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Promoting biodiversity: advances in evaluating native species for reforestation

Rebecca P. Butterfield[1]

Organization for Tropical Studies, Box 90630, Durham, NC 27708-0630, USA

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Abstract

To explore the potential of native tropical hardwoods for forestry development, 84 timber species were tested in a species screening trial in Costa Rica; 17 were widely planted tropical exotics, 52 were locally indigenous, and 15 were native to other areas of Costa Rica. A complete randomized block design was used with single tree plots replicated 24 times per site. At 3 years of age, survival, form, and growth were analyzed for species at four abandoned pasture sites at La Selva Biological Station, Sarapiquí, Costa Rica. Well-known exotics selected for fast growth made up 20% of the species tested but 40% of the fastest growing ten species. Of the top 25% of the species, 67% were indigenous species, in line with the original proportion tested. Candidate species for further testing were grouped according to different forestry objectives: timber plantations, agroforestry systems, enrichment plantings, and reforestation of buffer zones. These previously untested, little-known species demonstrate the large number of native species with high potential for reforestation for a variety of objectives.

Keywords: Screening trial; Neotropics; Biodiversity; Agroforestry; Tropical plantation; Enrichment planting

1. Introduction

One of the arguments for the protection of biological diversity is the economic potential of flora and fauna which has yet to be discovered or tested by science (McNeely et al., 1990). Progress has been made in the taxonomy of tropical tree species, yet forest scientists have been slow to go beyond classification towards the exploitation of tropical diversity to meet the needs of local human populations. In fact, the high diversity of arboreal species in the lowland rainforest is seen by some foresters as a hindrance, adding to the complexity of managing such systems and, sometimes, the low economic return from logging operations (Vega, 1987).

Little testing of this biological wealth has been undertaken for forestry development purposes. Native species are often overlooked in reforestation programs, owing to misconceptions about their silvicultural requirements and lack of management information (Butterfield and Fisher, 1994). Several thousand species of trees, most of them in the tropics, have yet to be used widely or even tested formally in either commercial or rural development efforts (National Research Council, 1991). However, native species do have the potential to perform as well as or better than widely used exotics. Where such species exist and especially where local people depend upon them for a variety of uses, they should be tested alongside promising exotics to identify the best species for reforestation.

[1] Present address: CARE-NIGER, 151 Ellis Street, Atlanta, GA 30303, USA.

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Table 1
Test sites for species screening trials at La Selva Biological Station, Sarapiquí, Costa Rica

	Geomorphic position	Vegetation/light	Soil		Years since abandonment
			Order[a]	Type	
Site A	Alluvial	Pasture/sun	Inceptisol	Fluventic Dystropept	[illegible]
Site B	Slope	Shrub/forest/sun	Ultisol	Typic Tropohumult	[illegible]
Site C	Slope	Pasture/sun	Ultisol	Typic Tropohumult	1
Site D	Slope	Shrub/forest/shade	Ultisol	Typic Tropohumult	9

[a]FAO soil classification: Inceptisol is same as Cambisol; Ultisol is same as Acrisol.

To explore the potential of lowland rainforest species for reforestation, the Organization for Tropical Studies (OTS), in collaboration with the Costa Rican Forest Service (Dirección General Forestal; DGF), initiated an ambitious project to develop basic scientific information on dozens of indigenous species. A species screening trial was established in the Atlantic lowlands of Costa Rica to evaluate wild, little-known tropical hardwoods and compare them with exotic species widely used for plantation forestry.

This initial step has provided useful information on numerous indigenous species and revealed the potential for lowland rainforest species to be domesticated. The methods used to test quickly a large number of species and the promising results are of interest to researchers, foresters and project managers concerned with issues of biological diversity. Considering that in 1980, 85% of industrial plantations in the tropics were established with just three genera—*Pinus*, *Eucalyptus*, and *Tectona*—greater efforts must be made to discover and develop the potential of tropical species (Evans, 1992).

2. Materials and methods

2.1. Materials

The OTS species screening trial was established at La Selva Biological Station in Puerto Viejo, Heredia, Sarapiquí, Costa Rica, from 1987 to 1990. The station is located within the Holdridge Tropical Wet Forest lifezone, which extends over 23% of the country (Hartshorn et al., 1982). It has a mean annual temperature of 25°C and annual precipitation of 3962 mm (Sanford et al., 1994). Significant amounts of rain fall every month; the driest months occur from February to April.

2.1.1. Sites

An outline of general site characteristics is given in Table 1. The four sites used for the screening trial are located at La Selva Biological Station and were chosen to reflect common soil and topographic types within the area (Sarapiquí). Emphasis was placed on marginal or degraded land unsuited for agriculture or long-term grazing, i.e. potential areas for reforestation under elevations less than 500 m.

Soils are characterized by low pH (4.8–5.0) with Al saturation from 47 to 66% and low cation exchange capacity (Butterfield, 1993). Each site had a different land-use history. Site A had been under mechanized rice cultivation in the 1950s and later converted to pasture. Sites B–D had been in pasture and abandoned from 1 to 9 years earlier. On Site D young second-growth vegetation was maintained to provide shade. This site served as an initial test of enrichment plantings, where valuable trees are planted under and between existing vegetation. This site was also unique among the four sites for the additional root competition from existing vegetation. The other three sites (A–C) were under full sun conditions.

2.1.2. Species

A master list of 150 species guided species selection. Included in the list were exotic species commonly used in tropical plantations, valuable timber species from lowland areas of Costa Rica, and little-known local species that grow to adequate size and form for potential commercial exploitation. It was not possible to locate adequate seed for all the species on the master list but at the end of the first 3 year phase 84 species had been planted on the four experimental sites, 17 of which were exotic species widely tested in the tropics, 52 were indigenous to the region, and 15 were native to other parts of Costa Rica (Table 2).

Commercial seed was unavailable for most of the native species tested. Data were collected on phenology, number of seeds per kilogram, and fresh seed germination rates for the little-known native species (González, 1991). Seeds or seedlings of the remaining species were purchased. An average of four or five mother trees was used for local seed collections; however, it was impossible to maintain this standard for all species, as some were rare or seed production among individuals was not synchronized. With a few exceptions, only one provenance per species was tested. All trees were raised in plastic bags in the nursery.

As it was logistically impractical to plant all the species at once, 8–12 species were planted at the same time on each site. Several months later another group was planted. No seedlings were planted during the driest months of the year, March–May. A total of eight sets was planted over a 3 year period.

2.2. Methods

The experimental layout for the species screening trial was a randomized complete block design with single tree plots. One tree per species was planted in each block with 24 blocks per site. Trees were planted at 3 m × 3 m spacing. The single tree plot design was highly efficient for testing a large number of species. The drawback was that species could only be measured for 3 years, after which inter-tree competition began. More traditional designs of small single-species blocks would have required as much as four times more seedlings and land for the same number of trees sampled (Butterfield, 1990).

Sites were prepared by clearing by machete. No burning was done. Herbicide (Roundup) was applied once, a few weeks prior to planting in an area of 1 m diameter around the stake marking the planting spot for each tree. Subsequent maintenance was done as needed by machete, with six to eight cleanings the first year and four to six the next year. No fertilizers or pesticides were applied, except for Sites B and D where large leaf-cutter ant nests near plantations were eliminated or reduced by Mirex applications near the nest site.

Trees dead after 1 month were replaced, after which no further planting was done. Trees were measured every 6 months for 36 months. Total height and dbh (diameter at breast height, once trees obtained a height of 1.3 m) and a pest variable were recorded. The pest variable denoted the presence (not severity) of ant (*Atta* sp.), insect (other than ant), mammal (white-tailed deer, peccary, rabbit) browsing, or other. The 'other' category included sickly trees (curled or yellow leaves, dropping leaves, etc.), apical die-back, broken tops, or anything else that indicated a physical sign of reduced plant vigor.

At the end of 3 years additional data on commercial stem length were collected from every tree to reflect tree form. The stem length variable indicated the height of potentially commercial stem. If the central stem of the tree was completely straight then the total height was used. Otherwise, the commercial stem length measurement extended to the first major fork, curve, or defect in the stem. To provide a general description of the species growing under full sun conditions the crown depth and width were measured for five representative trees of each species from each of the three sun sites (total 15 trees per species).

2.3. Analysis

To measure the effect of site, group (set of species planted together), and species within groups on survival at 3 years of age, means of 24 blocks per site were combined across sites. Distribution of the variable was binomial, so arcsin and square-root transformations were conducted prior to the analysis of variance (ANOVA) with Statistical Analysis Systems (SAS) Version 6.03 (Table 3). Similar analyses without the group effect were run for survival at each site and across the three sun sites to calculate per cent survival for each species. As poor survival could be due to herbivory problems (which potentially can be controlled) a damage index was developed to rate the susceptibility of species to the two most important herbivory problems: leaf-cutter ants (*Atta* sp.) and mammal (mostly deer) browsing. Frequency charts for observations for each damage code were developed and natural breaks were subjectively selected. Based on these breaks, species were labeled with codes from zero (no damage observed) to three (high frequency).

Potential commercial wood volume was calculated as

$$\text{volume} = 1.047 \times \text{DBH}^2 \times \text{commercial stem length}$$

No attempt was made to add a form factor for volume

Table 2
Species tested in the OTS species screening trials at La Selva Biological Station, Sarapiquí, Costa Rica

Scientific name	Family	Common name (Costa Rican)
Exotic species widely tested in the lowland humid tropics		
Araucaria hunsteinii K. Schumann	Araucariaceae	Araucaria
Acacia mangium[a] Willd	Mimosaceae	Acacia
Erythrina poeppigiana (Walp.) O.F. Cook	Papilionaceae	Poró gigante
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Eucalipto
Eucalyptus deglupta Blume	Myrtaceae	Eucalipto
Eucalyptus saligna Smith	Myrtaceae	Eucalipto
Gmelina arborea Roxb.	Verbenaceae	Melina
Hevea brasiliensis (H.B.K.) Muell-Arg.	Euphorbiaceae	Caucho de Brasil
Pinus caribaea var. *hondurensis*	Pinaceae	Pino
Pinus tecunumanii Schwerdtfeger	Pinaceae	Pino
Tectona grandis L.f.	Verbenaceae	Teca
Terminalia ivorensis[a] A. Chev.	Combretaceae	Terminalia
Terminalia superba[a] Engl. and Diels.	Combretaceae	Terminalia
Species indigenous to the region		
Brosimum lactecens (Moore) C.C. Berg	Moraceae	Lechoso
Calophyllum brasiliense Cambess	Clusiaceae	Cedro María
Carapa nicaraguensis C. DC.	Meliaceae	Cedro macho, caobilla
Castilla elastica Sessé	Moraceae	Hule
Cedrela odorata L.	Meliaceae	Cedro amargo
Cordia alliodora (Ruiz & Pavón) Oken	Boraginaceae	Laurel
Cordia bicolor A. DC.	Boraginaceae	Muñeco
Cordia megalantha S.F. Blake	Boraginaceae	Laurel mastate
Dalbergia tucurrensis J.D. Sm.	Papilionaceae	Granadillo
Dipteryx panamensis (Pittier) Record	Papilionaceae	Almendro
Genipa americana L.	Rubiaceae	Guatíl
Goethalsia meiantha (J.D. Sm.) Burret	Tiliaceae	Guácimo blanco
Hampea appendiculata (J.D Sm.) Standley	Malvaceae	Burío ratón
Hernandia didymantha J.D Sm.	Hernandiaceae	Zopilote
Hyeronima alchorneoides Allemao	Euphorbiaceae	Pilón
Hymenolobium mesoamericanum H. Lima	Papilionaceae	Cola de pavo
Ilex skutchii G. Edwin ex. T. Dudley	Aquifoliaceae	Siete cueros
Inga coruscans Willd	Mimosaceae	Guaba colorado
Inga edulis Martius	Mimosaceae	Guaba chilillo
Inga longispica Standley	Mimosaceae	Gauba ron-ron
Inga thibaudiana DC.	Mimosaceae	Guaba
Jacaranda copaia (Aublet) D. Don	Bignoniaceae	Gallinazo
Lacmellea panamensis (Woodson) Markgraf	Apocynaceae	Lagarto negro
Laetia procera (Poeppig) Eichl.	Flacourtiaceae	Manga Larga
Lecythis ampla Miers	Lecythidaceae	Olla de mono
Lonchocarpus velutinus Benth ex Seemann	Papilionaceae	Nene
Miconia multispicata Naudin	Melastomataceae	Lengua de vaca
Minquartia guianensis Aublet	Olacaceae	Manú
Nectandra kunthiana (Nees) Kosterm.	Lauraceae	Quizarrá
Nectandra membranacea (Sw) Griseb.	Lauraceae	Aguacatillo
Ochroma pyramidale (Cav. ex Lam.) Urban	Bombacaceae	Balsa
Ormosia macrocalyx Ducke	Papilionaceae	Frijolito
Otoba novogranatensis Moldenke	Myristicaceae	Cotón
Pentaclethra macroloba (Willd) Kuntze	Mimosaceae	Gavilán
Pithecellobium elegans Ducke	Mimosaceae	Ajillo
Pithecellobium macradenium Pittier	Mimosaceae	Ojos de gringo, arenillo
Pouteria spp.	Sapotaceae	Níspero
Pterocarpus rohrii Vahl	Papilionaceae	Sangrillo

Table 2 Continued

Scientific name	Family	Common name (Costa Rican)
Rollinia microsepala Standley	Annonaceae	Anonillo
Sclerolobium guianensis Benth.	Caesalpiniaceae	Tostado
Simarouba amara Aublet	Simaroubaceae	Aceituno
Stryphnodendron microstachyum Poeppig & Endl.	Mimosaceae	Vainillo
Tabebuia guayacan (Seemann) Hemsley	Bignoniaceae	Corteza amarilla
Terminalia amazonia[a] (J.F. Gmelin) Exell	Combretaceae	Roble coral
Terminalia oblonga (Ruiz & Pavón) Steudel	Combretaceae	Surá
Virola koschyni Warb.	Myristicaceae	Fruta dorada
Vitex cooperi Standley	Verbenaceae	Cacho de venado
Vochysia allenii Standley & L.O. Williams	Vochysiaceae	Botarrama blanco
Vochysia ferruginea Martius	Vochysiaceae	Botarrama
Vochysia guatemalensis J.D. Sm.	Vochysiaceae	Chancho
Zanthoxylum mayanum Standley	Rutaceae	Largarto
Species native to other parts of Costa Rica		
Albizia guachapele (Kunth) Little	Mimosaceae	Guayaquil
Bombacopsis quinata (Jacq.) Dugand.	Bombacaceae	Pochote
Brosimum utile (Kunth) Pittier	Moraceae	Lechoso
Dalbergia retusa (Hemsley)	Papilionaceae	Cocobolo
Dilodendron costaricense (Radlk) Gentry & Steyerm	Sapindaceae	Iguano
Enterolobium cyclocarpum (Jacq.) Griseb.	Mimosaceae	Guanacaste
Gliricidia sepium (Jacq.) Kunt ex Walp.	Papilionaceae	Madero negro
Myroxylon balsamum (L.) Harms	Papilionaceae	Chirraca
Ocotea spp.	Lauraceae	Ira rosa
Pithecellobium arboreum (L.) Urban	Mimosaceae	Ardillo
Pithecellobium idiopodum S.F. Blake	Mimosaceae	Cashá
Pithecellobium saman (Jacq.) Benth.	Mimosaceae	Cenízaro
Pseudobombax septenatum (Jacq.) Dugand	Bombacaceae	Ceibo
Simarouba glauca DC.	Simaroubaceae	Aceituno
Tabebuia rosea (Vertol.) DC.	Bignoniaceae	Roble sabana
Little known exotic species		
Guazuma crinita Martius (from Peruvian Amazon)	Sterculiaceae	–

[a]Two provenances.

Table 3
ANOVA for survival across sites

Source	df	Mean squares	Expected mean squares	P
Site	3	0.4921	$\sigma^2+10.7\sigma^2_{s\times g}+84\sigma^2_s$	0.004
Group	7	0.5352	$\sigma^2+4\sigma^2_{spp.\ (g)}+10.4\sigma^2_{s\times g}+41.8\sigma^2_g$	0.004
Site × Group	21 (error A)	0.0826	$\sigma^2+10.4\sigma^2_{s\times g}$	0.291
Spp. (Group)	76	0.3392	$\sigma^2+4\sigma^2_{spp.\ (g)}$	0.0001
Spp. × Site (Group)	228 (error B)	0.0714	σ^2	
Corrected total	335			

The ANOVA analysis used the following model:
Mean survivorship = Site + Group + Site × Group + Spp. (Group) + Error.

calculation, as for many species the variable is unknown and it would vary considerably among species. The volume variable (dm^3) is a crude estimate of usable wood and is used for comparative purposes only.

To evaluate the response of species to shade (Site D), a comparison was made with growth in an adjacent full sun plot (Site B). Both these sites shared common land-use histories, soil, topographic position, and problems with leaf-cutter ants. Differences, in percentage points, were calculated for survival for the two sites (per cent survival at Site D minus per cent survival at Site B). Average heights for each species were compared between the two sites to identify species that grew faster in the shade. Species were ranked from highest to lowest height differences.

3. Results and discussion

The interpretation of the results depends on the objective of the forestry program. End-use is of utmost importance in selecting species for reforestation. Therefore, results from this trial are presented according to potential uses: timber plantations, agroforestry systems, enrichment planting, and reforestation of conservation areas and buffer zones.

Before recommendations can be made to farmers, the species presented in these groups require further testing across target sites or under more realistic circumstances. These data represent the first screening to ascertain rates of survival and initial growth, as well as form and crown sizes when open-grown.

3.1. Survival across all species

Survival was significantly affected by sites, groups, and species within groups (all at $P<0.01$; Table 3). The experimental design and analysis only allow direct comparisons between species within a group rather than among all species. However, the effect of site–group interactions was not significant. For survival across all species, only Site C was significantly statistically different from the other sites (79% survival vs. 70%, 66% and 72% at Sites A, B, and D, respectively).

3.2. Timber species

The most common variable used to identify promising species for commercial forestry is volume. As trees were planted in single tree plots it was not possible to generate basal area or volume per hectare data. However, to reflect both survival and growth rates, individual tree volumes were summed for surviving trees across the three sun sites. The volume sum (dm^3) was used to select the top 25% of the species tested (Table 4). Where two provenances of the same species appeared in the top 25%, only one was chosen.

Of the top species, 67% were native species, which is the same proportion as in the original number tested. Also included in the top 25% are two of the five species currently recommended by the DGF for reforestation in the northern region of Costa Rica, *Gmelina arborea* and *Eucalyptus deglupta*. Two other species currently recommended for reforestation by the DGF, *Cordia alliodora* and *Tectona grandis*, did poorly. Teak had low survival at some sites (Site A: 54%) and poor growth and form (average tree volume of 19.8 dm^3). *Cordia alliodora*, one of the most widely used species for reforestation in the region (41% of the area in plantation; Butterfield and Espinoza, 1995), appeared in the bottom third for growth. Survival was also poor, barely above 50%.

Results from this trial and others (Butterfield and Espinoza, 1995) indicate several native species with good potential for large-scale reforestation. The DGF has approved several of these species for reforestation with government fiscal incentives, and farmer demand for them continues to increase (Butterfield and Fisher, 1994).

The species from Table 4 offer a wide range of options for further testing for commercial forestry purposes. Caution is urged in choosing too small a number of species from these trials for further testing. Early vigor of *Ochroma* and *Jacaranda* is of questionable duration, whereas sustained or increasing growth may be expected from other species such as *Terminalia* and *Vochysia*. The relative ranking of the species will continue to change over time, and longer-term tests will be needed to allow a better estimate of species performance. Species selection should go beyond growth and volume data to consider the final commercial product. Whereas a single species is often associated with a particular end-use (e.g. *Gmelina* for pulp, *Terminalia amazonia* for heavy construction timber), several different species may have similar physical, chemical, or mechanical properties. Low-grade timber can be harvested from plantations of *Gmelina*, *Vochysia*, and *Jac-*

Table 4
Top species for further testing in timber plantations, grouped by wood density, ranked by sum of tree volumes (dm^3; 72 trees per species); average survival, diameter, height, and volume at 3 years of age on surviving trees at sun sites (A, B and C) and a damage index; La Selva Biological Station, Costa Rica

Species	Average						
	Survival (%)	dbh (cm)	Height (m)	Volume (dm^3)	Rank (sum vol.)	Native (N) or Exotic (E)	Damage mammal/ant
Extra light wood (specific gravity <0.20)							
Ochroma pyramidale	55	16.4	11.6	285.0	3 (1126)	N	2 0
Pseudobombax septenatum	95	6.3	4.7	63.1	10 (4234)	N	0 0
Light to medium light wood (specific gravity 0.30–0.42)							
Cordia bicolor	95	11.8	6.1	43.8	13 (2984)	N	0 0
Eucalyptus deglupta	63	9.0	9.6	124.6	9 (5616)	E	2 0
Gmelina arborea	80	22.3	10.0	251.5	1 (14604)	E	2 3
Goethalsia meiantha	80	12.0	7.6	102.0	7 (6842)	N	1 0
Jacaranda copaia	86	11.9	7.8	113.2	6 (7030)	N	0 0
Pinus caribaea var. *hondurensis*	95	8.6	6.1	48.1	12 (3275)	E	0 0
Stryphnodendron microstachyum	93	12.3	7.7	92.3	8 (6196)	N	0 1
Vochysia ferruginea	98	9.4	5.6	55.0	11 (3913)	N	1 2
Vochysia guatemalensis	98	13.5	7.5	142.6	4 (10138)	N	0 2
Medium heavy to very heavy wood (specific gravity 0.42–0.72)							
Acacia mangium (Papua New Guinea)	83	18.7	11.2	211.7	2 (11870)	E	0 3
Eucalyptus saligna	40	7.6	7.1	72.5	21 (1961)	E	0 2
Laetia procera	98	6.9	6.5	37.8	15 (2691)	N	0 0
Nectandra membranacea	90	7.3	5.8	35.4	19 (2269)	N	0 1
Pinus tecunumanii	91	7.8	6.7	44.0	14 (2909)	E	0 0
Sclerolobium guianensis	93	7.6	7.3	36.9	17 (2440)	N	0 0
Terminalia ivorensis (Turrialba)	54	13.6	9.5	251.5	5 (9820)	E	0 3
Unknown wood density							
Albizia guachapele	98	8.0	6.2	27.7	20 (1973)	N	0 0
Pithecellobium macradenium	100	8.1	7.4	32.7	18 (2358)	N	0 0
Rollinia microsepala	88	7.4	5.7	41.0	16 (2629)	N	0 0

Specific gravity sources: Kukachka, 1970; FAO, 1977; National Research Council, 1983; Chudnoff, 1984; Interforest AB, 1986; Benitz and Montesinos, 1988; Carpio, 1992; González et al., undated.

aranda, and these provide diversification against unknown pests, problems, and changes in wood markets. Variability between species can, at times, be less than the variability within a species (Keating, 1978).

Technology continues to improve the ability to use more species in an array of products. Preservation and drying techniques are expanding the market for *Gmelina* as sawn timber. New milling techniques have provided a market for *Dipteryx panamensis*, previously considered too dense to saw. Species that have no market at the time of testing may be in demand just a few years later.

Species from this trial with low-density to moderately low-density wood and low durability with good growth potential are: *Gmelina arborea*, *Eucalyptus deglupta*, *Vochysia guatemalensis*, and *Jacaranda copaia*. The last two species are alternatives to *Gmelina* for pulp and low-value lumber, especially on less fertile sites where *Gmelina* does not grow well. For low-density wood and ease of treatability, *Goethalsia meiantha* and *Stryphnodendron microstachyum* offer alternatives.

Species with high potential in the medium-dense wood and durability category are *Terminalia ivorensis*

Table 5
Potential species for agroforestry testing; average survival, diameter, height, crown width, and per cent crown cover of stem at 3 years of age and a damage index (sun sites A, B and C); La Selva Biological Station, Sarapiquí, Costa Rica

Species	Sun sites (A,B,C)			Crown width (dm)	Crown cover of stem (%)	Native (N) or exotic (E)	Damage mammals/ants
	Survival (%)	dbh (cm)	Height (m)				
Light shade, short rotation							
Jacaranda copaia	86	11.9	7.8	31	63	N	0 0
Ochroma pyramidale	55	16.4	11.6	76	48	N	2 0
Terminalia ivorensis	54	13.6	9.5	85	72	E	2 3
Eucalyptus deglupta	63	9.0	9.6	47	45	E	2 0
Small crown, medium rotation							
Calophyllum brasiliense	76	2.9	3.3	16	65	N	2 1
Dipteryx panamensis	83	3.6	4.8	18	40	N	1 0
Laetia procera	98	6.9	6.5	42	60	N	0 0
Terminalia amazonia	70	7.1	6.9	38	65	N	1 2
Virola koschyni	72	2.8	2.6	18	53	N	3 0
Alley cropping (high biomass)							
Goethalsia meiantha	93	12.0	7.6	553	73	N	1 0
Inga edulis	97	10.6	6.3	81	48	E	0 1

and *Nectandra membranacea*. If fine tropical hardwoods are needed for furniture production, decorative wood, or heavy construction uses, then *Terminalia amazonia*, *T. superba*, *Hyeronima alchorneoides*, and *Laetia procera* should be considered. *Ochroma pyramidale* is for specialty markets but offers the highest individual tree volume of any species tested and at very short rotations.

One species will not meet all the wood needs of Costa Rica nor adequately exploit the international market for exports. The final selection of species for further testing in pilot plantations will depend on each grower and the wood markets in which they wish to compete.

3.3. Agroforestry species

There are many ways to incorporate trees on farms: border plantings along property boundaries or fields, trees in pastures, crops grown between trees planted at wide spacing or trees grown to benefit crops. Two ends of the agroforestry spectrum are timber species planted for harvest mixed with crops (taungya) and species used exclusively for their biomass to augment crop production (alley-cropping). The elimination trial provides information on several key variables for selecting species for different growing conditions. Average survival, dbh, and total height are given for trees grown in full sunlight as well as data on crown width and per cent crown cover of the stem (Table 5). The crown size data help to estimate the extent of shade (width) and quality of shade (crown cover), both factors to consider when mixing trees with crops.

The taungya system, where crops are grown between the young trees, can take several forms. Trees not suited to plantation cultivation owing to wide spreading crowns are grown with wide spacing, i.e. *Ochroma pyramidale* or *Terminalia ivorensis*. Sun-demanding crops could be interplanted for the first few years, to be replaced by crops or trees requiring a light shade covering. Another model is the establishment of initially slow-growing, small crown species of high value at wide spacings where intercropping can be maintained for many years, i.e. *Calophyllum brasiliense* or *Virola koschyni*. In the latter case, intercropping offsets high plantation establishment costs usually incurred when long-term weeding is required.

Species with high biomass production, coppicing ability and foliar N content are good candidates for alley-cropping systems. The multiple stems and wide spreading crown of *Inga edulis* make it an unsuitable species for timber production but it has excellent alley-

Table 6
Species of interest for enrichment or mixed species plantings, ranked by improved height growth in the shade; differences between shade (D) and sun (B) treatments for survival and height with total height and volume sum (dm^3; 24 trees per species) at 3 years of age; La Selva Biological Station, Sarapiquí, Costa Rica

Species	Shade site – sun site (D – B)			Total height (m)	Sum of volume (dm^3)	Native (N) or exotic (E)
	Survival percentage pts	Height difference (m)	Rank			
Carapa nicaraguensis	25	0.78	8	3.7	150	N
Dalbergia tucurrensis	–5	0.73	10	4.8	151	N
Gmelina arborea	21	1.69	2	7.5	1225	N
Goethalsia meiantha	–5	1.68	3	8.2	2110	N
Hernandia didymantha	20	0.84	7	4.5	276	N
Hyeronima alchorneoides	0	0.70	11	6.6	812	N
Jacaranda copaia	12	0.78	9	9.7	3287	N
Lacmellea panamensis	29	1.29	5	7.0	796	N
Lecythis ampla	58	2.22	1	3.2	40	N
Nectandra kunthiana	13	1.31	4	4.1	362	N
Terminalia superba (Ivory Coast)	4	0.88	6	3.3	7	E

Table 7
Average survival, diameter, height, and sum of individual tree volumes (72 trees planted per species) at 3 years of age for selected native species for reforestation of conservation areas and buffer zones; important food sources for monkeys and birds; based on observations at La Selva Biological Station, Costa Rica

Species	Sun sites (A, B and C)			
	Survival (%)	dbh (cm)	Height (m)	Sum of volume (dm^3)
Brosimum lactecens	61	1.4	1.6	9
Castilla elastica	37	3.2	2.4	129
Cordia bicolor	95	11.8	6.1	2984
Dipteryx panamensis	83	3.6	4.8	495
Genipa americana	75	3.9	4.0	466
Goethalsia meiantha	93	12.0	7.6	6842
Hampea appendiculata	65	4.6	4.0	938
Hyeronima alchorneoides	73	7.5	5.4	1675
Inga thibaudiana	91	4.9	4.6	452
Laetia procera	98	6.9	6.5	2691
Miconia multispicata	86	5.0	4.6	755
Minquartia guianensis	25	1.1	1.3	2
Simarouba amara	72	6.4	5.8	1522
Stryphnodendron microstachyum	93	12.3	7.7	6196
Virola koschyni	72	2.8	2.6	161
Vitex cooperi	81	4.1	4.3	458

Sources for important tree species for wildlife: Stoner, 1993; O. Vargas, personal communication, 1994; Bergeson, in preparation.

cropping characteristics. *Goethalsia meiantha* is a proficient biomass producer though its coppicing ability is unknown and it does not fix N.

3.4. Enrichment planting

Species that respond well to a shaded environment can be used in enrichment plantings as a means to establish additional species in a young forest. However, these types of plantings often fail owing to poor maintenance and competition with existing vegetation. Shade-tolerant species can also be used in mixed species plantations where companion species grow quickly and provide shade or if planting times are staggered.

The use of a shaded site (D) in the screening trial allowed the identification of species well suited to these types of plantings. Those species exhibiting improved height growth, on Site D over Site B, are ranked by improvement in Table 6. However, it may not be economically feasible to plant low-value species at low densities within existing vegetation. Higher-value timber species or those that are rare may prove to be the most attractive candidates for enrichment or mixed species plantings: *Carapa nicaraguensis*, *Dalbergia tucurrensis*, *Hyeronima alchorneoides*, *Lecythis ampla* or *Terminalia superba*.

3.5. Reforestation in conservation areas and buffer zones

The use of indigenous species is most appropriate within conservation areas or for reforestation of buffer zones. Species might be selected according to their rarity in the forest, whether owing to over-harvesting (*Cedrela odorata*) or naturally low population levels (*Hymenolobium mesoamericanum*, *Lecythis ampla*), or to provide food and habitat for wildlife (Table 7). Species selection can also include trees that attract birds and other seed dispersal agents to accelerate natural regeneration.

Several species can be dual purpose, offering both wildlife food and timber products (*Goethalsia meiantha*, *Hyeronima alchorneoides*, *Virola koschyni*), whereas others may serve key ecological functions for supporting important fauna, i.e. *Dipteryx panamensis* is an important food source for the great green macaw (*Ara ambigua*; Stiles and Skutch, 1989). Key wildlife or extremely rare species can also be incorporated into the borders of commercial plantations or along farm boundaries.

4. Conclusions

The exploration of native flora for useful reforestation species should be encouraged. Increasing the diversity of species used in forestry development projects can reduce risk, both biological and economic, by cultivating a variety of species for specific sites, growing conditions (plantation, field borders, mixed with crops), and end-uses. Previously untested indigenous species may complement or outperform the handful of exotic species currently used in forestry promotion activities.

The results from this trial suggest considerable potential for native species. The inclusion of well-known exotics helps to compare results with growth rates elsewhere and insures that the best species are selected for the sites and objectives of the project. Although the species screening trial in this study was oriented towards timber species, the results are useful for identifying species with a range of uses from commercial forestry plantations to agroforestry to buffer zone management.

The use of single tree plots was an efficient way to quickly test a large number of species. The testing of species on more than one site also yielded additional information on species site sensitivity (Butterfield, 1993) and different silvicultural regimes. These previously untested, little-known species demonstrate the large number of native species with high potential for management.

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