Amazonian forest restoration: an innovative system for native species selection based on phenological data and field performance indices

OLIVER H. KNOWLES[1] and JOHN A. PARROTTA[2]

[1] *Mineração Rio do Norte S.A., Porto Trombetas, 68275-0000, Pará, Brazil*
[2] *USDA Forest Service, International Institute of Tropical Forestry, PO Box 25,000, Río Piedras, PR 00928-2500.*

SUMMARY

One hundred and sixty taxa of upland moist forest trees were studied with reference to their suitability for forest restoration on bauxite mined lands in western Pará State, Brazil. Over a 14-year period, field observations in native primary forests, nursery studies, and evaluations of over 600 ha of mixed-species reforestation areas were used to characterize fruiting phenology, dispersal and seed viability, to determine the most cost-effective propagation methods, and to assess the post-plantation performance for each of the taxa studied. The systematic approach adopted in this study for screening large numbers of native tree species for which little or no ecological or silvicultural information was previously available is presented as a model for species selection and afforestation programme management, with broad applicability for forest rehabilitation and restoration worldwide.

Keywords: tropical forests, Brazil, restoration, mined lands, phenology.

INTRODUCTION

The reestablishment of native forest cover on severely degraded lands, such as abandoned anthropogenic grasslands and opencast mines where natural succession is impeded or retarded by physical, chemical and biological barriers, represents a formidable challenge demanding creative synthesis and application of ecological principles and sustainable silvicultural practices.

In the past, management of these lands has either been ignored or relied on the establishment of monospecific plantations, often with exotics, (e.g., *Eucalyptus*, *Pinus*, *Acacia* spp.), or a limited number of native tree taxa for which seeds are readily available and silvicultural practices have been developed. These plantation monocultures are often successful in terms of reestablishment of forest cover, erosion control and improvement of soil structure and fertility, and can in some instances be managed for production of timber or fuelwood on a long-term basis (Evans 1982). Under certain management conditions, such plantations can rapidly catalyse natural forest succession in the understorey and thus greatly accelerate the rate at which species-rich native forest stands develop on severely degraded lands (Lugo 1988, 1992, Parrotta 1993, Lugo *et al.* 1993, Brown and Lugo 1994).

While traditional plantations clearly do have an important role to play in the rehabilitation of degraded tropical lands, more innovative strategies are needed to guarantee the restoration of complex, diversified forest ecosystems over large areas with a minimal financial investment. The objective is to replicate, in an accelerated fashion, natural forest successional processes that lead to complex, self-sustaining forest ecosystems (Ashby 1987, Bradshaw 1987).

The basic silvicultural information needed to plan and carry out a restoration-oriented reforestation programme successfully is lacking except for a very limited number of commercially valuable species. Given the floristic richness of most tropical forest ecosystems, a systematic ecological approach is desirable to screen and evaluate the widest possible range of native tree taxa for possible inclusion in such reforestation programmes. By including a broad range of tree species in the screening programme, ignoring and irrespective of their commercial value or perceived 'importance' (based on human values), it is far more probable that diversified forests can be reestablished that will quickly resemble and function as natural tropical forests.

This was the goal of a Brazilian mining company's policy which envisaged the restoration of the primary forest cover that is inevitably destroyed during surface mining of bauxite at Trombetas, Pará State (Knowles 1982, Gaunt and Bliss 1983). An 'in-house' field and nursery research programme was initiated by the company in 1979 to evaluate systematically the basic ecological and silvicultural questions related to tropical forest restoration of mined lands. These studies eventually included 160 (76%) of the 210 tree taxa found in the immediate vicinity of the mine site, with the primary objective of developing a system for selecting the taxa suitable for multi-species plantations on an operational scale.

The system described in this paper is based on phenological data (prognosis of year-to-year seed availability), propagule dormancy and viability, plant nursery practice, field performance of the selected 'pioneer' species under 100% insolation and later natural or induced enrichment with shade-demanding species as seed becomes available from mother trees in the surrounding forest. Practical application of this system has been very easy with excellent results and, albeit relating to the specific forest environment of central Amazonia, it is postulated that the same strategy for species screening and selection can be applied to restoration work in a wide spectrum of other tropical and temperate regions.

BACKGROUND AND METHODS

The mine location and its environment

The Trombetas bauxite mine is located 65 km north-west of the town of Oriximiná and 30 km south of the River Trombetas in western Pará State, Brazil (1°45'S, 56°30'W). The mine is operated by Mineraçáo Rio do Norte S.A. (MRN), formed in 1976 by a group of Brazilian and international companies.

The local climate is classified as Am (tropical monsoonal) in the Köppen system and corresponds to the tropical moist forest life zone in the Holdridge system (Tosi and Velez-Rodriguez 1983). The mean annual rainfall at Porto Trombetas (1970-1993) is 2185±64 (S.E.) mm with distinctly dry (winter) and wet (summer seasons). The mean monthly rainfall exceeds 100 mm in all months except July - October (see Figure 1). The mean maximum and minimum temperatures are respectively 34.6°C and 19.9°C.

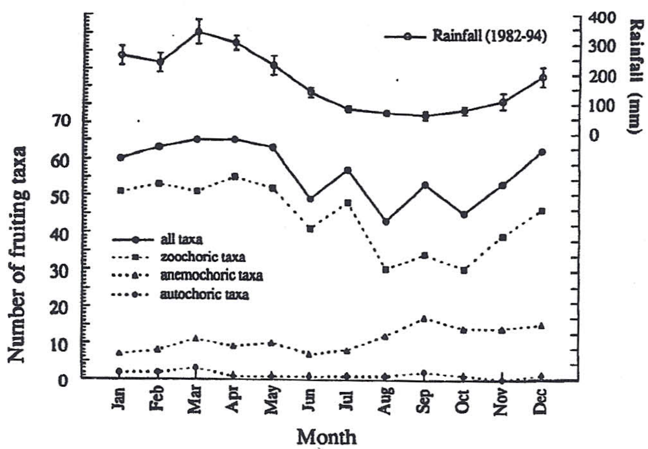

FIGURE 1. *Mean monthly rainfall (± S.E.) and numbers of tree taxa yielding fruit (1979-1994) on Saracá plateau at Trombetas.*

The regional vegetation is climax evergreen equatorial moist forest with three basic environments: limited seasonal floodplains ('varzea'), very extensive undulating sandy uplands ('flanco'), and occasional 'mesas' capped by bauxite and clay ('planalto'). The tree flora of the uplands ('flanco' and 'planalto') is rather similar, being comprised principally of Leguminosae (56 spp.), Lauraceae (14 spp.), Sapotaceae (13 spp.), Annonaceae (11 spp.), Moraceae (10 spp.), Chrysobalanaceae (9 spp.), Lecythidaceae (9 spp.), and Burseraceae (7 spp.) (FCAP 1991).

The mid-storey and upper-storey of the flanco are 18-25 m and 25-35 m high, respectively, with occasional emergents reaching 45 m. The understorey consists of stemless palms, seedlings and occasional herbaceous plants. Lianas are common but do not form thickets. The planalto forests contain a much higher proportion of large trees, many of which are emergents reaching 45 m, and the mid-storey and upper-storey are clearly more heterogenous with canopies from 5-18 m and 20-35 m high. Lianas are common but rarely form thickets. Other significant differences are associated with edaphic conditions; the sandy soils of the flanco are covered by an 8 cm thick layer of accumulated humus and loose peat interwoven with tree roots, whereas the planalto clay soils exhibit only a thin humus layer with an uneven surface caused by frequent, very large worm casts.

Mining operations at Trombetas began in 1979 and are presently confined to a single 'mesa' with planalto forest type, and progress at an average rate of 140 ha per year, producing 7.5 million tons of ore which is shipped to smelters outside the region. The bauxite seam is located under a 4-10 m horizon of yellow clay capped by a 70 cm layer of organically-enriched topsoil sustaining the primary forest cover. The basic post-mining activities, usually carried out within a year of forest clearance and bauxite extraction, are levelling of the clay overburden and replacement of about 15 cm of topsoil. These rehabilitated areas are then deep-ripped to 90 cm depth at 1 m intervals and planted with tree propagules during the following wet season. Planting is made along alternate rip-lines at 2 m x 2 m spacing (2500 plants per ha) using a mixture of large seeds, stumped saplings and potted seedlings, embracing at least 70 different species (varying from year to year according to seed availability), and ensuring that 2 individuals of the same species are not planted adjacent to one another.

Phenology and seed dispersal

During a 14-year period between 1980-94, the fruiting phenologies and seed dispersal mechanisms were evaluated for 160 common tree species (or taxa) found within 50 m on either side of 113 km of roads through primary and secondary forests in the vicinity of the Saracá plateau. This represents approximately 76% of the tree taxa attaining stem diameters greater than 10 cm (FCAP 1991). For the vast majority of taxa, at least 10 individual mature trees were included in these observations. Seed dispersal mechanisms were classified as: (1) autochorous: seeds released from explosively dehiscing fruits (e.g. *Hevea brasiliensis* Muell. Arg.); (2) anemochorous: wind-dispersed seeds (e.g. *Cedrela odorata* L.); (3) synzoochorous: seeds dispersed by birds or mammals without their being ingested (e.g. *Caryocar villosum* (Aubl.) Pers.); (4) endozoochorous: seeds dispersed by birds or mammals following passage though their digestive tracts (e.g. *Dialium guianensis* (Aubl.) Steud.; or (5) endo/synzoochorous: seeds dispersed by both endozoochoric or synzoochoric means (e.g. *Virola* spp.).

Seed viability and collection

Data on seed longevity under natural (forest) conditions and understorey regeneration, based on field observations, were recorded for all taxa. These data are now routinely used to schedule collection of seeds and very young wild seedlings ('wildings') for propagation in the company nursery.

For each taxon, the relative ease of seed collection was determined by considering several factors, namely seed size, dispersal characteristics and rates of predation or long-distance transport by birds, bats and other animals. For example, trees that produce large, indehiscent fruits containing numerous seeds, or large-seeded fruits which fall to the ground would be classified as 'easy' for seed collection. Some seeds are readily available if the human collector arrives first at trees with fruits which are avidly ingested by the fauna, while other fruits are eaten by the fauna but the seeds are easily collected after excretion or regurgitation. On the other hand, small, widely-scattered, wind-dispersed seeds, and small fruits containing small seeds readily eaten by animals, would be considered 'difficult' for seed collection.

Seed dormancy

Each of the taxa considered in this study was classified with regard to their seed dormancy. Four categories were recognised in this classification: (1) seeds with superficial dormancy requiring no treatment prior to sowing; (2) seeds requiring mechanical abrasion of their seed coats to facilitate germination; (3) seeds requiring scarification by brief immersion in boiling water or soaking in warm water; and (4) seeds requiring chemical scarification by soaking in concentrated sulphuric acid. It should be noted that if 'acceptable' germination percentages were obtained without any treatment (category '1' above), then no additional tests involving mechanical or other scarification methods were conducted for these species. The operational definition of 'acceptable' germination rates varied among taxa depending on seed availability and annual planting requirements. For example, a low germination rate for abundant and easily collected seeds is considered 'acceptable', while only very high germination rates for seeds that are difficult to collect are considered 'acceptable.'

Planting stock selection

Four options for production of planting stock were evaluated for all taxa. The primary purpose of these evaluations was to identify the most cost-effective technique that could be used for successful large-scale reforestation. The techniques, entailing progressively increased labour and financial investment, were: (1) direct seeding; (2) stumped saplings; (3) wildings (wild seedlings); and (4) seedlings produced in the nursery from seed.

Early post-plantation performance

Evaluation of post-planting performance for each taxon considered a combination of factors: reaction to open site conditions encountered during the first year after outplanting, sapling vigour and growth rates during the first 2 years after establishment. Taxa classified as 'good' accept full sun from the moment of outplanting, attain >75% survival and produce vigorous leading shoots. Those classed as 'fair', although accepting full sun, prefer at least partial shade during the first 6 to 12 months, have a 50-75% survival rate and active shoot growth. Taxa classified as 'poor' react adversely to full sun, have a survival rate of less than 50% and stagnant shoot growth. Any intermediate cases are automatically downgraded.

Development of a species rating system

In order to compare and rank the 160 taxa studied with respect to the permutations of the diverse factors relative to propagation and suitability for reforestation, a scoring system was developed which considered: (1) seed germination treatment requirements, (2) alternatives for production of planting stock, and (3) adaptability to plantation site environment (open sunlight) and early growth rates. Within each of these categories, taxa were assigned numerical values (points) based on the results of nursery and field studies, with higher points for the easiest/most economical option and fewer points for the more difficult/expensive options. The maximum score that could be assigned to any specific taxon was 12, made up by adding the maximum of 2 points in the seed treatment category, a maximum of 4 points in the planting stock category and a maximum of 6 points in the adaptability and early growth category. While this system is more qualitative than quantitative, it was conceived to serve the practical needs of the nursery manager and silviculturalist for choosing native forest species with the guarantee that they can be successfully used in the company's mineland reforestation programmes.

When applied to seed treatment requirements, it can be seen that taxa that can be sown without treatment (= easiest and cheapest) received the maximum of 2 points while those requiring either mechanical, hot water or chemical scarification received only 1 point. Regarding planting stock production, options were assigned 1, 2, 3, or 4 points for species that could be successfully propagated using seedlings produced in the nursery from seed, or wildlings, or stumped saplings, or by direct seeding (= easiest and cheapest), respectively. Blanks in this section of Table 2 indicate that a particular technique was found to be impractical, based on comparative experimental work in the nursery and/or field. With reference to adaptability (environmental tolerance) and early growth, taxa rated as good (= most successful), fair, or poor are given 6, 4, or minus 1 points, respectively.

RESULTS AND DISCUSSION

Phenology, seed dispersal, seed collection and viability

Fruit production for many taxa occurs over an extended period (Table 1), while in some cases displays a discontinuous seasonal pattern. In many cases, fruiting by individual trees or taxa normally occurs over a more limited time period within a given year. Three important factors contribute to the broader or discontinuous fruiting periods presented, which are based on a 14-year observation period. First, the fruiting periods for individual species can vary up to two months earlier or later than the average from one year to the next, which is likely to be due to yearly climatic variations. Second, many species will flower and set fruit twice in a given year and/or individual trees will produce seeds "out of season" relative to other individuals of the species. Both of these phenomena have been documented elswhere in Amazonia (Roth 1987, Figlolia and Aguiar 1993, Kageyama and Piña-Rodrigues 1993, Piña-Rodrigues and Piratelli 1993). Finally, some of the taxa included in the data embrace several individual species (e.g. *Aspidosperma* spp.) or even genera (e.g. *Protium* and *Tetragastris* spp. = 'Breu'), each with their own specific fruiting periods.

Despite these individual taxa variations it can be seen that, in the primary forests surrounding the Trombetas mine, fruit production taken as a whole across all taxa is more or less continuous throughout the year, although there are clear seasonal patterns associated with taxa groups with seeds that are dispersed by mammals and birds (zoochoric species) and wind (anemochoric species). In the case of zoochoric taxa the numbers of fruiting species show clear seasonal patterns that closely parallel seasonal rainfall fluctuations, with a higher proportion of taxa producing fruits during the wetter months (December-May) than the drier months. For anemochoric taxa, this pattern is reversed, with an increase in the proportion of taxa producing fruits during the dry season (August-December) as can be logically expected. Differences between zoochoric and anemochoric taxa with respect to seasonality of fruiting have been reported in other neotropical upland moist forests. Seed viability is also closely related to seasonal fruiting periods (Foster 1982, Piña-Rodrigues 1993).

In spite of the yearly variations in fruiting phenology for individual taxa and the broad seasonal patterns exhibited by zoochoric and anemochoric taxa groups, the data confirm that during any given year there is always ample production of seeds and wildings of a broad array of species during all months. This permits year-round nursery activity based on seeds and wildings (though not constant in terms of species composition) as well as a reliable source of seeds of certain desirable species required for direct seeding and later enrichment sowing at all times.

Under natural conditions most (69%) of the taxa studied produce seeds that are dispersed by animals, either synzoochorically or endozoochorically. Anemochoric and autochoric taxa comprised respectively 26% and 4% of the total. Similar frequencies of zoochoric, anemochoric and autochoric species in upland moist tropical forests have been reported for other sites in the Brazilian Amazon region and Central America (Foster 1982, Hartshorn 1980, Piña-Rodrigues and Aguiar 1993, van Roosmalen 1985).

Approximately two-thirds of the taxa studied produce seeds that were considered either easy (36%) or only moderately difficult (27%) to collect (Table 1). For the purposes of reforestation programme management, no collection was made of the remaining 37% of the taxa with seeds classified as 'difficult', it being more efficient and economical to locate wildings or use stumped saplings from the forest.

Most of the species studied produce seeds with very limited periods of viability (Table 1). The seeds of approximately 22% of these, i.e. recalcitrant species, retained their germinative capacity for less than 1 month after fruitfall (under natural conditions) or collection (and storage in the nursery). An additional 32% retained their viability for periods or between 1 and 3 months. Approximately 19% of the species had seeds that retained their viability for 3 to 6 months, and only 27% yielded seeds retaining their germinative capacity for more than 6 months. The relatively short fruiting periods and limited seed viability exhibited by most of the taxa studied require that seeds are sown as soon as possible after collection, either in the nursery or in the afforestation area. Given this limitation, it is critical that seed collection, nursery production and planting operations be well managed to avoid losses and ensure that ample planting stock for the broadest range of taxa suitable for reforestation will be available during each planting season. The phenological data can be used to produce a monthly prognosis for species (taxa) in fruit in order to guide the field collection, plan seedling stock production in the nursery and evaluate wilding availability.

Seed dormancy and planting stock selection

The seeds of a large majority (71%) of the taxa studied do not require mechanical or chemical scarification to break dormancy (Table 2). An additional 21% of the taxa require mechanical scarification of their seed coats to break dormancy and facilitate germination. Only 11 taxa (7%) produce seeds that require chemical scarification. In the case of these latter taxa, the potential hazards to safety associated with acid scarification of seeds indicated that stumped saplings or wildings should be chosen over nursery-grown seedlings as the preferred planting stock in most instances.

Artificially applied treatments used to break seed dormancy (none vs. mechanical, hot water, or acid scarification) are apparently uncorrelated with the treatments to which seeds are subjected under natural conditions by their principal dispersal agents, usually birds and/or mammals. For most of those species whose seeds are, under natural conditions, ingested and undergo an acid scarification in an animal's digestive tract prior to excretion or regurgitation, a simple mechanical scarification was usually found to be a good substitute, and less difficult and hazardous than sulphuric acid treatment, to facilitate germination in the

TABLE 1. *Trombetas native forest species fruiting characteristics.*

Family	Scientific name	Common name			Fruiting months										Dispersal mechanism	Ease of seed collection	Viability (months)
			J	F	M	A	M	J	J	A	S	O	N	D			
Anacardiaceae	Anacardium giganteum Hancock ex.Engl.	Caju-açu			I			L				I			syn.zoo	Difficult	<1
Anacardiaceae	Astronium lecointei	Muiracatiara							I						anemo	Moderate	1 to 3
Anacardiaceae	Spondias lutea	Taperiba			H	H	L								end.syn	Easy	>6
Anacardiaceae	Tapirira guianensis Aubl.	Tatapiririca		H	H										end.zoo	Moderate	<1
Annonaceae	Annona, Dughettia, Guatteria, & Xylopia spp.	Envira	H	H	H	H	H	H	L	I	L	I	I	H	end.zoo	Difficult	1 to 3
Apocynaceae	Aspidosperma cf. eteatum	Araracanga	I	I	L	I	I				I	I	L		anemo	Moderate	1 to 3
Apocynaceae	Aspidosperma oblongum A. DC.	Carapanauba		L	I	L	L	L				L	I		anemo	Difficult	1 to 3
Apocynaceae	Aspidosperma sp.	Marfim falso									L	L	L	L	anemo	Moderate	<1
Apocynaceae	Couma guianensis Aubl.	Sorva	L	I	L		I	I			L			I	end.zoo	Easy	1 to 3
Apocynaceae	Geissospermum sericeum (Benth.) Hook.	Quinarana			L	H	H								syn.zoo	Moderate	1 to 3
Apocynaceae	Himatanthus sucuuba (Spruce) Woodson	Sucuuba												I	anemo	Difficult	1 to 3
Apocynaceae	Macoubea guianensis Aubl.	Amapa amargosa		L	I									I	end.zoo	Difficult	1 to 3
Apocynaceae	Malquetia ducke MGF	Molongó				I		L	I						end.syn	Difficult	1 to 3
Araliaceae	Schlefflera morototoni (Aubl.) Maguire	Morototó						L	H	I	I				end.zoo	Difficult	3 to 6
Bignoniaceae	Jacaranda copaia (Aubl.) D. Don.	Parapará				I	L				H				anemo	Difficult	1 to 3
Bignoniaceae	Tabebuia spp.	Pau d'arco					I							I	anemo	Difficult	1 to 3
Bixaceae	Bixa spp.	Urucu bravo					L						I	L	syn.zoo	Easy	3 to 6
Bombacaceae	Bombax globosum Aubl.	Mamorana da terra firme										I			anemo	Difficult	<1
Bombacaceae	Ceiba pentadra (L.) Gaertn.	Sumauma											L	I	anemo	Difficult	<1
Boraginaceae	Cordia goeldiana Hub.	Freijo											I		anemo	Moderate	1 to 3
Boraginaceae	Cordia spp.	Uruazeiro	H	L	I	I							L	L	end.zoo	Easy	3 to 6
Burseraceae	Protium & Tetragastris spp.	Breu	H	H	H	H	H						I	I	end.zoo	Difficult	<1
Burseraceae	Trattinickia rhoifolia Willd.	Breu sucuruba	I			L			I	L					end.zoo	Moderate	>6
Caryocaraceae	Caryocar glabrum Aubl.	Piquiarana		I		L	I								syn.zoo	Moderate	3 to 6
Caryocaraceae	Caryocar villosum (Aubl.) Pers.	Piquiá	L	L	I	H	I		L	L					syn.zoo	Easy	3 to 6
Celastraceae	Goupia glabra Aubl.	Cupiuba						I	L		I				end.zoo	Difficult	3 to 6
Chysobalanaceae	Couepia longipedunculo Pilger	Castanha de galinha	I	L		I		I							syn.zoo	Easy	3 to 6
Chysobalanaceae	Couepia spp.	Pajurá	L	L	I	L	I		L				L	I	syn.zoo	Moderate	>6
Chysobalanaceae	Licania cf. heteromorpha	Macucú	L		L	L	L	L	L		L				end.zoo	Difficult	1 to 3
Chysobalanaceae	Licania cf. micrantha	Cariperana	I	H	H	H	I	L	L	L				L	syn.zoo	Easy	3 to 6
Chysobalanaceae	Pariniari excelsa Sabine	Parinari	I												syn.zoo	Easy	3 to 6
Combretaceae	Buchenavia spp.	Cuiarana, Tanimbouco		I	L	H	I	I	I	I			L		end.zoo	Easy	>6
Connaraceae	Connarus sp.	Arara mirá				I	I	I							end.zoo	Difficult	<1
Ebenaceae	Diospyros sp.	Caquí						L					L	I	end.zoo	Moderate	1 to 3
Elaeocarpaceae	Sloanea grandis Ducke	Urucurana				I	L		I				L		syn.zoo	Moderate	3 to 6
Euphorbiaceae	Aparisthmium & Conceveiba spp.	Pau de indio	I	H	I									I	syn.zoo	Difficult	3 to 6
Euphorbiaceae	Croton sp.	Pau gaivota, Dima			I		L								auto	Difficult	3 to 6
Euphorbiaceae	Glycidendron sp.	Glicia			L								I		syn.zoo	Moderate	>6
Euphorbiaceae	Hevea brasiliensis Muell. Arg.	Seringueira	I		H				L						auto	Easy	<1
Euphorbiaceae	Hevea guianesis Aubl.	Seringa itauba	L	H	H	L									auto	Easy	<1
Euphorbiaceae	Hevea spp.	Seringarana		L				L						I	auto	Easy	<1

Notes: (1) Common names are those used in the vicinity of Trombetas, Pará. (2) Fruiting months—symbols indicate frequency of fruiting observations based on 14 years of observations: "L" indicates low frequency, "I" indicates intermediate frequency, "H" indicates high frequency. Blanks indicate that fruiting not observed during month. (3) Dispersal mechanism: "anemo" = anemochory, "auto" = autochory, "end.zoo" = endozoochory, "syn.zoo" = synzoochory, "end.syn" = endozoochory and synzoochory.

Table 1. *Continued*

Family	Scientific name	Common name	J	F	M	A	M	J	J	A	S	O	N	D	Dispersal mechanism	Ease of seed collection	Viability (months)
			Fruiting months														
Euphorbiaceae	Joannesia hevioides Ducke	Castanha arara									I	I			auto	Moderate	>6
Euphorbiaceae	Unidentified species	Caxixá	I	I	I	I									end.zoo	Difficult	3 to 6
Flacourtaceae	Laetia procera (Poepp. & Endl.) Eichl.	Pau jacare		L			I	L			L		L	I	end.zoo	Difficult	>6
Guttiferae	Moronobea sp.	Ananí da terra firme			L	I									syn.zoo	Moderate	>6
Guttiferae	Platonia insignis Mart.	Bacurí							I						syn.zoo	Moderate	>6
Guttiferae	Vismia spp.	Lacre	I	L	I	L	L	I	L	L	L	L	L	I	end.zoo	Easy	3 to 6
Humiriaceae	Endopleura uchi (Huber) Cuatr.	Uchi liso	I	I	L	I	H	I	I				I		syn.zoo	Easy	>6
Humiriaceae	Humiria balsamifera J. St. Hil.	Umirí			I				L				L		end.zoo	Difficult	3 to 6
Humiriaceae	Saccoglottis sp.	Uchi coroa	L	L		I	L	L		I					syn.zoo	Easy	>6
Humiriaceae	Vantanea guianensis Aubl.	Achuá	I	L	I	H	I		I		I			I	syn.zoo	Easy	>6
Humiriaceae	Vantanea paraensis L.	Uchi morcego	I	I					L				L		syn.zoo	Easy	>6
Lauraceae	Aniba canelilla (H.B.K.)	Casca preciosa					I	I		L					end.zoo	Difficult	<1
Lauraceae	Aniba, Nectandra & Ocotea spp.	Louro	H	I	H	I	H	I	L	I	H	I	H	H	end.zoo	Difficult	<1
Lauraceae	Mezilaurus itauba (Meissn.) Taubert ex Mez	Itauba				L		I	H	I	L				end.zoo	Difficult	<1
Lecythidaceae	Bertholletia excelsa Humb. & Bonpl.	Castanheira do pará	H	H	I	H	L								syn.zoo	Easy	>6
Lecythidaceae	Cariniana micrantha Ducke	Tauari côco						L		L		H	L		anemo	Moderate	3 to 6
Lecythidaceae	Chytroma basilaris Miers	Jarana amarela		L	H	L	L			L					syn.zoo	Difficult	1 to 3
Lecythidaceae	Couratari oblongifolia Ducke	Tauari branco	L					L						I	anemo	Difficult	1 to 3
Lecythidaceae	Eschweilera & Lecythis spp.	Matamatá branco	H	H	H	I	I	L	I	L	L				end.zoo	Moderate	1 to 3
Lecythidaceae	Lecythis usitata Miers	Sapucaia				I			L	L				I	syn.zoo	Difficult	3 to 6
Legum.-Caes.	Cassia sp. [1]	Cassia piolho	L	L	L	L	L	L	L	L	L	L	L	L	anemo	Easy	>6
Legum.-Caes.	Cassia sp. [2]	Marimarí pequena da terra firme	L	L	L	L	L	L	I	I	I	I	I	I	end.zoo	Easy	>6
Legum.-Caes.	Cassia spruceana Benth.	Marimarí grande da terra firme											I		syn.zoo	Easy	>6
Legum.-Caes.	Copaifera martii Hayne	Copaiba					I								end.zoo	Moderate	1 to 3
Legum.-Caes.	Dialium guianensis (Aubl.) Steud.	Jutaí pororoca				L	L	L	I						end.zoo	Moderate	>6
Legum.-Caes.	Dimophandra macrostachya Benth.	Fava pombo		I											syn.zoo	Difficult	3 to 6
Legum.-Caes.	Dimophandra sp.	Falso angelim		L									I	I	anemo	Moderate	>6
Legum.-Caes.	Hymenaea courbaril L.	Jutaí-açu, Jatoba	L			I	L	I	H	H	I	I	L	L	syn.zoo	Easy	>6
Legum.-Caes.	Hymenaea intermedia Ducke	Jutaí mirim									L		I		syn.zoo	Easy	>6
Legum.-Caes.	Macrolobium spp.	Fava carapato								I					auto	Moderate	1 to 3
Legum.-Caes.	Peltogyne lecointei	Pau roxo	I								L	L			anemo	Difficult	>6
Legum.-Caes.	Peltogyne paradoxa Ducke	Coataquicaua					L				I				anemo	Difficult	1 to 3
Legum.-Caes.	Schizolobium amazonicum (Aubl.) Ducke	Canafistula									H				anemo	Moderate	>6
Legum.-Caes.	Sclerolobium racemosa	Tachí dos campos							L	I		L	H	L	anemo	Easy	>6
Legum.-Caes.	Swartzia polyphylla A. DC.	Pitaica											I		syn.zoo	Easy	<1
Legum.-Caes.	Swartzia spp.	Gombeira	L	I	L	I	I	I	L		L	I	I	L	end.zoo	Easy	<1
Legum.-Caes.	Tachigalia spp.	Tachí preto			H	H	L	L	L	L	I	L	L		anemo	Easy	3 to 6
Legum.-Caes.	Vouacapoua americana Aubl.	Acapú					I	I							syn.zoo	Easy	1 to 3
Legum.-Mimos.	Albizia sp. [1]	Fava dentinho					L					I			syn.zoo	Moderate	>6
Legum.-Mimos.	Albizia sp. [2]	Fava segmentada									I				auto	Difficult	1 to 3
Legum.-Mimos.	Cedrelinga catanaeformis Ducke	Cedrorana		I		I									anemo	Moderate	1 to 3

Table 1. *Continued*

Family	Scientific name	Common name	Fruiting months												Dispersal mechanism	Ease of seed collection	Viability (months)
			J	F	M	A	M	J	J	A	S	O	N	D			
Legum.-Mimos.	Dinizia excelsa Ducke	Angelim vermelho						L	H	H	I				anemo	Easy	>6
Legum.-Mimos.	Enterolobioum maximum Ducke	Tamboril									I	I			syn.zoo	Easy	>6
Legum.-Mimos.	Enterolobium schomburkii Benth.	Fava de rosca							L	L		L	I		syn.zoo	Easy	>6
Legum.-Mimos.	Inga spp.	Ingá	I	H	I	L	I			H	I	L		I	end.zoo	Moderate	<1
Legum.-Mimos.	Parkia gigantacarpa	Fava arara tucupi	L								L		H	L	anemo	Easy	>6
Legum.-Mimos.	Parkia oppositifolia Benth.	Fava bengüe									I	L			syn.zoo	Easy	>6
Legum.-Mimos.	Parkia pendula (Willd.) Benth. ex Walp.	Fava bolota	I								L		L		syn.zoo	Easy	>6
Legum.-Mimos.	Parkia sp.	Fava japacanim										I			syn.zoo	Moderate	>6
Legum.-Mimos.	Piptadenia communis Benth.	Timborana			H				L						anemo	Difficult	<1
Legum.-Mimos.	Pithecellobium racemosum Ducke	Angelim rajado				I									syn.zoo	Difficult	1 to 3
Legum.-Mimos.	Pithecellobium sp. [1]	Fava cordão				H	L								syn.zoo	Difficult	<1
Legum.-Mimos.	Pithecellobium sp. [2]	Mapuchiquí, Parica											I	I	syn.zoo	Moderate	>6
Legum.-Mimos.	Pithecellobium spp.	Fava olho de peixe					L	L	L	I					syn.zoo	Difficult	<1
Legum.-Mimos.	Pterocarpus rohrii Vahl	Mututí da terra firme										I		H	anemo	Easy	1 to 3
Legum.-Mimos.	Stryphnodendron pulcherrimum (Willd.) Hochr.	Barbatimão, Camuze						L	L		H	I	I		syn.zoo	Easy	>6
Legum.-Papil.	Andira sp.	Andira-uchí											L	I	syn.zoo	Moderate	>6
Legum.-Papil.	Bowdichia cf. nitida	Sucupira amarela			I										anemo	Easy	1 to 3
Legum.-Papil.	Bowdichia spp.	Sucupira preta			L	I					L				anemo	Easy	1 to 3
Legum.-Papil.	Dalbergia spruceana Benth.	Jacaranda do pará							L	I	L	I	I	L	anemo	Easy	>6
Legum.-Papil.	Diplotropis purpurea (Rich.) Amsh.	Sucupira escamosa								H					anemo	Easy	>6
Legum.-Papil.	Dipteryx magnifica Ducke	Cumarú rosa				I		I		L				I	syn.zoo	Easy	3 to 6
Legum.-Papil.	Dipteryx odorata (Aubl.) Willd.	Cumarú					L	I	H	I					syn.zoo	Easy	3 to 6
Legum.-Papil.	Hymenolobium excelsum (Ducke) Benth.	Angelim da mata											L	I	anemo	Easy	1 to 3
Legum.-Papil.	Hymenolobium sp. [1]	Angelim aroeira		L	H	H	H		L	I	L		I		anemo	Easy	1 to 3
Legum.-Papil.	Hymenolobium sp. [2]	Angelim blindado										I		I	anemo	Difficult	1 to 3
Legum.-Papil.	Ormosia spp.	Tento	I	I		L		H	I	I	L	L	L		end.syn	Moderate	>6
Legum.-Papil.	Platymiscium ducke Huber.	Macacauba da terra firme	L							I	I			I	anemo	Moderate	3 to 6
Legum.-Papil.	Swartzia spp.	Coração de negro	I	L								I		I	end.zoo	Difficult	<1
Legum.-Papil.	Vataireopsis speciosa Ducke	Fava amargosa									I	L			anemo	Easy	3 to 6
Leguminosae	Peltogyne paniculata	Mulateiro								I	H				anemo	Easy	1 to 3
Malpighiaceae	Byrsonima spp.	Murucí		I	L			I	L	I	L			L	end.syn	Moderate	>6
Melastomataceae	Belucia dichotoma Cogn.	Muuba, Goiaba de anta	L	L	L	L	L	L	I	L	L	I	L	L	end.syn	Easy	>6
Melastomataceae	Miconia longifolia DC.	Sapateiro									L		I	L	end.zoo	Difficult	1 to 3
Melastomataceae	Miconia sp.	Maramara	I	L			L	I	I			I	L		end.zoo	Moderate	1 to 3
Melastomataceae	Mouriri brachyanthera Ducke	Muirauba	H	H									L	I	end.zoo	Moderate	<1
Meliaceae	Carapa guianensis Aubl.	Andiroba	L	I	L	I	L		I						syn.zoo	Easy	1 to 3
Meliaceae	Cedrela odorata L.	Cedro vermelho									I	L			anemo	Difficult	1 to 3
Meliaceae	Guarea jatuarana Harms.	Jatoá			I	I			I						syn.zoo	Difficult	1 to 3
Meliaceae	Swietenia macrophylla King	Mogno								I					anemo	Easy	3 to 6
Meliaceae	Trichilia lecointei Ducke	Jatauba					L				I	L			end.zoo	Difficult	1 to 3
Moraceae	Bagassa guianesis Aubl.	Tatajuba												H	end.zoo	Moderate	3 to 6

Table 1. *Continued*

Family	Scientific name	Common name	J	F	M	A	M	J	J	A	S	O	N	D	Dispersal mechanism	Ease of seed collection	Viability (months)
			Fruiting months														
Moraceae	Brosimum lactescens (S. Moore) C.C. Berg	Janitá		I		H	L								syn.zoo	Difficult	1 to 3
Moraceae	Brosimun rubescens Taub.	Muirapiranga	L			I							I		end.zoo	Difficult	1 to 3
Moraceae	Cecropia obtusa Terc.	Imbauba branca	L	L	L	L	L	L	L	I	L	L	L	I	end.zoo	Difficult	1 to 3
Moraceae	Clarisia racemosa Ruiz & Pavon	Guariuba	I	I	I										end.zoo	Moderate	<1
Moraceae	Maquira & Helicostylis spp.	Muiratinga da terra firme	L		I	L	I							I	end.syn	Moderate	<6
Moraceae	Pourouma sp.	Imbaubarana		I		I									end.syn	Moderate	1 to 3
Moracee	Brosimum potabile	Amapa doce									L	I		L	syn.zoo	Easy	1 to 3
Myristicaceae	Iryanthera & Osteophloeum spp.	Ucuubarana	H	H	H	H	L		L	L	L	L		I	end.syn	Easy	<1
Myristicaceae	Virola spp.	Ucuuba	H	H	L	I	I		L	L	L	H		I	end.syn	Easy	<1
Myrtaceae	Myrcia cf. falex	Murta/Goiabinha	H	H	H	I		I	I			L	I	H	end.zoo	Moderate	<1
Myrtaceae	Myrcia spp.	Pixuna			L				L						end.zoo	Difficult	<1
Myrtaceae	Psidium sp.	Goiabeira	L	I	I									I	end.syn	Easy	>6
Myrtaceae	Unidentified species	Socoró da mata	I		I									I	syn.zoo	Difficult	<1
Nyctaginaceae	Neea sp.	João mole	I				I								syn.zoo	Difficult	<1
Olacaceae	Minquartia guianensis Aubl.	Acariquara			L		L		L		I	I			end.zoo	Moderate	3 to 6
Olacaceae	Olacacea sp.	Olacacea casca grossa						H		H					anemo	Difficult	1 to 3
Proteaceae	Roupala montana Aubl.	Faieira												I	end.zoo	Difficult	1 to 3
Rubiaceae	Duroia spp.	Puruí						L	L	L					end.zoo	Difficult	3 to 6
Rubiaceae	Genipa americana L.	Genipapo		L	I								L		end.zoo	Easy	1 to 3
Rubiaceae	Palicourea spp.	Erva de rato		L	I		L	L	L						end.zoo	Easy	<6
Rutaceae	Spathelia excelsa	Pau para tudo					H								anemo	Difficult	1 to 3
Sapindaceae	Talisia spp.	Pitomba							I			I		I	end.zoo	Difficult	1 to 3
Sapotaceae	Manilkara amazonica	Maparajuba	H	L	H	H	L	I						I	end.zoo	Difficult	1 to 3
Sapotaceae	Manilkara huberi (Ducke) Chev.	Maçaranduba	I	I											end.zoo	Difficult	<1
Sapotaceae	Micropholis spp.	Rosadinha	I	I	I	L	L								end.zoo	Difficult	<1
Sapotaceae	Pouteria, Chrysophyllum & Micropholis spp.	Abiurana	H	H	H	H	H	I	I	L	I	L	L	I	end.zoo	Moderate	<1
Simarubaceae	Simaruba amara Aubl.	Marupa	L			I									end.zoo	Moderate	<1
Sterculiaceae	Sterculia spp.	Axixá	I	I		I						L		L	end.zoo	Moderate	1 to 3
Sterculiaceae	Theobroma sp.	Cacau da mata	I		L	L	I							I	syn.zoo	Difficult	<1
Tiliaceae	Apeiba spp.	Pente de macaco		I					L		L	I	L	I	end.syn	Easy	>6
Tiliaceae	Lueheopsis rosea Burret.	Acoita cavalo	L											I	anemo	Difficult	1 to 3
Ulmaceae	Trema micrantha (L.) Bl.	Curimin	L	L	L	L	L	L	L	L	I	L	L	L	end.zoo	Easy	3 to 6
Violaceae	Rinorea spp.	Jacamin			L									I	syn.zoo	Difficult	1 to 3
Vochysiaceae	Erisma uncinatum Warm.	Quarubarana		I	L		L								anemo	Moderate	3 to 6
Vochysiaceae	Qualea spp.	Mandioqueira		I	L	L									anemo	Difficult	1 to 3
Vochysiaceae	Vochysia obscura Warm.	Quaruba rosa			I										anemo	Difficult	<1
	Unidentified species	Taperibarana	I	L					L		L		L	L	syn.zoo	Moderate	<1

nursery. These data clearly indicate that, while it may be useful to keep in mind how seed dormancy may be broken by various scarification "treatments" under natural conditions, the vast majority of species can easily be propagated by seed without pretreatment or at the most by a simple mechanical scarification.

Selection of the appropriate planting stock for each taxon is critical for ensuring plantation success and minimizing time and labour costs. In this study, 21% of the taxa could be successfully established in reforestation areas of the mine by direct seeding. Species that could be propagated most efficiently by direct seeding were restricted to a subset of taxa with relatively large seeds (>2 cm long and broad) that can be manipulated easily in the field by the planting crew.

At Trombetas, direct seeding, where applicable, was by far the most economical means of plantation establishment as it involved greatly reduced costs relative to the use of stumped saplings, wildings or nursery-grown seedings. The next most economical planting stock option, stumped saplings, was found to be appropriate for an additional 13 taxa (8%). Use of wildings, which were a somewhat less economical source of planting material, was found to be the best alternative for 78 taxa (49%). Only 35 taxa (22%) required the relatively costly production of nursery-grown seedlings (from seed).

Under actual operational conditions at Trombetas, the proportion of taxa for which wildings and seedlings are used varies from year to year, with wildings accounting for between one-third and one-half of the taxa and seedlings for up to 25% of the taxa. The variation is due to unpredictable year-to-year fluctuations in the availability in the surrounding forest of wildings during the months immediately preceeding and during the planting season.

Adaptability and early post-plantation performance

Of the 160 taxa evaluated in this study, 37% (59 taxa) were rated as 'good.' These taxa are well-adapted to the open site conditions of the reforestation site, and exhibited vigorous shoot growth, with survival rates of 75% or greater during the first 2 years after planting (Table 2). An additional 30 taxa (19%) were rated as 'fair,' with survival rates of 50-75% and good shoot growth. Species rated as 'fair' were those that generally prefer partial shade during the first year after planting, but grow vigorously thereafter under full sunlight. Thus, a total of 89 taxa, or 56%, performed acceptably well in the reforestation areas. The remaining 71 taxa (44%) showing 'poor' performance when planted under full open light conditions, with survival rates of less than 50% and stagnant shoot growth. These taxa generally require shade, at least during the first two years, and are not recommended for planting under open site conditions, being preferably used exclusively for later enrichment plantings, as will be discussed below.

Species rating and the design of appropriate reforestation strategies

The rating system incorporating the results of studies on seed treatment requirements, suitability of the various planting stock options, and post-planting adaptability and early growth was used to rank and classify the 160 taxa evaluated in this study with respect to their suitability for use in the reforestation programme at the Trombetas mine site (Table 2). These taxa were divided into 3 categories: *Highly suitable*, sun-demanding taxa; *Suitable* taxa, preferring shaded conditions during the first 6 to 12 months; and *Shade-demanding* taxa that performed poorly under open site conditions.

Within each of these categories, the total number of points given to each taxon varies widely in relation to seed treatment requirements and the most appropriate planting stock options. As point totals inversely reflect the time, effort, and costs re-quired for successful propagation and establishment, the ranking presented in Table 2 can serve as a practical guide for native species selection, indicating adaptability combined with relative economic costs, as determined under operational conditions. As previously noted, the application of this system in reforestation programmes requires flexibility in the selection of taxa and determination of their relative abundance in the mixed-species plantings in any given year, based on current availability of planting stock (seeds, seedlings and stumped saplings). For this reason, the natural abundance of taxa in the vicinity of the mine was not considered to be relevant for the development of the rating system.

Thus, taxa included in the *Highly suitable* and *Suitable* categories can be guaranteed to perform well when planted under the open conditions encountered in the mine reforestation sites, while those in the *Shade-demanding* category should be excluded from the initial stage of forest restoration at this site. However, since this last category includes nearly half of the taxa characteristic of the species-rich native forests surrounding the mine, it is absolutely essential that they are introduced into the plantation systems at some later stage of development, once propitious shade conditions have been established in the plantation. While admitting that traditional plantations can be floristically enriched by natural means - through seed transport from surrounding primary forests by birds and mammals - this process is known to be extremely slow and uncertain at the Trombetas site (H. Knowles, personal observation). This is due to several factors that appear to inhibit seed-transporting wildlife from visiting or residing in the plantations. These include the often long distances between seed sources (in surrounding primary forests) and plantation areas, the presence of roads separating the plantations from the primary forests, the movement of heavy vehicles along these and other roads on the plateau and the lack of attractive feeding or roosting habitat within the plantations. Therefore, we recomm-end accelerating the process by enrich-

TABLE 2. *Trombetas native forest species propagation characteristics. Numbers in boldface used to calculate point totals for each taxon.*

Scientific name	Family	Seed Treatment Required: None	Mech.	Hot Water	Chem.	Planting Stock: dir. sdg.	stumped saplings	wild-ings	seed-lings	Adaptability and Early Growth: Good	Fair	Poor	Total Points
Highly suitable, sun-tolerant taxa													
Spondias lutea	Anacardiaceae	2				4	3		1	6			12
Caryocar villosum	Caryocaraceae	2				4			1	6			12
Hevea brasiliensis	Euphorbiaceae	2				4		2	1	6			12
Hevea guianesis	Euphorbiaceae	2				4		2	1	6			12
Dipteryx magnifica	Legum.-Papil.	2	1			4		2	1	6			12
Dipteryx odorata	Legum.-Papil.	2	1			4		2	1	6			12
Tabebuia spp.	Bignoniaceae	2					3	2	1	6			11
Ceiba pentadra	Bombacaceae	2					3	2	1	6			11
Aparisthmium & Conceveiba spp.	Euphorbiaceae	2					3	2	1	6			11
Joannesia hevioides	Euphorbiaceae		1			4			1	6			11
Hymenaea courbaril	Legum.-Caes.		1		1	4			1	6			11
Hymenaea intermedia	Legum.-Caes.		1		1	4			1	6			11
Schizolobium amazonicum	Legum.-Caes.		1			4			1	6			11
Enterolobioum maximum	Legum.-Mimos.		1	1	1	4			1	6			11
Parkia gigantacarpa	Legum.-Mimos.		1		1	4			1	6			11
Parkia sp.	Legum.-Mimos.		1	1	1	4			1	6			11
Belucia dichotoma	Melastomataceae	2					3	2		6			11
Tapirira guianensis	Anacardiaceae	2						2	1	6			10
Aspidosperma cf. eteatum	Apocynaceae	2						2	1	6			10
Couma guianensis	Apocynaceae	2						2	1	6			10
Schlefflera morototoni	Araliaceae		1	1	1		3	2	1	6			10
Jacaranda copaia	Bignoniaceae	2						2	1	6			10
Goupia glabra	Celastraceae				1		3	2	1	6			10
Sloanea grandis	Elaeocarpaceae	2						2	1	6			10
Unidentified species	Euphorbiaceae		1		1		3	2		6			10
Cassia sp. [1]	Legum.-Caes.		1	1	1		3	2	1	6			10
Stryphnodendron pulcherrimum	Legum.-Mimos.		1	1	1		3		1	6			10
Bowdichia cf. nitida	Legum.-Papil.	2	1					2	1	6			10
Bowdichia spp.	Legum.-Papil.	2						2	1	6			10
Hymenclobium excelsum	Legum.-Papil.	2						2	1	6			10
Hymenclobium sp. [1]	Legum.-Papil.	2						2	1	6			10
Vataireopsis speciosa	Legum.-Papil.	2						2	1	6			10
Cedrela odorata L.	Meliaceae	2						2	1	6			10
Swietenia macrophylla	Meliaceae	2						2	1	6			10
Spathelia excelsa	Rutaceae	2						2	1	6			10
Simaruba amara	Simarubaceae	2						2	1	6			10
Bixa spp.	Bixaceae	2							1	6			9
Trattinickia rhoifolia	Burseraceae		1		1			2	1	6			9
Buchenavia spp.	Combretaceae		1					2	1	6			9
Croton sp.	Euphorbiaceae				1			2	1	6			9
Laetia procera	Flacourtaceae				1			2	1	6			9

TABLE 2. *Continued*

Scientific name	Family	Seed Treatment Required: None	Mech.	Hot Water	Chem.	Planting Stock: dir. sdg.	stumped saplings	wild-ings	seed-lings	Adaptability and Early Growth: Good	Fair	Poor	Total Points
Vismia spp.	Guttiferae				1			2	*1*	6			9
Cassia sp. [2]	Legum.-Caes.		1	*1*	*1*			2	*1*	6			9
Sclerolobium racemosa	Legum.-Caes.		1	*1*	*1*			2		6			9
Dinizia excelsa	Legum.-Mimos.		1	*1*	*1*			2	*1*	6			9
Enterolobium schomburkii	Legum.-Mimos.		1	*1*	*1*			2	*1*	6			9
Parkia pendula	Legum.-Mimos.		1	*1*	*1*			2	*1*	6			9
Dalbergia spruceana	Legum.-Papil.	2							1	6			9
Miconia longifolia	Melastomataceae				1		3	*2*	*1*	6			9
Bagassa guianesis	Moraceae	2							1	6			9
Cecropia obtusa	Moraceae				1			2		6			9
Psidium sp.	Myrtaceae		1	*1*	*1*			2	*1*	6			9
Sterculia spp.	Sterculiaceae	2							1	6			9
Apeiba spp.	Tiliaceae		1	*1*	*1*			2	*1*	6			9
Trema micrantha	Ulmaceae				1			2	*1*	6			9
Cassia spruceana	Legum.-Caes.		1	*1*	*1*				1	6			8
Parkia oppositifolia	Legum.-Mimos.		1		*1*				1	6			8
Diplotropis purpurea	Legum.-Papil.		1	*1*	*1*				1	6			8
Byrsonima spp.	Malpighiaceae		1	*1*	*1*				1	6			8
Suitable, though prefer shaded conditions initially													
Caryocar glabrum	Caryocaraceae	2				4			*1*		4		10
Couepia longipedunculo	Chysobalanaceae	2				4		*2*	*1*		4		10
Bertholletia excelsa	Lecythidaceae	2				4		*2*	*1*		4		10
Inga spp.	Legum.-Mimos.	2				4		*2*	*1*		4		10
Andira sp.	Legum.-Papil.	2	1			4			*1*		4		10
Carapa guianensis	Meliaceae	2				4			*1*		4		10
Astronium lecointei	Anacardiaceae	2						2	*1*		4		8
Aspidosperma sp.	Apocynaceae	2						2	*1*		4		8
Geissospermum sericeum	Apocynaceae	2						2	*1*		4		8
Cordia goeldiana	Boraginaceae	2						2	*1*		4		8
Aniba, Nectandra & Ocotea spp.	Lauraceae	2						2	*1*		4		8
Mezilaurus itauba	Lauraceae	2						2	*1*		4		8
Copaifera martii Hayne	Legum.-Caes.	2						2	*1*		4		8
Macrolobium spp.	Legum.-Caes.	2						2	*1*		4		8
Swartzia spp.	Legum.-Caes.	2						2	*1*		4		8
Tachigalia spp.	Legum.-Caes.	2						2	*1*		4		8
Cedrelinga catanaeformis	Legum.-Mimos.	2						2	*1*		4		8
Hymenolobium sp. [2]	Legum.-Papil.	2						2	*1*		4		8
Platymiscium ducke	Legum.-Papil.	2						2	*1*		4		8
Palicourea spp.	Rubiaceae		1		*1*		3	*2*	*1*		4		8
Erisma uncinatum	Vochysiaceae	2						2			4		8
Qualea spp.	Vochysiaceae	2						2			4		8

TABLE 2. *Continued*

Scientific name	Family	Seed Treatment Required: None	Mech.	Hot Water	Chem.	dir. sdg.	Planting Stock: stumped saplings	wild-ings	seed-lings	Adaptability and Early Growth: Good	Fair	Poor	Total Points
Vochysia obscura Warm.	Vochysiaceae	2						2			4		8
Annona, Dughettia, Guatteria, & Xylopia spp.	Annonaceae				1			2	1		4		7
Bombax globosum Aubl.	Bombacaceae	2							1		4		7
Diospyros sp.	Ebenaceae	2							1		4		7
Humiria balsamifera	Humiriaceae		1	1	1			2	1		4		7
Pithecellobium sp. [2]	Legum.-Mimos.		1	1	1			2	1		4		7
Cordia spp.	Boraginaceae				1				1		4		6
Ormosia spp.	Legum.-Papil.		1	1	1				1		4		6
Shade demanding taxa suitable for underplanting/seeding in established stands													
Couepia spp.	Chysobalanaceae	2				4		2	1			(-1)	5
Licania cf. micrantha	Chysobalanaceae	2				4		2	1			(-1)	5
Hevea spp.	Euphorbiaceae	2				4		2	1			(-1)	5
Moronobea sp.	Guttiferae	2				4			1			(-1)	5
Endopleura uchi	Humiriaceae	2				4		2	1			(-1)	5
Saccoglottis sp.	Humiriaceae	2				4		2	1			(-1)	5
Vantanea guianensis	Humiriaceae	2				4			1			(-1)	5
Vantanea paraensis	Humiriaceae	2				4		2	1			(-1)	5
Chytroma basilaris	Lecythidaceae	2				4		2	1			(-1)	5
Eschweilera & Lecythis spp.	Lecythidaceae	2				4		2	1			(-1)	5
Lecythis usitata	Lecythidaceae	2				4			1			(-1)	5
Swartzia polyphylla	Legum.-Caes.	2				4			1			(-1)	5
Vouacapoua americana	Legum.-Caes.	2				4		2	1			(-1)	5
Brosimum potabile	Moracee	2				4			1			(-1)	5
Glycidendron sp.	Euphorbiaceae		1			4			1			(-1)	4
Anacardium giganteum	Anacardiaceae	2						2	1			(-1)	3
Aspidosperma oblongum	Apocynaceae	2						2	1			(-1)	3
Himatanthus sucuuba	Apocynaceae	2						2	1			(-1)	3
Macoubea guianensis	Apocynaceae	2						2	1			(-1)	3
Protium & Tetragastris spp.	Burseraceae	2						2	1			(-1)	3
Aniba canelilla	Lauraceae	2						2	1			(-1)	3
Couratari oblongifolia	Lecythidaceae	2						2	1			(-1)	3
Dialium guianensis	Legum.-Caes.		1		1		3	2				(-1)	3
Peltogyne lecointei	Legum.-Caes.	2						2	1			(-1)	3
Peltogyne paradoxa	Legum.-Caes.	2						2				(-1)	3
Piptadenia communis	Legum.-Mimos.	2						2				(-1)	3
Pithecellobium racemosum	Legum.-Mimos.	2						2				(-1)	3
Pithecellobium sp. [1]	Legum.-Mimos.	2						2	1			(-1)	3
Pithecellobium spp.	Legum.-Mimos.	2						2	1			(-1)	3
Pterocarpus rohrii	Legum.-Mimos.	2						2	1			(-1)	3
Peltogyne paniculata	Leguminosae	2						2	1			(-1)	3
Miconia sp.	Melastomataceae				1		3	2				(-1)	3

TABLE 2. *Continued*

Scientific name	Family	Seed Treatment Required: None	Mech.	Hot Water	Chem.	dir. sdg.	Planting Stock: stumped saplings	wildings	seedlings	Adaptability and Early Growth: Good	Fair	Poor	Total Points
Brosimun rubescens	Moraceae	2						2	1			(-1)	3
Clarisia racemosa	Moraceae	2						2	1			(-1)	3
Maquira & Helicostylis spp.	Moraceae	2						2	1			(-1)	3
Pourouma sp.	Moraceae	2						2	1			(-1)	3
Iryanthera & Osteophloeum spp.	Myristicaceae	2						2	1			(-1)	3
Unidentified species	Myrtaceae	2						2	1			(-1)	3
Neea sp.	Nyctaginaceae	2						2	1			(-1)	3
Minquartia guianensis	Olacaceae	2						2	1			(-1)	3
Roupala montana	Proteaceae	2						2				(-1)	3
Talisia spp.	Sapindaceae	2						2	1			(-1)	3
Manilkara amazonica	Sapotaceae	2						2	1			(-1)	3
Manilkara huberi	Sapotaceae	2						2	1			(-1)	3
Micropholis spp.	Sapotaceae	2						2	1			(-1)	3
Pouteria, Chrysophyllum & Micropholis spp.	Sapotaceae	2						2	1			(-1)	3
Lueheopsis rosea	Tiliaceae	2						2				(-1)	3
Rinorea spp.	Violaceae	2						2	1			(-1)	3
Unidentified species		2						2	1			(-1)	3
Malquetia ducke	Apocynaceae	2							1			(-1)	2
Licania cf. heteromorpha	Chysobalanaceae	2							1			(-1)	2
Pariniari excelsa	Chysobalanaceae	2							1			(-1)	2
Connarus sp.	Connaraceae	2							1			(-1)	2
Platonia insignis	Guttiferae	2							1			(-1)	2
Cariniana micrantha	Lecythidaceae	2							1			(-1)	2
Albizia sp. [2]	Legum.-Mimos.		1	1	1			2	1			(-1)	2
Swartzia spp.	Legum.-Papil.	2							1			(-1)	2
Mouriri brachyanthera	Melastomataceae	2							1			(-1)	2
Guarea jatuarana	Meliaceae	2							1			(-1)	2
Trichilia lecointei	Meliaceae	2							1			(-1)	2
Brosimum lactescens	Moraceae	2							1			(-1)	2
Virola spp.	Myristicaceae	2							1			(-1)	2
Myrcia cf. falex	Myrtaceae	2							1			(-1)	2
Olacacea sp.	Olacaceae	2							1			(-1)	2
Duroia spp.	Rubiaceae	2							1			(-1)	2
Genipa americana	Rubiaceae	2							1			(-1)	2
Theobroma sp.	Sterculiaceae	2							1			(-1)	2
Dimophandra macrostachya	Legum.-Caes.		1		1				1			(-1)	1
Dimophandra sp.	Legum.-Caes.		1	1	1				1			(-1)	1
Albizia sp. [1]	Legum.-Mimos.		1	1	1				1			(-1)	1
Myrcia spp.	Myrtaceae				1				1			(-1)	1

ment plantings and/or broadcast seeding of shade-demanding species approximately 5 years after establishment of the initial planting which uses only *Highly suitable* and *Suitable* taxa.

CONCLUSIONS

The restoration of species-rich moist tropical forests on sites that have been severely degraded, such as mined areas in Amazonia, is hampered by incomplete knowledge of the ecological dynamics of disturbed tropical forest systems which are still poorly understood, and because published basic silvicultural information is lacking for all but a very small proportion of the tree species that characterize these forests. If such lands are to be managed with the goal of ecological restoration, innovative approaches are needed to select the broadest possible range of native species for inclusion in reforestation programmes to recreate quickly and economically stable forest ecosystems that, over time, will develop and function as mature, natural, late secondary and primary forest systems. One such approach, based on 14 years experience of operational-scale reforestation at a bauxite mine site in central Amazonia, incorporates ecological data along with information derived from a systematic programme of field and nursery studies. Although long-term predictions concerning the successional development of forests established using this approach are as problematic as they would be for natural secondary forest stands in this region, the results obtained thus far at Trombetas are promising.

The studies have shown that it is indeed possible to evaluatesystematically, at relatively low cost, a large number of native tree species about which little or no previously published information exists with respect to critical aspects of fruiting phenology, seed biology, nursery practice or performance under the stressful conditions typically encountered on severely degraded soils under harsh microclimatic conditions. The systematic approach utilized at the Trombetas bauxite mine site was designed to meet the needs of an operational-scale reforestation programme for rapid development of protocols for efficient planting stock selection, nursery production, and plantation practices for 160 native tree taxa. It has yielded basic, essential information that can be used directly for forest restoration elsewhere in the region. Perhaps more importantly, it provides a universal model for species selection based on local phenological data and local germplasm that can be confidently applied wherever environmental degradation calls for rehabilitation efforts to restore, as quickly and economically as possible, the native forests that existed prior to their destruction.

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