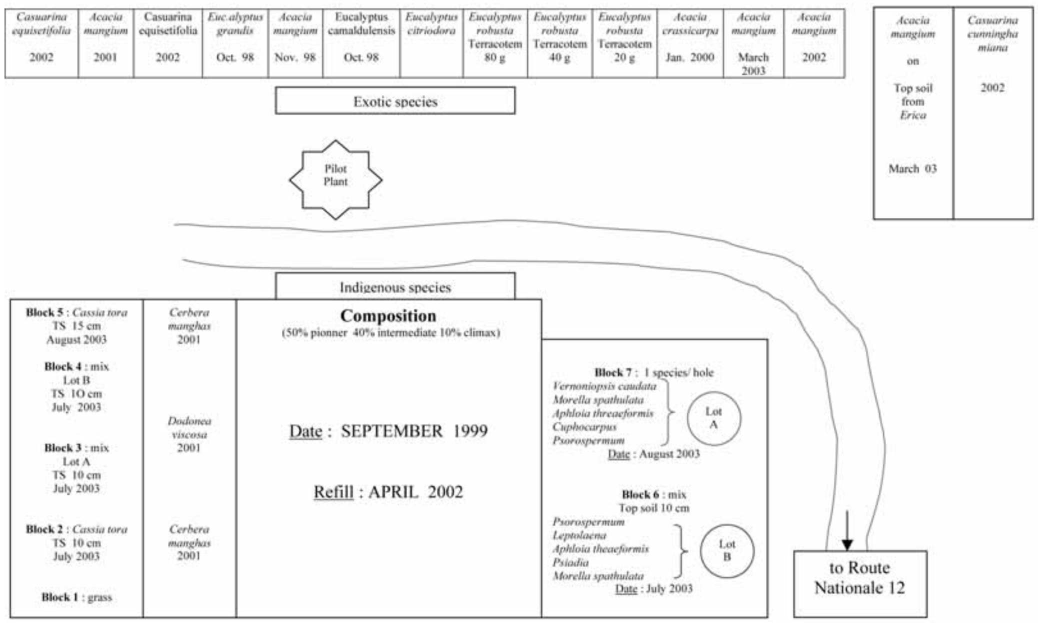

Figure 1. Schema of the plantation on demineralized sand at Site 4. TS = topsoil; Terracotem = commercial fertilizers and water absorbent polymers (see Rarivoson and Mara Chapter 6.3).

(Brassicaceae). This plant has a very deep root system that allows resprouting after fire. Therefore, 16.5% of the saplings planted in Block G were *C. obovata*. All native tree plantations except Block H were established along the natural forest of the Mandena Conservation Zone (M15/M16). Blocks H1 and H2 were located several hundred meters away from the nearest forest. These plantations were intended to test the effects of the distance of the plantation from the natural forest on natural regeneration (Fig. 2).

Plantation on non-demineralized sand: native species mixed with introduced *Acacia* (Fabaceae) and *Eucalyptus* (Myrtaceae)

Exotic species were planted to promote quick vegetation regrowth and to provide shade for the native saplings, and they included *Eucalyptus robusta* and *Acacia mangium*. *Eucalyptus robusta* was chosen because large numbers of native tree species regenerate with notable species diversity underneath *E. robusta* plantations in the Tolagnaro region. There was no prior local experience with *A. mangium* as a shade tree. At these plantations, the native saplings were surrounded by different combinations of the two exotic tree species. In the case illustrated in Figure 3, the ratio of saplings was 33% native species, 33% *A. mangium*, and 33% *E. robusta*, and each native tree sapling "N" was surrounded by three *A. mangium* and three *E. robusta*. This plantation type was installed over an area of 90 x 100 m^2 as a mixed native/exotic tree species corridor to link the two natural forest fragments of M4 and M5.

Measurements and statistical analyses

The survival and growth of the saplings in the plantations were used as measures of their performance. For this, the number of surviving plants and their heights were measured at 13, 32 – 36, and 57 – 63 months after plantation. Survival and growth rates were analyzed statistically only after 57 months. Samples were pooled per species and per site. Thus, each species entered the analysis only once per site.

The average height of the saplings at the time of plantation was 9.3 ± 1.9 cm (mean and standard deviation of 36 species). This value was then used for the statistical analyses as the size of all trees at the time of planting. This assumption had to be made because the height of saplings at the time of plantation was not measured for all plantations. Growth rate was calculated as the height of the plant minus 9.3 cm (average height at the time of plantation), and divided by the number of years between measurements. Dead saplings were not included in the calculations of growth rates. Survival rates deviated significantly from

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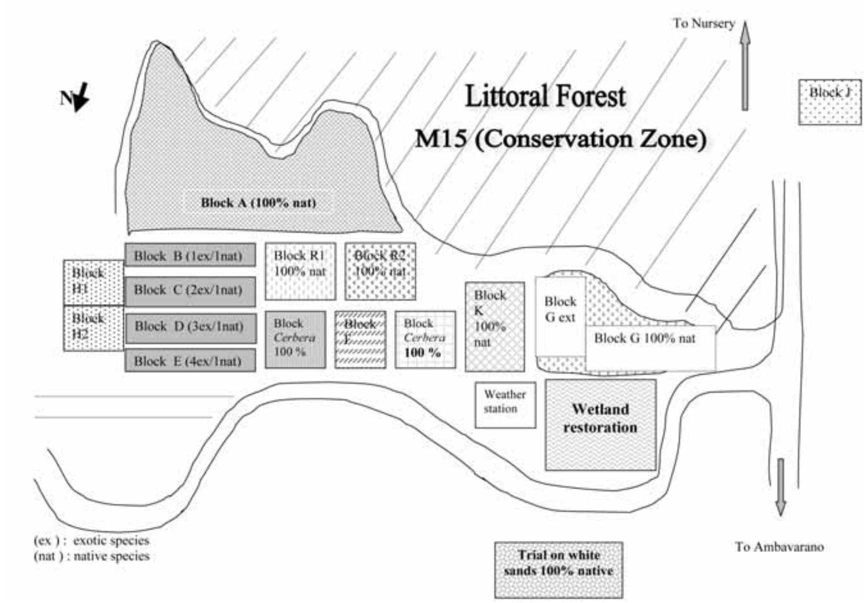

Figure 2. Restoration block trial at Mandena. Block G ext. = Block G extension.

						A	E	N	A	E	N
						N	A	E	N	A	E
						A	E	N	A	E	N
						N	A	E	N	A	E
						E	A	N	E	A	N

Figure 3. Schematic view of plantations consisting of 33% native tree species (N), 33% *Eucalyptus robusta* (E), and 33% *Acacia mangium* (A).

normality and could not be transformed to match the requirement for parametric analysis. Therefore, only non-parametric tests were used for the analysis of survival rates. For the sake of uniformity, growth rates, which did not deviate significantly from normality, were also analyzed with non-parametric tests using SPSS (1999). Significance levels in multiple pair-wise comparisons were Bonferroni corrected.

The following aspects were analyzed:

1. Degree of demineralization of the sand with three classes:
   - Large scale demineralization to a depth of 2 m (mimicking the mining process: Site 4);
   - Simulated demineralization (Blocks R1 and R2);
   - No demineralization.
2. Arrangement of topsoil with two classes:
   - Continuous cover of the plantation area with 20 cm of topsoil;
   - Topsoil added only to the hole where the sapling was planted.
3. Distance to natural forest as a source for regeneration.
4. Plantations of native tree species with or without exotic species as shade trees with two classes:
   - No exotic trees;
   - With exotic trees: 20 – 80% of the saplings were *Acacia mangium* or *Eucalyptus robusta*. The experimental blocks B – F and J were designed to test the impact of *A. mangium* and *E. robusta* on the growth of saplings of native tree species. Considering only the plantations with various percentages of exotic species (Blocks B – F and J), there was no correlation between the percentage of exotic species and the survival or growth rates of native tree species. Therefore, we classified these blocks as plantations either with or without exotic tree species.

5. Successional stages of tree species with three classes based on studies on forest succession:
   • Pioneer (sun-loving);
   • Intermediate;
   • Late successional (climax or shade-loving).
6. Trees with ectomycorrhiza, nitrogen fixation, and unknown microbial associations.

Table 1. Date of plantation and mixtures of native trees with various percentages of exotic tree species at Mandena. % Er = percentage of *Eucalyptus robusta*, and % Am = percentage of *Acacia mangium* compared to the total number of saplings planted. If not otherwise noted, a 20 cm layer of topsoil was added to a planting hole of 40 x 40 cm.

Site / Block	Treatment	Date of plantation month/year	# Native tree species	# Native trees	% Native trees	% Er	% Am
Plantation on demineralized sand: native species							
Site 4	Large scale demineralized sand (35 x 35 x 2 m) covered with a layer of 20 cm topsoil spread over the whole area; saplings planted at 2 m intervals.	09/1999	39	296	100	0	0
Site 4 Extension	Additional saplings planted in 1 m intervals at Site 4 between the trees planted in 1999; plants were 50% pioneer, 40% intermediate, and 10% climax species.	01/2002	41	853	100	0	0
Plantation on partially demineralized sand: native species							
Block R1	Removal of soil in a hole of 100 x 100 x 40 cm prior to planting; incomplete simulation of humus removal during mining.	04/2000	29	100	100	0	0
Block R2		04/2000	29	100	100	0	0
Plantation on non-demineralized sand: native species; plantations close to natural forest							
Block A	20 cm layer of topsoil around sapling.	05/2000	19	291	100	0	0
Block G	Plantations as corridors to link an artificial swamp with the native forest; special emphasis on the plantation of *Pandanus dauphinensis* as a habitat for frogs; 20 cm layer of topsoil around sapling.	11/2000	26	134	100	0	0
Block G Extension		11/2002	20	39	100	0	0
Block K	20 cm layer of topsoil spread over the whole plantation area.	04/2002	47	283	100	0	0
Plantation on non-demineralized sand: native species; plantations away from natural forest							
Block H1	20 cm layer of topsoil around sapling.	01/2001	11	214	100	0	0
Block H2		01/2001	15	411	100	0	0
Plantation on non-demineralized sand: native species mixed with *Acacia* and *Eucalyptus*							
Block B	Addition of fast growing exotic species planted to attain vegetation cover as quickly as possible and to provide shade for native saplings.	05/2000	17	85	50	25	25
Block C		05/2000	10	98	33	33	33
Block D		05/2000	12	91	25	37.5	37.5
Block E		05/2000	13	67	20	40	40
Block F		05/2000	19	145	34	33	33
Block J		05/2000	13	302	33	33	33
Corridor M4-M5	Corridor between forest fragments M4 and M5.	07/1999	not recorded	450	20	40	40

Results

Ninety-two species of native trees were used in the experiments. The results reported here are based on the survival rates and growth characteristics. The blocks R1 and R2 were difficult to assign to one of the treatments because it was unclear whether the preparation of the soil actually mimicked the mining process in the same way as that of Site 4. Possibly, the survival rates of the plants growing in these two blocks were rather similar to those in the extension of Site 4 on demineralized soil. In contrast, growth rates were similar to those of the trees planted on untreated sand. Due to this uncertainty of how to assign these two blocks, they are not considered further. Blocks H1 and H2 were destroyed by fire and subsequently overgrown by *Melaleuca quinquenervia* (Myrtaceae), and have also been removed from the analysis.

Survival rates

Survival rates of different native species in the demineralized sand at Site 4 (i.e. the precise model for reforestation after mining) ranged between 73 and 100% after 1.5 years, with a median of 100%. Survival remained high with a median of 90% after five years (Tables 2, 3). In the plantations on non-demineralized sand, the survival rates were variable (Tables 2, 4). Survival of native trees was reduced in the mixed stands where the native trees were surrounded by exotic species. There, the average survival ranged between 33% and 100% after one year and dropped to 0 – 50% after 63 months (Tables 2, 5). In the corridor, the exotic species survived but all native species had died 2-3 years after plantation before measurements were taken. The experiment was not followed up because the two forest fragments were destroyed by charcoal makers in 2005. Survival rates decreased significantly with time in all plantations (Table 2). Except for the plantation at Block J, the survival rates of *Eucalyptus robusta* and *Acacia mangium* were close to 100% after five years at all plantations (Table 2).

Effect of demineralization

To study the effect of demineralization (i.e. the mining process), the survival rates of trees planted at Site 4 were compared with those of trees planted without exotic species for shade (i.e. Blocks A and G). Survival rates were higher at Site 4 than at the other sites (Mann Whitney U test: $z = 2.02$, $p = 0.04$; Fig. 4). The difference becomes non-significant after Bonferroni correction.

The effects of exotic trees for shade were studied by comparing tree performance in non-demineralized blocks with (Blocks B – F and J) and without (Blocks A and G) exotic species.

Survival rates were significantly reduced in blocks with exotic trees compared to those without (Mann-Whitney U test: $z = 2.64$; $p = 0.008$; Fig. 5). The difference remained significant with $p < 0.05$ after Bonferroni correction.

Differences between species belonging to different successional stages

Survival rates did not differ between pioneer, intermediate, and climax species when all sites were combined, or when data were analyzed per treatment group (demineralized/non-demineralized with or without exotic tree species; according to Kruskal-Wallis Analyses of Variance; Fig. 6).

Trees with ectomycorrhiza, nitrogen-fixation, and unknown microbial associations

All species of the family Sarcolaenaceae from the littoral forest are known to have ectomycorrhiza (Ducousso *et al*. 2004). Of the potentially nitrogen

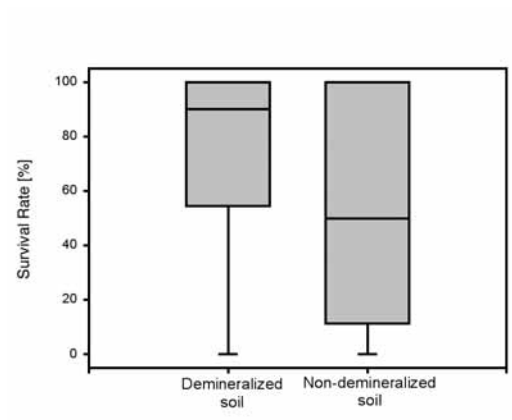

Figure 4. Effect of demineralization: Survival rates of native tree species after 60 months on demineralized sand (Site 4), and after 57 months on non-demineralized sand (Blocks A and G combined). Values are medians, quartiles, and ranges based on species means.

Table 2. Average survival and annual growth rates (in cm) of native tree species measured at different times after plantation. N = number of species. In the calculation of growth rates, only surviving species were considered. Values are medians and quartiles for survival rates (listed as Q_{25} – median – Q_{75}), and means and standard deviations for growth rates. The calculation of these statistics was based on the mean value of each species per site. Sample sizes of the different tree species are listed in Tables 3, 4, and 5.

Block	Months after plantation	Survival N	Survival %	Annual growth N	Annual growth cm
Plantation on demineralized sand: native species					
Site 4	17	39	73 – 100 - 100		
	60	39	55 – 90 - 100	33	13.1 ± 13.0
Site 4 Extension	36	41	6 – 44 - 72	31	6.3 ± 6.5
Plantation on partially demineralized sand: native species					
R1	13	29	55 – 100 – 100		
57	29	0 – 40 - 94		15	21.1 ± 15.5
R2	13	29	44 – 88 – 100		
	57	29	0 – 25 – 100	18	17.6 ± 12.8
Plantation on mineralized sand: native species					
A	13	19	30 – 67 – 83	17	24.1 ± 14.7
	57	19	9 – 26 – 33	16	22.6 ± 14.9
G	13	26	81 – 100 – 100	23	21.0 ± 17.5
	57	26	55 – 94 – 100	21	18.8 ± 13.0
G Extension	32			20	12.3 ± 7.2
K	33	47	20 – 71 – 100	39	11.1 ± 9.5
Plantation on mineralized sand: native species mixed with *Acacia* and *Eucalyptus*					
B	12	17	50 – 67 – 100		
	63	17	0 – 33 – 100	13	12.8 ± 7.9
C	12	10	88 – 100 - 100		
	63	10	0 – 0 – 100	4	12.9 ± 5.5
D	12	12	0 – 75 – 100		
	63	12	0 – 0 – 75	4	6.1 ± 4.3
E	12	13	0 – 50 – 100		
	63	13	0 – 0 – 100	5	16.5 ± 9.0
F	12	19	50 – 100 – 100		
	63	19	0 – 50 - 67	15	16.6 ± 9.6
J	12	14	0 – 33 – 100		
	63	14	0 – 0 - 2	4	7.3 ± 3.0

fixing family Fabaceae, only *Intsia bijuga* was represented in the restoration experiments. Microbial associations of the other species are unknown. Given that the majority of tree species in the tropics have endomycorrhiza (Wilcoxon 2001), all other species were classified as "other" meaning no ectomycorrhiza and no fixation of nitrogen from the air with the help of bacteria. Only blocks without exotic trees were used in this analysis.

Species of all three groups had higher survival rates when planted in demineralized soil than in non-demineralized soil. Under both conditions, nitrogen-fixing species had the highest survival rates, followed by the species of the "other" group. Species with ectomycorrhiza had the lowest survival rates. Low sample size prohibited statistical analysis.

Figure 5. Effect of exotic tree species: Survival rates of native tree species after 63 months on non-demineralized sand with exotic tree species (Blocks B - F and J combined), and after 57 months without exotic tree species (Blocks A and G combined). Values are medians based on species means, quartiles, and ranges.

Growth rates

Measurements of growth rates of the same plants for different periods were available for Blocks A and G (Table 2). At these sites, growth rates did not differ between the measured periods of one and five years (Wilcoxon test; z = 0.28, n = 34, not significant). Therefore, growth rate was considered to have been constant during the time period considered here (up to five years after plantation). For all subsequent analyses of growth rates, we employ the value per block of the longest period for which measurements were available. Growth rates for exotic tree species were much higher than those of the native species. Five years after plantation, exotic trees were 6 - 9 m tall while the native species were much shorter (Tables 3, 4, 5).

Effect of top soil restricted to holes or spread over large surfaces

Block G - extension (20 cm layer of topsoil around individual saplings) and Block K (20 cm layer of topsoil over the entire plantation) were used to test whether the distribution of topsoil affects the growth of the saplings. Both blocks consist only of native trees. Growth of the saplings was measured in these two blocks 32 and 33 months after plantation. Annual growth rates were almost identical to 12.3 ± 7.2 cm per year in the extension of Block G, and 11.1 ± 9.5 cm in Block K. Growth rates are based on 20 and 39 tree species, respectively (Table 1). The difference is not significant (Mann Whitney U test: z = 0.99, $p > 0.05$).

Effect of demineralization

To study the effect of demineralization (i.e. the mining process), growth rates of trees planted at Site 4 were compared with trees planted in Blocks A and G. The latter blocks do not have exotic tree species for shade. Growth rates were lower at Site 4 (mean = 13.1 ± 13.0; n = 33) than at sites A and G (mean = 20.4 ± 13.8; n = 37; Mann Whitney U test: z = 2.31, p = 0.021; Fig. 7).

Effects of exotic trees for shade

The effects of exotic trees for shade were studied by comparing tree performance in non-demineralized blocks with (Blocks B – F and J; n = 45) and without exotic trees (Blocks A and G; n = 37). For the tree species that survived, growth rates were reduced

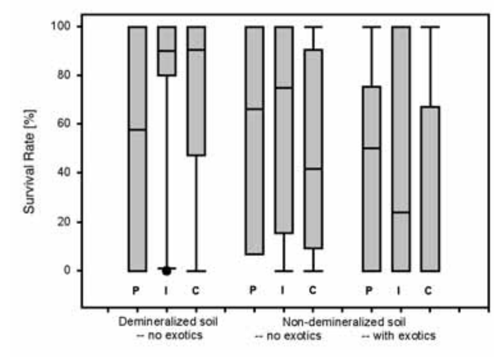

Figure 6. Differences between successional stages: Survival rates of native tree species assigned to different successional stages (P = pioneer; I = intermediate; C = climax) after 60 months on demineralized sand (Site 4), after 57 months on non-demineralized sand without exotic trees (Blocks A and G combined), and after 63 months on non-demineralized sand with exotic trees (Blocks B - F and J combined). Values are medians, quartiles, and ranges based on species means.

in blocks with exotic trees compared to blocks without exotic trees (Mann Whitney U test: z = 2.19, p = 0.29). However, the difference is not significant after Bonferroni correction (Fig. 8).

Differences between species of different successional stages

The question of whether tree species assigned to different successional stages differed in growth rates was restricted to the blocks without exotic species. Growth rates were lower at Site 4, but did not differ between species assigned to different successional stages (two-factorial ANOVA - successional stage: F = 2.11, $p > 0.05$; demineralization: F = 6.08, $p < 0.05$; interaction not significant). The results for all treatments are summarized in Figure 9.

Trees with ectomycorrhiza, nitrogen-fixation, and unknown microbial associations

Growth rates of species with different microbial associations varied significantly in relation to treatments. When planted in non-demineralized soil, species with ectomycorrhiza and nitrogen-fixing

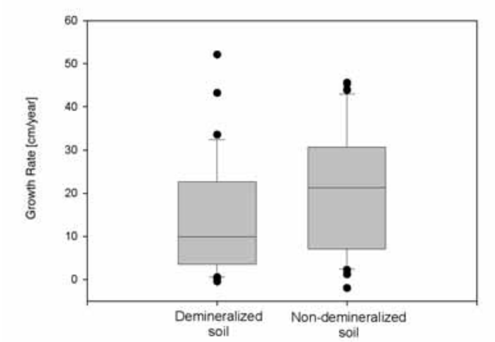

Figure 7. Effect of demineralization: Growth rates of native tree species after 60 months on demineralized sand (Site 4), and after 57 months on non-demineralized sand (Blocks A and G combined). Values are medians based on species means, 10, 25, 75, and 90 percentiles, and values outside the 10/90 percentiles.

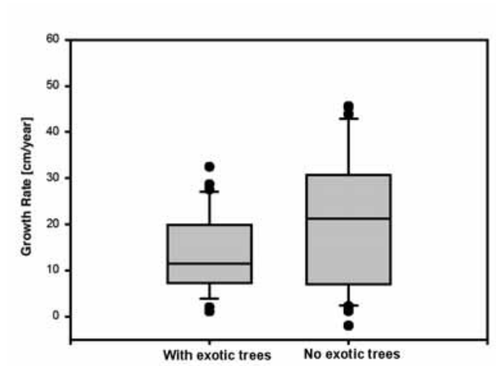

Figure 8. Effect of exotic tree species: Growth rates of native tree species after 63 months on non-demineralized sand with exotic trees (Blocks B - F and J combined), and after 57 months without exotic trees (Blocks A and G combined); values as in Figure 7.

bacteria did not grow as fast as the "other" species. On demineralized soil, the results were reversed. Here species with ectomycorrhiza and nitrogen-fixing bacteria had higher growth rates than the "other" species (Table 6).

Discussion

Survival rates

The demineralization of sandy soils as during mining (i.e. the removal of the heavy minerals, such as ilmenite ($FeTiO_2$) and zircon) did not have any measurable effect on the survival rates of trees. These minerals are stable and do not seem to be taken up by plants, which need ions in water solution for assimilation. Several trees produced flowers and fruits, and hence, demineralization did not seem to affect the reproductive state of the plants.

Native trees planted in combination with the exotic species *Eucalyptus robusta* and *Acacia mangium* had a very low survival rate or were totally overtaken by the exotic species. Within five years, the exotic species reached heights of at least 5 m. Only a few shade tolerant species such as *Apodytes bebile*, *Astrotrichilia ellioti*, and *Poupartia chapelieri* survived under these conditions. However, it is unclear whether the low survival rate of the native species is due to competition for light or allelochemical interactions with products from the exotic trees (Harborne 1993). In the experimental plots without these exotic tree species, native species from the sun-loving/pioneer and intermediate classes survived well. These plants will probably be important for the first stage of restoration of native littoral forest after mining.

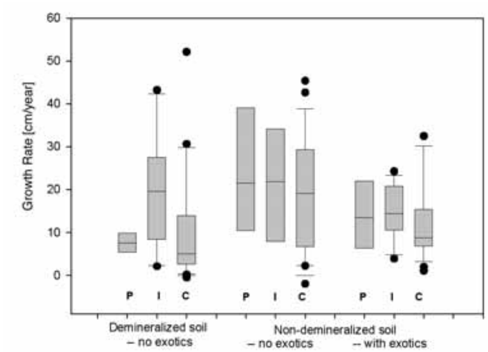

Figure 9. Differences between successional stages: Survival rates of tree species assigned to different successional stages (P = pioneer; I = intermediate; C = climax) after 60 months on demineralized sand (Site 4), after 57 months on non-demineralized sand without exotic trees (Blocks A and G combined), and after 63 months on non-demineralized sand with exotic trees (Blocks B - F and J combined); values as in Figure 7.

Growth rates

The effects of the various factors on the growth rates of plants are difficult to evaluate. All experiments have been performed under non-nursery conditions. The environmental conditions certainly differed between plots (such as humidity and ambi-

Table 3. Survival rate and height of trees in native tree species plantations on demineralized soil. Type: tree species were assigned to P = pioneer, S = sun-loving, I = intermediate, and C = late successional (climax/shade-loving) species. Table 1 provides explanations of the block codes (e.g., R1, R2, S4). Np = number of saplings planted; %s = percentage of trees surviving either 13, 17, 36, 57, or 60 months after plantation; H = height (in cm) for 36, 57, or 60 months after plantation. For family names of the different plant species see Rabenantoandro *et al*. Chapter 3.1.

Latin Name	Vernacular Name	Family	Type	R1	R1	R1	R1	R2	R2	R2	R2	S4	S4	S4	S4	S4 Ex	S4 Ex	S4 Ex
				Np	%s 13	%s 57	H 57	Np	%s 13	%s 57	H 57	Np	%s 17	%s 60	H 60	Np	%s 36	H 36
Ophiocolea delphinensis	*akondronala*	Bignoniaceae	I	1	100	100	20	1	0	0	.	2	100	100	29	25	60	16
Plagioscyphus louvelii	*ambirimpiso*	Sapindaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tambourissa castri-delphinii	*ambora*	Monimiaceae	I	.	.	.	.	.	.	.	.	.	.	.	.	25	48	32
Vepris elliottii	*ampoly*	Rutaceae	I	2	100	100	175	2	100	100	53	9	89	89	92	25	92	16
Trema orientalis	*andrarezo*	Ulmaceae	I	6	83	0	.	6	100	17	20	21	24	5	20	21	0	.
Crataeva obovata	*belataka*	Brassicaceae	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dombeya mandenensis	*berehoka*	Malvaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	25	44	17
Trilepisium madagascariense	*beronono*	Moraceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dypsis prestoniana	*boakandambo*	Arecaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dypsis lutescens	*jambo coo*	Arecaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Garcinia sp.	*ditsaky*	Clusiaceae	I	.	.	.	.	1	100	100	35	.	.	.	.	.	.	.
Dracaena bakeri	*falinandro*	Convallariaceae	I	.	.	.	.	.	.	.	.	.	.	.	.	25	64	40
Dracaena reflexa	*falinandro be*	Convallariaceae	C-I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Aphloia theiformis	*fandramanana*	Aphloiaceae	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Mollugo decandra	*fandriakibo*	Aizoaceae	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Asteropeia multiflora	*fanola*	Asteropeiaceae	I	1	100	0	.	1	100	0	.	2	50	100	122	2	0	.
Canthium sp.	*fantsikahitra*	Rubiaceae	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Burasaia madagascariensis	*farisaty*	Menispermaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ficus sp.	*fihamy*	Moraceae	C	4	0	0	.	4	50	0	.	10	80	20	86	1	0	.
Vernoniopsis caudata	*fitobohantsiny*	Asteraceae	S	5	60	40	63	5	100	100	132	10	0	0	.	1	0	.
Leptolaena multiflora	*fonto*	Sarcolaenaceae	P	8	88	0	.	8	38	0	.	21	91	90	124	32	88	35
Leptolaena pauciflora	*fontomadinika*	Sarcolaenaceae	P	2	50	50	81	2	50	100	48	5	0	0	.	.	.	.
Schizolaena elongata	*fontondahy*	Sarcolaenaceae	P	.	.	.	.	.	.	.	.	.	.	.	.	25	88	60
Diospyros sp.	*forofoka*	Ebenaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Leptolaena delphinensis	*fotombavy*	Sarcolaenaceae	C-I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Podocarpus madagascariensis	*harambilo*	Podocarpaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Intsia bijuga	*harandranto*	Fabaceae	S	4	25	0	.	4	50	0	.	13	100	100	163	.	.	.
Psorospermum revolutum	*harongampanihy*	Clusiaceae	C-I	4	75	75	107	4	75	50	88	10	90	90	59	27	85	28
Stephanodaphne cremostachya	*havoa*	Thymelaeaceae	C	.	.	.	.	.	.	.	.	3	100	100	71	.	.	.
Diospyros gracilipes	*hazomainty*	Ebenaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	25	68	17
Apodytes bebile	*hazomamy*	Icacinaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	25	44	13
Campylospermum obtusifolium	*hazombato*	Ochnaceae	S	.	.	.	.	.	.	.	.	.	.	.	.	25	72	15
Cerbera manghas	*kabokala*	Apocynaceae	C-I	8	100	88	140	8	88	63	113	27	93	93	66	27	74	39
Drypetes madagascariensis	*kambatrikambatry*	Euphorbiaceae	S	.	.	.	.	.	.	.	.	.	.	.	.	3	0	.
Elaeodendron alluaudianum	*kotofotsy*	Celastraceae	C	.	.	.	.	.	.	.	.	.	.	.	.	23	78	22
Noronhia sp.	*lahinampoly*	Oleaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Anthocleista madagascariensis	*lendemy*	Gentianaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Oncostemum sp.	*lona*	Myrsinaceae	S	.	.	.	.	.	.	.	.	.	.	.	.	26	15	27
Brochoneura acuminata	*mafotra*	Myristicaceae	C	.	.	.	.	.	.	.	.	1	100	100	30	.	.	.
Cynometra cloiselii	*mampay*	Fabaceae	S	.	.	.	.	.	.	.	.	1	100	0	.	.	.	.
Trachylobium verrucosa	*mandrorofo*	Fabaceae	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Homalium brevipedunculatum	*marankoditra*	Salicaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rinorea pauciflora	*membaloha*	Violaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Erythroxylum myrtoides	*menavoa*	Erythroxylaceae	I	.	.	.	.	.	.	.	.	.	.	.	.	.	100	10
Sarcolaena multiflora	*meramaitso*	Sarcolaenaceae	I	3	100	100	17	3	33	33	65	11	100	82	226	97	24	72
Sarcolaena eriophora	*meramavo*	Sarcolaenaceae	I	7	0	0	.	7	0	0	.	23	96	91	177	1	0	.
Faucherea hexandra	*nato*	Sapotaceae	C	6	100	83	67	6	100	100	100	12	83	83	141	26	85	28
Syderoxylon sp.	*natobonaka*	Spotaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Vitex chrysomalum	*nofotrakoho*	Lamiaceae	S	1	100	0	.	1	100	0	.	1	100	100	36	.	.	.
Ficus sp.	*nonoky*	Moraceae	C	4	100	100	45	4	75	25	20	11	100	55	35	25	28	98

Table 3. continued

Latin Name	Vernacular Name	Family	Type	R1	R1	R1	R1	R2	R2	R2	R2	S4	S4	S4	S4	S4 Ex	S4 Ex	S4 Ex
				Np	%s 13	%s 57	H 57	Np	%s 13	%s 57	H 57	Np	%s 17	%s 60	H 60	Np	%s 36	H 36
Pandanus dauphinensis	*vakoa*	Pandanaceae	C	6	0	0	.	6	0	0	.	15	73	80	27	28	50	27
Homalium albiflorum	*ramirisa*	Salicaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Canarium bullatum ined.	*ramy*	Burseraceae	P	.	.	.	.	.	.	.	.	1	0	0	.	1	0	.
Ambavia gerardii	*roandria*	Annonaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	24	67	42
Eugenia cloiselii	*ropasy*	Myrtaceae	S	.	.	.	.	.	.	.	65	.	.	.	.	25	56	20
Eugenia sp.	*ropoaky*	Myrtaceae	I	1	100	0	.	1	0	0	.	2	100	100	13	0	0	.
Syzigium emirnensis	*rotry*	Myrtaceae	I	4	25	75	105	4	75	25	110	12	75	75	72	28	43	16
Tina thouarsiana	*sagnirambazana*	Sapindaceae	C	1	100	100	280	1	100	100	170	1	100	100	7	.	.	.
Macphersonia radlkoferi	*sagnirifotsy*	Sapindaceae	S	1	100	0	.	1	100	100	235	1	0	0	.	1	0	.
Turraea lanceolata	*sakaimboalavo*	Meliaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	25	40	14
Albizia mahalao	*sambalahy*	Fabaceae	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Astrotrichilia ellioti	*sanira*	Meliaceae	S	.	.	.	.	.	.	.	.	3	100	100	27	.	.	.
Malleastrum mandenense	*sarigoavy*	Meliaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	25	24	11
Ficus reflexa	*sarinonoka*	Moraceae	C	2	0	0	.	2	0	0	.	5	100	60	12	24	25	15
Scutia myrtina	*senty*	Rhamnaceae	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Poupartia chapelieri	*sisikandrongo*	Anacardiaceae	S	.	.	.	.	.	.	.	.	1	100	100	270	.	.	.
Garcinia sp.	*sivory*	Clusiaceae	C	.	.	.	.	.	.	.	.	1	100	100	58	.	.	.
Rhodocolea racemosa	*somontsoy*	Bignoniaceae	C	.	.	.	.	.	.	.	.	1	100	100	62	.	.	.
Phylloxylon xylophylloides	*sotro*	Fabaceae	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hypericanthus mandenensis	*taholagna*	Rubiaceae	I	.	.	.	.	.	.	.	.	3	67	67	11	.	.	.
Gaertnera sp.	*tanatananala*	Rubiaceae	S	4	100	75	65	4	100	25	75	10	60	40	20	26	23	28
Petchia madagascariensis	*tandrokosy*	Apocynaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dracaena reflexa	*tavolobotraky*	Convallariaceae	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cryptocarya sp.	*tavolohazo*	Lauraceae	C	.	.	.	.	.	.	.	.	2	100	100	40	.	.	.
Ocotea brevipes	*tefimoa*	Lauraceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Memecylon delphinensis	*tomizo*	Melastomataceae	C	.	.	.	.	.	.	.	.	.	.	.	.	25	12	19
Rhopalocarpus coriaceus	*tsilavimbinato*	Sphaerosepalaceae	S	1	100	0	.	1	100	0	.	2	100	100	29	.	.	.
Dodonea viscose	*tsiokanomby*	Asteraceae	P	7	100	100	135	7	100	100	143	26	89	58	59	28	43	12
Croton sp.	*tsivoanio*	Euphorbiaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Secamone sp.	*vahifotsy*	Asclepiadaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Flagellaria indica	*vahipiky*	Flagellariaceae	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dillenia triquetra	*varikandana*	Dilleniaceae	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Morella spathulata	*voalaka*	Myricaceae	P	4	100	75	227	4	100	100	182	10	40	80	123	5	0	.
Plagioscyphus jumellei	*voambirimbarika*	Sapindaceae	C	1	100	0	.	1	100	100	25	1	100	0	.	.	.	.
Brexia madagascariensis	*voankarepoka*	Celastraceae	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Homalium albiflorum	*voankazoala*	Salicaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cuphocarpus aculeatus	*voantsilana*	Araliaceae	I	1	100	100	120	.	.	.	.	3	100	100	137	25	72	42
Uapaca littoralis	*voapaky*	Euphorbiaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	1	100	30
Phyllarthron ilicifolium	zahambe	Bignoniaceae	C	.	.	.	.	.	.	.	.	.	.	.	.	25	64	16
Grisollea sp.	*zambo*	Icacinaceae	C	2	100	0	.	2	50	0	.	3	100	100	25	.	.	.
Dycoryphe stipulacea	*zora lahy*	Hamamelidaceae	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Scolopia erythrocarpa	*zora mena*	Salicaceae	C	.		.	.	.	.	.	.	.	.	.	.	.	.	.

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Table 4. Survival rate and height of trees in native tree species plantations on mineralized soil. For explanations of block codes (A, G, K) see Table 1, and for other abbreviations see Table 3. For family names of the different plant species see Rabenantoandro *et al.* (Chapter 3.1.)

Latin name	Type	A	A	A	A	A	G	G	G	G	G	G Ext	G Ext	K	K	K
		Np	%s 13	H 13	%s 57	H 57	Np	%s 13	H 13	%s 57	H 57	Np	H 32	Np	%s 33	H 33
Ophiocolea delphinensis	I	10	30	7	10	15	5	100	.	100	33		.	1	100	9
Plagioscyphus louvelii	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Tambourissa castri-delphinii	C-I	.	.	.	.	.	.	.	.	.	.		.	4	50	39
Vepris elliotii	I	.	.	.	.	.	.	.	.	.	.		.	3	133	28
Trema orientalis	I	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Crataeva obovata	C-I	.	.	.	.	.	.	.	.	.	.		.	3	0	.
Dombeya mandenensis	C	.	.	.	.	.	.	.	.	.	.	3	16	19	100	22
Trilepisium madagascariensis	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Dypsis prestoniana	C	.	.	.	.	.	.	.	.	.	.		.	5	80	53
Dypsis lutescens	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Garcinia sp.	I	.	.	.	.	.	.	.	.	.	.		.	5	40	35
Dracaena bakeri	I	.	.	.	.	.	.	.	.	.	.		.	5	20	5
Dracaena reflexa	C-I	.	.	.	.	.	.	.	.	.	.	1	34	.	.	.
Aphloia theiformis	P	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Mollugo decandra	P	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Asteropeia multiflora	C-I	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Canthium sp.	C	.	.	.	.	.	.	.	.	.	.		.	1	0	.
Burasaia madagascariensis	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Ficus sp.	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Vernoniopsis caudata	P	.	.	.	.	.	1	100	23	100	172		.	.	.	.
Leptolaena multiflora	C	3	67	42	33	90	.	.	.	.	.		.	.	.	.
Leptolaena pauciflora	C-I	.	.	.	.	.	.	.	.	.	.		.	6	83	65
Schizolaena elongata	C	.	.	.	.	.	.	.	.	.	.		.	2	100	97
Diospyros sp.	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Leptolaena delphinensis	C-I	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Podocarpus madagascariensis	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Intsia bijuga	C	15	20	24	53	87	9	100	59	78	24	1	65	.	.	.
Psorospermum revolutum	C-I	30	63	40	0	.	8	100	32	75	90	1	49	9	89	28
Stephanodaphne cremostachya	C	3	67	27	33	110	.	.	.	.	.		.	4	25	34
Diospyros gracilipes	C	.	.	.	.	.	.	.	.	.	.		.	15	0	.
Apodytes bebile	C	15	40	37	27	117	1	100	57	100	170	2	51	.	.	29
Campylospermum obtusifolium	P	.	.	.	.	.	.	.	.	.	.		.	2	0	.
Cerbera manghas	C-I	19	100	68	37	137	14	100	38	100	89	2	50	5	100	33
Drypetes madagascariensis	C	.	.	.	.	.	.	.	.	.	.	1	28	4	100	20
Elaeodendron alluaudianum	C	.	.	.	.	.	.	.	.	.	.		.	19	95	35
Noronhia sp.	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Anthocleista madagascariensis	C	.	.	.	.	.	5	100	28	100	157		.	1	100	53
Oncostemum sp.	C	.	.	.	.	.	.	.	.	.	.		.	20	10	20
Brochoneura acuminata	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.

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Table 4. continued

Latin name	Type	A	A	A	A	A	G	G	G	G	G	G Ext	G Ext	K	K	K
		Np	%s 13	H 13	%s 57	H 57	Np	%s 13	H 13	%s 57	H 57	Np	H 32	Np	%s 33	H 33
Cynometra dauphinensis	C	3	100	18	0	.	4	75	13	75	21		.	2	50	39
Hymenaea verrucosa	I	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Homalium brevipedunculatum	C	6	83	50	50	212	.	.	.	.	.		.	3	100	48
Rinorea pauciflora	C	.	.	.	.	.	.	.	.	.	.		.	1	0	.
Erythroxylum myrtoïdes	I	.	.	.	.	.	.	.	.	.	.	2	15	7	71	10
Sarcolaena multiflora	C-I	.	.	.	.	.	.	.	.	.	.	4	18	1	0	.
Sarcolaena eriophora	C-I	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Faucherea hexandra	C	.	.	.	.	.	.	.	.	.	.	1	66	.	.	.
Syderoxylon sp.	C	18	72	32	28	148	2	50	18	50	225		.	6	100	39
Vitex chrysomalum	P	11	18	16	9	25	2	50	39	0	.		.	14	100	46
Ficus reflexa	C	16	69	30	13	50	6	83	.	0	.	1	44	3	100	25
Pandanus dauphinensis	C	27	7	.	0	.	24	96	18	88	46	8	35	12	67	22
Homalium albiflorum	C	.	.	.	.	.	.	.	.	.	.		.	.	.	62
Canarium bullatum	C	.	.	.	.	.	3	100	37	100	149		.	1	0	.
Ambavia gerrardii	C	19	58	32	26	176	.	.	.	.	.	2	78	6	67	57
Eugenia cloiselii	C	19	84	33	32	113	6	100	.	100	80	1	38	2	100	44
Eugenia sp.	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Syzygium emirnensis	C	18	61	34	17	140	.	.	.	.	.	1	51	7	100	38
Tina thouarsiana	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Macphersonia radlkoferi	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Turraea lanceolata	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Albizia sp.	Ex	.	.	.	.	.	1	100	12	100	111		.	.	.	.
Astrotrichilia elliotii	C	.	.	.	.	.	4	100	40	75	26		.	.	.	.
Malleastrum mandenense	C	.	.	.	.	.	3	100	63	0	.	4	11	23	30	13
Ficus sp.	C	.	.	.	.	.	.	.	.	.	.		.	13	0	.
Scutia myrtina	P	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Poupartia chapelieri	C	3	0	.	0	0	.	.	.	.	.		.	.	.	.
Garcinia sp.	C	.	.	.	.	.	1	100	9	100	40		.	.	.	.
Rhodocolea sp.	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Phylloxylon xylophylloides	C	.	.	.	.	.	2	50	7	0	.		.	1	100	60
Hypericanthus mandenensis	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Gaertnera sp.	C	.	.	.	.	.	4	100	17	100	116		.	2	50	15
Petchia madagascariensis	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Dracaena reflexa	C-I	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Cryptocarya sp.	C	.	.	.	.	.	7	100	40	0	.		.	.	.	.
Ocotea cymosa	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Memecylon delphinensis	C	.	.	.	.	.	.	.	.	.	.		.	3	33	18
Rhopalocarpus coriaceus	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Dodonea viscose	P	37	95	61	32	218	3	67	33	100	93		.	.	.	.
Croton sp.	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Secamone sp.	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Flagellaria indica	C-I	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Dillenia triquetra	C-I	.	.	.	.	.	.	.	.	.	.	1	49	6	100	59
Morella spathulata	C-I	.	.	.	.	.	4	100	80	100	154		.	1	100	95
Plagioscyphus jumelii	C	.	.	.	.	.	1	100	21	100	20		.	3	0	.
Brexia madagascariensis	C-I	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Homalium albiflorum	C	.	.	.	.	.	.	.	.	.	.	1	55	1	0	.
Cuphocarpus aculeatus	C-I	19	79	53	21	226	7	86	40	86	178		.	1	100	133
Uapaca littoralis	C	.	.	.	.	.	7	71	16	57	74		.	15	20	30
Phyllarthron ilicifolium	C	.	.	.	.	.	.	.	.	.	.	1	25	8	63	21
Grisollea sp.	C	.	.	.	.	.	.	.	.	.	.		.	2	100	15
Dycoryphe stipulacea	C	.	.	.	.	.	.	.	.	.	.		.	.	.	.
Scolopia erythrocarpa	C	.	.	.	.	.	.	.	.	.	.	1	66	6	100	59

Table 5. Survival rate and height of tree species planted with different proportions of *Acacia mangium* and *Eucalyptus robusta* as cover crops**.** For explanations of block codes (B, C, D, E, etc.) see Table 1, and for other abbreviations see Table 3. For family names of the different plant species see Rabenantoandro *et al.* Chapter 3.1.

Latin Name	B				C				D				E				F				J			
	Np	%s 12	%s 63	H 63	Np	%s 12	%s 63	H 63	Np	%s 12	%s 63	H 63	Np	%s 12	%s 63	H 63	Np	%s 12	%s 63	H 63	Np	%s 12	%s 63	H 63
Acacia mangium	22	100	100	875	40	100	100	845	37	92		604	27	93	93	770	48		96	806	76	86	61	440
Eucalyptus robusta	21		95	638	41	100	100	732	37	95		592	26	100	100	683	46		92	590	92		75	269
Ophiocolea delphinensis	1	0	0		1	100	0						1	0	0		2	50	50	30	2	50	0	
Vepris elliotii													1	100	100	120								
Crataeva obovata																					51	0	0	
Flacourtia ramontchii	2	50	0										1	100	0		2	100	0		2	0	0	
Leptolaena multiflora	1	0	0														1	100	0					
Intsia bijuga	2	50	50	50								60	1	0	0		3	67	33	55	2	0	0	
Psorospermum revolutum	6	67	67	119	3	100	100	63					1	0	0		5	40	40	100	5	100	100	45
Stephanodaphne chremostachya													1	100	0									
Apodytes bebile	2	100	100	40	1	100	0		1	100	100	30					2	50	50	50	3	33	0	
Diospyros gracilipes																				100				
Cerbera manghas	3	100	100	117	2	100	100	90	1	100	0						3	100	100	77	3	100	0	
Cynometra dauphinensis																	1	0	0					
Homalium brevipedunculatum	2	100	50	75													1	100	100	180	1	100	0	
Sideroxylon sp.	2	50	0		2	50	0		1	100	100	15	1	0	0		3	100	33	140				
Vitex chrysomalum	2	100	50	20	1	100	0		1	0	0						2	50	50	50	2	50	0	
Ficus reflexa	2	50	50	20	1	100	0		1	0	0		1	100	100	160	3	100	67	70				
Pandanus dauphinensis	4	25	25	55	2	0	0		2	0	0		1	0	0		4	0	0		3	100	67	35
Ambavia gerardii	3	100	0						1	100	0		1	0	0		3	33	0		3	0	0	
Eugenia closelii	2	100	100	60	1	100	0		2	0	0		1	100	100	50	3	67	67	45				
Syzygium emirnensis	3	67	33	80					2	50	0		1	100	100	50	3	100	33	180	3	33	0	
Poupartia chapelieri	1	100	100	150													1	100	100	80	1	0	0	
Rhodocolea racemosa								45	1	100	0													
Dodonea viscose	5	80	60	130	3	100	100	110	2	100	100	60	2	50	50	100	6	100	67	154				40
Cuphocarpus aculeatus				80					2	0	0						3	100	100	137	53	15	8	70

Table 6. Survival and growth rates of tree species with different types of symbiotic microorganisms in the rhizosphere. "Other" species summarize those for which these types of microbial associations are unknown, but which are unlikely to have neither ectomycorrhiza nor N-fixation. Values are means and standard errors. N = number of species based on species means (each species was used only once for the calculations of the means).

	Survival (%)		Annual growth (cm)	
	Non-demineralized soil	Demineralized soil	Non-demineralized soil	Demineralized soil
Ectomycorrhiza	33.0	65.9 ± 22.1	17.0	33.3 ± 5.9
	n = 1	n = 4	n = 1	n = 3
Nitrogen-fixation	82.8.0 ± 17.3	100.0	15.4 ± 6.2	30.7
	n = 2	n = 1	n = 2	n = 1
Other	82.8	70.4 ± 6.5	19.9 ± 2.7	10.4 ± 2.7
	n = 30	n = 34	n = 26	n = 29

ent temperature in relation to the distance from the forest edge) and these factors could not be controlled. Limitation of the number of plants produced in the tree nursery also prohibited balanced replicas using parallel numbers of the same species in the different experiments. These effects did not seem to be too dramatic in the analyses of the survival rates, but they are difficult to integrate and consider in the analyses of growth rates.

For example, the experiments using large-scale demineralized soil were carried-out far away from the natural forest (Fig. 1), while most of the other experiments were installed at the border of the natural forest (Fig. 2). In the tree nursery, saplings kept close to the edge of the natural forest grew more rapidly than the saplings further away from the forest edge. This is consistent with large-scale restoration experiments of fallow land in the evergreen rainforests of Brazil (Reisdorff *et al*. 2002). In addition, trees growing in small isolated patches of forest (i.e. groups of trees growing in an open landscape) were generally much smaller than those in the larger blocks of forest. These observations support the idea that restoration activities should commence by enlarging existing forest blocks rather than starting with isolated plantations.

The supply of topsoil has become a significant management issue at Mandena, especially since most natural forests outside the conservation zone were destroyed. The original plan was to collect topsoil from these forests before they were destroyed by mining. In this case, the topsoil found there could have been deposited at the reforestation sites. Since the addition of topsoil has a major impact on the growth of the saplings, it is important to use the remaining topsoil as efficiently as possible. In the experiments presented here, either saplings were planted with a 20 cm layer of topsoil concentrated around them, or in an area covered with a continuous, 10 cm layer of topsoil.

The idea of using exotic trees to provide shade and a suitable microclimate for saplings of native trees needs to be abandoned. Even though some exotic tree species such as *Eucalyptus robusta* might have fewer negative effects on the survival and growth of the native tree species, competition for light and growth-enabling components make these species unsuitable pioneer plants for the restoration of native littoral forests.

As shown in these experiments, associations of trees with nitrogen-fixing bacteria and mycorrhiza are ubiquitous and of paramount importance for the growth and survival of trees. The fungi can penetrate the roots and cells of their counterparts forming endomycorrhiza, or remain in close association with the roots without penetrating the cell, forming ectomycorrhiza. The latter forms mixed-mycelium root structures that largely increase the resorptive surface of the tree and facilitate the uptake of nutrients. Apart from increasing the resorptive surface of the root system, ectomycorrhizal fungi seem to be able to mobilize essential plant nutrients directly from minerals. This may be important in particular for forest restoration as it may enable ectomycorrhizal plants to extract essential nutrients from insoluble mineral sources by excretion of organic acids (Landeweert *et al*. 2001). Ectomycorrhizal symbioses are known in less than 5% of terrestrial plant species and are more common in temperate zones than in the tropics. Follow up research on ectomycorrhizal associations of the Sarcolaenaceae, a tree family endemic to Madagascar with eight species occurring in the littoral forest (Ducousso *et al*. 2004, see Rabenantoandro *et al*. Chapter 3.1), is recommended. Whether ectomycorrhiza represents an advantage over endomycorrhiza for plants growing on nutrient-poor sand remains to be studied in more detail. The importance of either form of mycorrhiza is unknown for the tree species of the littoral forests of southeastern Madagascar. However, it is worth mentioning that saplings planted on the demineralized soil (Site 4) hardly grew for several years and then suddenly increased in height. This might indicate that the plants first had to acquire their mycorrhizal fungi or bacteria before they could start growing. Species with ectomycorrhiza or nitrogen-fixing bacteria seem to have advanced growth on demineralized soil, growing about three times faster than other species. Under normal conditions, this advantage was not outstanding. Thus, knowledge of these symbiotic associations and their species specificities may facilitate programs of successful forest restoration.

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