Chapter 6.3
Testing of Fast Growing Tree Species for the Rehabilitation of Mine Sites

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Abstract

This chapter describes the methodology and results of experiments assessing the utility of various fast growing species (20) for the rehabilitation of degraded habitat after mining. For 10 of the species, tests could be performed with seeds of different origins, resulting in the testing of seeds from 29 different stocks. They were planted in various substrates. The tests were designed to simulate post-mining conditions such as demineralized sand, and to determine the species best adapted to the sandy and acidic soil. The survival and growth rates were measured. The results showed that *Eucalyptus camaldulensis* had the highest survival and growth rates, and thus, seems best adapted to the post-mining conditions. There were no significant differences between the substrates tested.

Résumé

Essais sur des espèces d'arbres à croissance rapide pour la réhabilitation des sites miniers. Ce chapitre décrit la méthodologie et les résultats obtenus dans des expériences destinées à évaluer différentes espèces à croissance rapide (20) pour leur utilisation dans la réhabilitation des habitats dégradés après exploitation minière. Pour 10 de ces espèces, les essais pouvaient être réalisés avec des graines de diverses origines en permettant ainsi de tester des graines de 29 sources différentes. Elles ont été plantées dans divers substrats. Les essais ont été élaborés de manière à simuler les conditions après exploitation minière (sables déminéralisés) et pour évaluer les espèces les mieux indiquées pour s'adapter aux conditions pauvres d'un sol sableux et acide. Les taux de survie et la croissance en hauteur ont été mesurés. Les résultats ont montré que *Eucalyptus camaldulensis* montrait les meilleurs taux de survie et de croissance et semblait être l'espèce la mieux adaptée aux conditions après exploitation minière. Nous n'avons trouvé aucune différence significative entre les divers substrats testés.

Introduction

In the context of the exploitation of mineral sands (ilmenite) at Mandena, site rehabilitation is planned to take place (QMM 2001). Since 85% of Mandena's vegetation is comprised of herbaceous or shrub-like species, which were introduced following anthropogenic disturbances (see Vincelette *et al.* Chapter 2.4, and Rabenantoandro *et al.* Chapter 3.1), different rehabilitation options have been tested (see Vincelette *et al.* Chapter 6.5). The options we favor include putting in place a vegetation cover of fast-growing tree species that are economically viable in the short term (8 to 10 years) to meet local demands for wood and other forest products. This option also focuses on preserving the biodiversity of residual native forests by encouraging local people to use plantation products instead of natural forest products to meet their household and commercial needs.

QMM has been conducting rehabilitation experiments since 1996 to identify fast-growing species that can adapt to the local soil and climate conditions. This chapter describes the methodology and results of these experiments to assess plant growth and survival based on seed source and origin, and the substrates that simulate post-mining conditions (sand demineralization). Further, these experiments take into account the need for optimizing the costs of conducting these tests, and the need for quick results in order to have several options in place before the commencement of mining. This research was instrumental in preparing a list of plant species adapted to local conditions for future rehabilitation work.

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Methods

Testing in a partially simulated and controlled environment

We identified exotic, fast-growing species that already exist in Madagascar, specifically in the Tolagnaro region. This list of species was assembled based on published and gray literature, contacts with scientific institutions, discussions with economic operators, technical services, environmental NGOs, and field observations.

Several introduced species were tested for less than one year based on aspects of growth and soil preparation, using proper conditions of moisture, wind, and sun exposure. Seven different soil preparation types were tested. Our goal was to identify regionally available materials that could be added to the demineralized soil (without ilmenite) to augment plant growth rates.

A zone measuring 20 x 12 m was constructed; comprising a series of plastic sacks (20 cm in diameter x 30 cm in height) arranged side by side and filled with different substrates. The sacks were sown with the seeds of the identified plant species. Three complete repetitions were made in a randomized block design, having two randomized factors (species and substrate), with observation units or "plots" of eight sacks (30 species x 7 substrates x 8 plots x 3 repetitions), or 5,208 observations. These plots were watered every day to ensure proper moisture for plant growth. Two months after seed germination, once the plants had reached an average height of eight cm, height measurements of each plant were periodically taken to estimate growth over six months, the duration of the experiment.

In order to estimate the growth of each species, we calculated the difference between the initial plant height at an age of 90 days, and that of 210 days. In order to determine whether seed origin, or the stock, of the plant had a significant effect on its growth and survival rates, an analysis of variance (ANOVA) was performed. The same style of analysis was used to determine whether substrate quality could significantly influence the growth and survival rates of the species tested. Growth was estimated in centimeters per week. The survival rate at the end of the test was estimated as the percentage of the initial number of plants that were still living, or the ratio of living plants to the initial number of plants. This test was followed by species observations under conditions that more closely resembled actual rehabilitation conditions. Given the local materials available, seven soil preparation types, or substrates, were tested (Table 1).

Observations in a simulated environment

An analysis of the results of the above-mentioned experiments made it possible to select quick-growing species. These species were observed under circumstances more closely resembling actual rehabilitation conditions, specifically having considerable sun exposure and only receiving water via precipitation. Due to technical and space-related constraints, the seeds were planted in plastic pots measuring 40 cm in diameter x 60 cm in height, and filled with demineralized sand from a former ilmenite extraction test site and different substrates (Table 1). Six bags were used per species and type of substrate.

In order to further imitate the actual post-mining environmental conditions, a small-scale rehabilitation site was created within an ilmenite separation unit. The surface area of this site was 70 x 35 m. The species ultimately selected, based on the results of the previous tests, were produced in a nursery and replanted on this site starting in 1998 to confirm their fast-growing ability.

Table 1. Soil preparation types used in the fast-growing tree experiments.

Substrate number	Type of preparation
1	Topsoil from *Erica* spread out on demineralized sand
2	Demineralized sand (control)
3	Sisal waste mixed with demineralized sand
4	Cattle manure mixed with demineralized sand
5	Topsoil from *Erica* mixed with demineralized sand
6	Topsoil from natural forest mixed with demineralized sand
7	Topsoil from natural forest spread out on demineralized sand

Results

We used 20 species for the experiments. For nine of them we tested seeds of different origins. The first phase of the tests revealed that *Corymbia citriodora* (site of origin = Analazaza), *Eucalyptus torelliana* (Sambava), *E. camaldulensis* (Antsanitia), *Casuarina equisetifolia* (Ambila Lemaitso), and *C. cunninghamiana* (Central Highlands) had the highest growth rates (Table 2). The highest survival rates were found in *Acacia auriculiformis* (Ampitambe), *E. camaldulensis* (Antsanitia), *Grevillea robusta* (Australia), *Pinus caribaea* (Ambalahady), and *P. elliottii* (Mahatsinjo). Of the fast-growth species, only *E. camaldulensis* is among those with a high survival rate (Table 3).

Table 2. Mean growth rate per week (in cm) measured over 210 days for non-Malagasy plants used in the experiments. The sites where the seed stock was obtained are given in the Origin column. Values are means and standard deviations (below each mean) based on three replicates consisting of eight sacks each.

Stock number	Species	Origin	Substrate							Total
			1	2	3	4	5	6	7	
1	*Acacia auriculiformis*	AMPITAMBE Madagascar	0.27	0.50	0.55	0.95	0.69	0.92	1.14	0.72
			0.20	0.32	0.26	0.50	0.11	0.35	0.29	0.39
2	*Albizia lebbeck*	ANDRANOMANDEVY Madagascar	0.06	0.21	0.28	0.07	0.16	0.27	0.10	0.16
			0.04	0.24	0.29	0.06	0.06	0.41	0.01	0.20
3	*Casuarina cunninghamiana*	QUEENSLAND Australia	0.01	0.54	1.45	0.63	0.33	1.13	1.15	0.75
			0.01	0.20	0.80	0.24	0.25	0.23	0.15	0.57
4	*C. cunninghamiana*	Central Highlands Madagascar	0.98	3.48	1.48	2.41	0.23	1.06	1.86	1.64
			1.69	5.38	2.02	1.90	0.39	1.10	1.88	2.34
5	*C. equisetifolia*	AMBILA LEMAITSO Madagascar	1.66	1.79	1.67	2.52	0.59	1.28	2.58	1.73
			1.26	2.17	1.44	1.37	0.74	1.04	2.38	1.48
6	*C. equisetifolia*	ANTETEZANA Madagascar	0.02	0.24	0.76	0.76	0.18	0.55	0.40	0.42
			0.02	0.21	0.60	0.19	0.15	0.11	0.35	0.37
7	*C. equisetifolia*	SAI TONG PRACHUAB Thailand	0.04	0.18	0.67	1.33	0.16	0.44	0.20	0.43
			0.06	0.17	0.82	1.73	0.14	0.55	0.17	0.77
8	*C. equisetrifolia*	RICHARD'S BAY South Africa	0.10	0.20	0.80	0.06	0.45	0.46	0.38	0.35
			0.18	0.21	0.80	0.10	0.02	0.03	0.38	0.38
9	*Cajanus cajan*	MANDRITSARA Madagascar	0.00	0.37	1.53	1.02	0.60	0.84	1.64	0.86
			0.01	0.33	1.32	0.17	0.52	0.17	0.29	0.74
10	*Eucalyptus cloeziana*	PALOMA RANGE, QUEENSLAND Australia	0.03	0.35	2.11	0.88	0.24	0.72	0.37	0.67
			0.04	0.30	0.71	1.10	0.23	0.07	0.12	0.79
11	*E. cloeziana*	HELEN VALE, QUEENSLAND Australia	0.16	0.22	0.74	4.17	0.07	0.76	0.66	0.97
			0.07	0.10	0.70	3.90	0.08	0.42	0.15	1.86
12	*E. deglupta*	Papua New Guinea	0.00	0.13	0.92	0.53	0.36	0.39	0.68	0.43
			0.00	0.18	1.01	0.79	0.28	0.33	0.51	0.55
13	*E. microcorys*	QUEENSLAND Australia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	*E. tereticornis*	KENNEDY RIVER QUEENSLAND Australia	0.05	0.34	2.53	1.59	0.49	1.47	1.17	1.09
			0.08	0.04	0.69	1.04	0.24	0.82	0.57	0.97
15	*E. camaldulensis*	ANTSANITIA Madagascar	0.43	3.28	3.49	4.10	0.93	2.25	4.01	2.64
			0.51	5.28	1.56	2.37	0.66	1.75	4.71	2.85
16	*E. camaldulensis*	PETFORD QUEENSLAND Australia	0.05	0.29	1.89	1.29	0.39	1.75	1.18	0.98
			0.09	0.09	0.05	0.92	0.09	0.50	0.23	0.78
17	*Corymbia citriodora*	ANALAZAZA Madagascar	1.58	4.27	4.03	4.38	1.96	1.61	4.30	3.16
			1.89	5.20	3.32	4.19	1.62	1.43	4.13	3.12
18	*E. cloeziana*	MAROFODY Madagascar	0.03	0.02	0.11	1.45	0.02	0.65	2.08	0.61
			0.05	0.03	0.19	2.05	0.03	1.13	3.37	1.51
19	*E. grandis*	RICHARD'S BAY South Africa	0.26	0.21	1.69	2.63	0.22	1.26	1.24	1.07
			0.23	0.20	0.71	1.10	0.22	0.16	0.24	0.97

Table 2. continued

Stock number	Species	Origin	Substrate							Total
			1	2	3	4	5	6	7	
20	*E. maculata*	RICHMOND RANGE NSW Australia	0.09	0.36	0.70	0.66	0.43	1.31	0.28	0.55
			0.16	0.04	0.73	0.58	0.10	0.32	0.35	0.51
21	*E. maculata*	SAHAMBAVY Madagascar	1.14	2.83	1.14	3.97	0.61	1.70	1.11	1.79
			1.65	4.69	1.23	3.85	0.62	1.44	0.97	2.39
22	*E. microcorys*	ANDASIBE Madagascar	0.68	1.93	2.23	2.44	0.49	0.58	2.14	1.50
			0.75	2.94	1.46	2.27	0.44	0.15	2.30	1.70
23	*E. tereticornis*	Tanzania	1.77	3.34	3.78	4.37	1.24	1.82	3.30	2.80
			2.35	5.18	2.27	3.60	1.40	0.93	2.95	2.73
24	*E. torelliana*	SAMBAVA Madagascar	0.26	12.04	0.86	3.04	1.07	0.98	3.02	2.71
			0.37	17.03	1.33	0.69	1.28	0.99	4.05	5.51
25	*Grevillea robusta*	CANGAI MANN RIVER NSW Australia	0.13	0.18	0.65	1.32	0.16	0.48	0.48	0.49
			0.03	0.05	0.18	1.12	0.03	0.21	0.08	0.54
26	*Pinus caribaea*	AMBALAHADY Madagascar	0.15	0.45	0.35	0.42	0.20	0.43	0.29	0.33
			0.19	0.50	0.18	0.47	0.29	0.53	0.41	0.35
27	*P. caribaea*	RICHARD'S BAY South Africa	0.13	0.27	0.55	2.00	0.32	0.64	0.36	0.61
			0.13	0.04	0.23	0.08	0.28	0.56	0.33	0.65
28	*P. elliottii*	RICHARD'S BAY South Africa	0.38	0.12	0.46	0.92	0.21	0.53	0.50	0.45
			0.35	0.11	0.18	0.05	0.03	0.00	0.11	0.28
29	*P. elliottii*	MAHATSINJO Madagascar	0.32	0.64	0.38	0.71	0.26	0.22	0.46	0.43
			0.28	0.80	0.26	0.65	0.32	0.19	0.41	0.43

Table 3. Mean survival rates after 210 days for non-Malagasy trees used in the experiments. The sites where the seed stock was obtained are given in the Origin column. Values are means and standard deviations based on three replicates consisting of eight sacks each.

Species	Origin	Substrate							Total
		1	2	3	4	5	6	7	
Acacia auriculiformis	AMPITAMBE Madagascar	0.63	0.67	0.75	0.88	0.96	0.83	0.96	0.81
		0.54	0.58	0.22	0.00	0.07	0.19	0.07	0.30
Albizia lebbeck	ANDRANOMANDEVY Madagascar	0.46	0.92	0.58	0.50	0.88	0.92	0.79	0.72
		0.44	0.07	0.07	0.50	0.13	0.07	0.07	0.29
Casuarina cunninghamiana	QUEENSLAND Australia	0.54	0.96	0.83	0.75	0.92	0.83	0.75	0.80
		0.47	0.07	0.19	0.25	0.07	0.07	0.33	0.25
C. cunninghamiana	Central Highlands Madagascar	0.13	0.50	0.38	0.92	0.21	0.75	0.54	0.49
		0.22	0.00	0.45	0.07	0.36	0.25	0.31	0.36
C. equisetifolia	AMBILA LEMAITSO Madagascar	0.88	0.83	0.96	0.88	0.29	0.88	0.96	0.81
		0.22	0.07	0.07	0.22	0.26	0.13	0.07	0.26
C. equisetifolia	ANTETEZANA Madagascar	0.63	0.50	0.88	0.75	0.63	0.83	0.50	0.67
		0.54	0.50	0.22	0.22	0.54	0.19	0.50	0.38
C. equisetifolia	SAI TONG PRACHUAB Thailand	0.21	0.38	0.33	0.17	0.21	0.38	0.29	0.28
		0.36	0.33	0.38	0.07	0.19	0.38	0.19	0.26
C. equisetrifolia	RICHARD'S BAY South Africa	0.29	0.33	0.83	0.13	0.46	0.71	0.29	0.43
		0.51	0.47	0.14	0.22	0.47	0.26	0.26	0.38
Cajanus cajan	MANDRITSARA Madagascar	0.04	0.29	0.25	0.71	0.33	0.46	0.79	0.41
		0.07	0.26	0.13	0.40	0.29	0.29	0.19	0.33
Eucalyptus cloeziana	PALOMA RANGE, QUEENSLAND Australia	0.13	0.46	0.46	0.29	0.46	0.58	0.42	0.40
		0.22	0.29	0.31	0.31	0.26	0.19	0.26	0.26
E. cloeziana	HELEN VALE QUEENSLAND Australia	0.33	0.33	0.38	0.67	0.42	0.71	0.46	0.47
		0.38	0.31	0.45	0.31	0.07	0.26	0.07	0.29
E. deglupta	Papua New Guinea	0.25	0.38	0.50	0.46	0.54	0.67	0.67	0.49
		0.43	0.25	0.50	0.44	0.19	0.58	0.47	0.39

Table 3. continued

Species	Origin	Substrate							Total
		1	2	3	4	5	6	7	
E. microcorys	QUEENSLAND Australia	0.50	0.83	0.71	0.83	0.71	1.00	0.75	0.78
		0.35	0.19	0.51	0.19	0.14	0.50	0.22	0.31
E. tereticornis	KENNEDY RIVER QUEENSLAND Australia	0.67	0.92	0.96	0.92	0.96	0.96	0.88	0.89
		0.58	0.07	0.07	0.07	0.07	0.07	0.13	0.22
E. camaldulensis	ANTSANITIA Madagascar	0.29	0.58	0.29	0.58	0.50	0.63	0.54	0.49
		0.31	0.51	0.51	0.52	0.13	0.54	0.51	0.40
E. camaldulensis	PETFORD QUEENSLAND Australia	0.67	1.00	0.96	0.88	0.67	1.00	0.96	0.88
		0.58	0.00	0.07	0.22	0.19	0.00	0.07	0.25
Corymbia citriodora	ANALAZAZA Madagascar	0.71	0.92	0.83	0.92	0.79	0.25	0.79	0.74
		0.14	0.14	0.19	0.07	0.26	0.43	0.14	0.29
E. cloeziana	MAROFODY Madagascar	0.00	0.00	0.00	0.00	0.00	0.25	0.08	0.05
		0.00	0.00	0.00	0.00	0.00	0.43	0.14	0.18
E. grandis	RICHARD'S BAY South Africa	0.13	0.63	0.50	0.46	0.75	0.88	0.67	0.57
		0.13	0.25	0.33	0.19	0.00	0.13	0.26	0.29
E. maculata	RICHMOND RANGE NSW Australia	0.67	0.88	0.63	0.63	1.00	0.79	1.25	0.83
		0.58	0.22	0.54	0.54	0.00	0.14	0.54	0.42
E. maculata	SAHAMBAVY Madagascar	0.46	0.83	0.71	0.83	0.71	0.63	0.75	0.70
		0.40	0.07	0.40	0.29	0.31	0.25	0.13	0.27
E. microcorys	ANDASIBE Madagascar	0.33	0.67	0.17	0.54	0.96	0.17	0.50	0.48
		0.31	0.58	0.29	0.47	0.07	0.29	0.50	0.43
E. tereticornis	Tanzania	0.33	0.29	0.25	0.38	0.58	0.58	0.88	0.47
		0.58	0.31	0.43	0.54	0.51	0.19	0.13	0.41
E. torelliana	SAMBAVA Madagascar	0.06	0.21	0.13	0.00	0.13	0.38	0.21	0.16
		0.09	0.19	0.13	0.00	0.13	0.13	0.07	0.15
Grevillea robusta	CANGAI MANN RIVER NSW Australia	0.67	1.00	0.92	0.92	1.00	0.92	1.00	0.92
		0.58	0.00	0.14	0.14	0.00	0.14	0.00	0.23
Pinus caribaea	AMBALAHADY Madagascar	0.83	0.79	0.96	0.88	0.92	1.25	0.75	0.91
		0.07	0.36	0.07	0.22	0.07	0.54	0.25	0.28
P. caribaea	RICHARD'S BAY South Africa	0.29	0.96	0.88	0.92	0.83	0.54	0.33	0.68
		0.26	0.07	0.13	0.07	0.14	0.26	0.31	0.32
P. elliottii	RICHARD'S BAY South Africa	0.46	0.88	0.83	0.71	0.83	0.96	0.71	0.77
		0.44	0.13	0.29	0.07	0.19	0.07	0.26	0.25
P. elliottii	MAHATSINJO Madagascar	0.88	0.92	0.83	0.88	0.92	0.79	1.00	0.89
		0.22	0.14	0.29	0.22	0.07	0.26	0.00	0.18

Substrate effect

Information is presented in Figure 1 on the survival, after 210 days (in %), and growth rate (cm/week) distribution, respectively, across tested species and seed sources. Survival probabilities and growth rates differed significantly from a normal distribution, and consequently, non-parametric tests, including Kruskal Wallis analysis of variance, were applied. Parametric analysis of variance (ANOVA) was used to explore whether the species tested would respond differently to the various substrates (Table 3). For this, "species" and "substrate" were entered as simultaneous independent factors. Both factors were highly significant, but the interaction term between species and substrate was not significant ($p > 0.5$). Therefore, single factor, non-parametric analyses seem sufficient.

The substrate had a significant effect on species survival and growth rates ($x^2 = 42.07$ and 55.55, $p < 0.001$, df = 6, respectively). According to post-hoc tests, the survival and growth rates for substrate 1 (Table 1) are significantly lower than those of any other substrate. No other comparisons were significant. Figures 2 and 3, and figures 4 and 5 illustrate the effects of the origin of the seeds and the substrate type on the survival and growth rates of plants, respectively.

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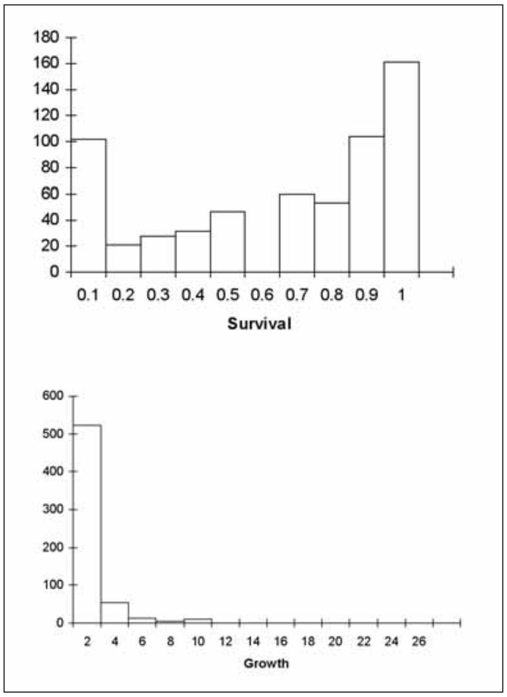

Figure 1. Frequency distribution of survival, after 210 days (in %), and growth rates (in cm/week).

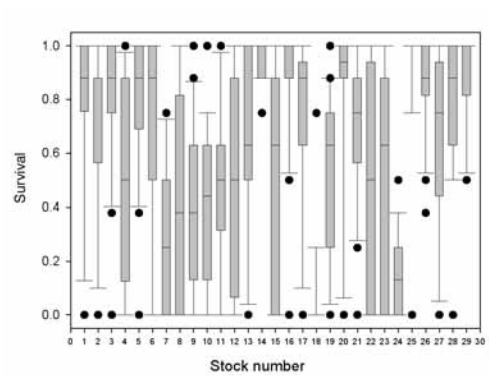

Figure 2. Survival of plants after 210 days (in %) in relation to stock number. Values are medians, 10, 25, 75 and 90 percentiles, and values outside the 10 / 90 percentiles.

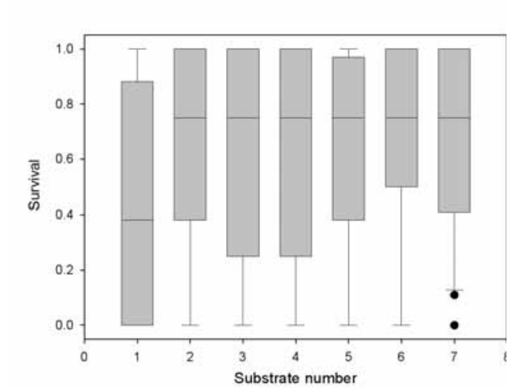

Figure 3. Survival of plants (in %) in relation to substrate type across species; values are as in Figure 2.

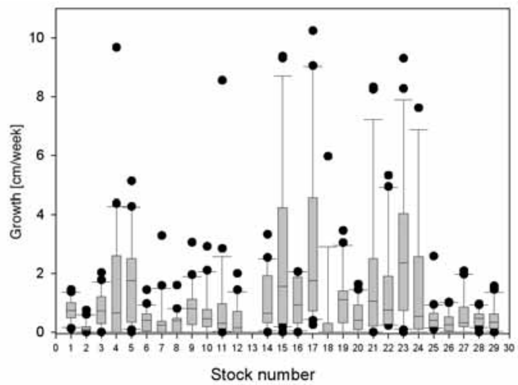

Figure 4. Plant growth in relation to stock number. Values are as in Figure 2. One value for stock number 24 (= 24.08 cm/week) is outside the figure.

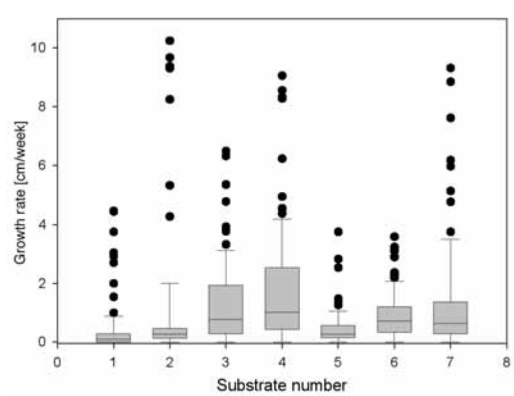

Figure 5. Plant growth in relation to substrate. Values as in Figure 2. One value for stock number 24 (= 24.08 cm/week) is outside the figure.

Table 4. Chi-square statistics based on Kruskal Wallis analysis of variance showing the effect of the origin of seeds on the survival and growth of seedlings over 210 days. Mean growth rates are listed in Table 2. The percentage of surviving plants is listed in Table 3. Level of significance is indicated by asterisks such that * = p<0.05, ** = p<0.01, and *** = P < 0.001.

Species	Number of sites	Survival x^2	Growth x^2
Casuarina cunninghamiana	2	8.39**	0.07
C. equisetifolia	4	24.25***	16.63***
Eucalyptus camaldulensis	2	12.80***	2.63
E. cloeziana	3	23.43***	8.94***
E. maculata	2	4.02*	2.90
E. microcorys	2	4.74*	33.93***
E. tereticornis	2	13.80***	4.85*
Pinus caribaea	2	5.12*	1.78
P. elliottii	2	3.26	0.73

Table 5. List of species whose seed origin had an impact on survival and growth rates based on Kruskal Wallis analysis of variance.

Survival rate	Growth
Casuarina cunninghamiana	
C. equisetifolia	*C. equisetifolia*
Eucalyptus camaldulensis	
E. cloeziana	*E. cloeziana*
E. maculata	
E.microcorys	*E. microcorys*
E. tereticornis	*E. tereticornis*
Pinus caribaea	

Effect of seed origin

The survival rates of plants differed significantly in relation to the origin of seeds for all species except *Pinus elliottii* (Table 4). The origin of the seeds has a significant influence on the growth of four out of the nine species tested (Table 4). These include *Casuarina equisetifolia*, *Eucalyptus cloeziana*, *E. microcorys*, and *E. tereticornis*. The results are summarized in Table 5.

Subsequent tests with older individuals indicated no effect of seed origin on the growth rate or survival of the trees.

Discussion

The goal of this project was to identify fast-growing species, which could replace some wooden forest resources used for fire and construction wood. At the start of the project, little information was available on the performance of the various species and their suitability for plantation in the demineralized, littoral sands of southeastern Madagascar, except for *Eucalyptus camaldulensis*.

According to our tests in the tree nursery, the various tree species differed significantly in their survival and growth rates. The origin of the seeds was shown to affect the survival or growth of some species. However, the type of substrate did not have any pronounced effect on the survival or growth of the seedlings. The survival and growth of plants were reduced only when planted in demineralized soil mixed with topsoil from *Erica*.

An estimation of growth characteristics and final yield (adult height and volume) can be extrapolated from juvenile height (Kremer 1981, Lambeth *et al.* 1983, Nanson, 1988, Bouvet, 1989, Raley *et al*. 2003). In the absence of interaction between substrate and species, it can also be asserted that the differences in height and growth are due mainly to genotypic variability between the species.

The selection of species for the establishment of large-scale tree plantations was based on the survival rates for each. Since the different substrates tested had no influence on the survival and growth of the different species, no effort was made to identify the most suitable substrate for their cultivation. In the local context, there would be an insufficient quantity of useful substrates for large-scale plantations anyway, and the cost would be too high for insignificant productivity gains. In view of these results, it was decided that a commercial soil additive known as TerraCottem (www.terracottem.com) would be added to the substrate. This product, made from fertilizers and water absorbent polymers, should be added to the soil at a level of 20 to 30 g per plant.

Among the species tested, *Eucalyptus camaldulensis* appears to be the best adapted to the local conditions. The source of this species' seeds had little impact on growth. This represents an economic advantage of this species. In addition, there are a number of baseline data and experiences with this species, which can be used for more detailed planning of costs and benefits (e.g., Bellefontaine *et al.* 1979).

Conclusion

There has been considerable debate over the years about the use of *Eucalyptus* spp. in plantations outside their natural range. However, there are many benefits to planting members of this genus. They are easy to introduce at sites with extremely poor soil, are quality sources of firewood and charcoal, and have rapid growth rates. In the current situation of the Tolagnaro region, and of Madagascar as a whole, *Eucalyptus* spp. will become increasingly important for most households and will have an important place in the national reforestation policy for years to come. This is in part because remarkably little attention has been given to the prospects of native trees in plantation situations on Madagascar (see Rarivoson *et al*. Chapter 6.4 and Vincelette *et al.* Chapter 6.5).

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