GROWTH OF NATIVE TREE SPECIES PLANTED IN OPEN PASTURE, YOUNG SECONDARY FOREST AND MATURE FOREST IN HUMID TROPICAL COSTA RICA

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Piotto, D. 2007. Growth of native tree species planted in open pasture, young secondary forest and mature forest in humid tropical Costa Rica. Twenty-four native species with high timber value and well-known for wildlife use were planted in open pasture, young secondary forest (10 years old) and mature forest without causing major disturbances to natural vegetation. Plots were established in cooperation with local farmers in the Sixaola River valley in Talamanca, Limón, Costa Rica. In the center of each 64-tree single species plot, a 36-tree plot (6 × 6 trees) was defined as the measurement plot. The averages of total height, diameter at breast height (dbh), basal area, volume and survival were calculated for each plot. Mean annual increment in volume (MAIV) was used to compare species performance. The most productive species in open pasture were *Rollinia microsepala* (MAIV = 33.3 m^3/ha/year), *Virola koschnyi* (MAIV = 24.4 m^3/ha/year), *Abarema idiopoda* (MAIV = 20.0 m^3/ha/year), *Inga coruscans* (MAIV = 14.4 m^3/ha/year) and *Terminalia amazonia* (MAIV = 14.0 m^3/ha/year). The most productive species in young secondary forest were *Cordia alliodora* (MAIV = 12.5 m^3/ha/year), *Rollinia microsepala* (MAIV = 8.3 m^3/ha/year), *Abarema idiopoda* (MAIV = 5.5 m^3/ha/year) and *Terminalia oblonga* (MAIV = 4.6 m^3/ha/year). All plots in mature forest showed low productivity, where the largest MAIV was achieved by *Hyeronima alchorneoides* and *Virola sebifera*. Species showed differences in survival and growth among habitats.

Keywords: Enrichment planting, reforestation, management

Piotto, D. 2007. Pertumbuhan spesies pokok asli yang ditanam di padang rumput terdedah, hutan sekunder yang muda dan hutan matang di kawasan tropika lembap di Costa Rica. Sebanyak 24 spesies asli yang mempunyai nilai kayu yang tinggi serta berguna untuk hidupan liar ditanam di kawasan padang rumput yang terdedah, hutan sekunder muda berusia 10 tahun dan juga di hutan matang. Sepanjang kajian, kami pastikan agar gangguan terhadap tumbuhan asal sentiasa terkawal. Plot dibina dengan kerjasama peladang tempatan di lembah Sungai Sixaola di Talamanca, Limón, Costa Rica. Di tengah-tengah plot yang mengandungi 64 spesies tunggal itu, satu plot 36 pokok (6 × 6 pokok) di kenal pasti sebagai plot ukuran. Purata ketinggian keseluruhan, diameter aras dada (dbh), isi padu dan kemandirian dikira bagi setiap plot. Tambahan tahunan min isi padu (MAIV) diguna untuk membandingkan prestasi spesies. Spesies yang paling produktif di padang rumput terdedah ialah *Rollinia microsepala* (MAIV = 33.3 m^3/ha/tahun), *Virola koschnyi* (MAIV = 24.4 m^3/ha/tahun), *Abarema idiopoda* (MAIV = 20.0 m^3/ha/tahun), *Inga coruscans* (MAIV = 14.4 m^3/ha/tahun) dan *Terminalia amazonia* (MAIV = 14.0 m^3/ha/tahun). Di hutan sekunder muda, spesies yang paling produktif pula ialah *Cordia alliodora* (MAIV = 12.5 m^3/ha/tahun), *Rollinia microsepala* (MAIV = 8.3 m^3/ha/tahun), *Abarema idiopoda* (MAIV = 5.5 m^3/ha/tahun) and *Terminalia oblonga* (MAIV = 4.6 m^3/ha/tahun). Semua plot di hutan matang menunjukkan produktiviti yang rendah. MAIV tertinggi dicapai oleh *Hyeronima alchorneoides* and *Virola sebifera*. Spesies di ketiga-tiga habitat yang dikaji tidak menunjukkan sebarang perbezaan dalam kemandirian serta pertumbuhan.

INTRODUCTION

Forest plantations play an important role in promoting sustainable development in the tropics. With high growth rates plantations can supply the wood market, thus, reducing the pressure on natural forests for timber wood (Sedjo 2001). However, the use of commercially valuable native hardwood species in tropical planted forests worldwide still remains limited (Evans & Turnbull 2004).

In Costa Rica, in past decades several native species have shown good performance in reforestation conditions (Butterfield & Fisher 1994, Montagnini *et al.* 1995). Some of these species are currently used in reforestation

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projects by farmers in the Caribbean lowlands (Piotto *et al.* 2003a, Redondo-Brenes 2007). Reforestation efforts have always focused on planting trees on low productive lands that are unsuitable for agriculture or on abandoned lands where low soil fertility conditions prevail. Recently, interest has arisen in planting trees by enrichment of secondary forest as a source of timber and environmental services. This interest has led some researchers to study silvicultural techniques appropriate to improve timber stock in secondary forests, e.g. enrichment planting techniques and management of secondary forests (Ramos & del Amo 1992, Montagnini *et al.* 1997, Guariguata 2000).

The selective effect of initial site conditions on dispersion, seedling establishment, growth and survival is a major determinant of the species richness of secondary forests in the tropics (Finegan 1996). Many important commercial timber species are rarely found in sites submitted to frequent disturbances; thus, to increase the economic value of secondary forests it is important to develop management alternatives that facilitate the growth of commercial species. The most common technique is called enrichment planting. Basically, it consists of introducing valuable species in degraded forests, without removing the vegetation already present. Enrichment planting allows cultivation of shade-tolerant species which cannot grow in open areas (Montagnini *et al.* 1997). Shade-tolerant species commonly have valuable hardwood (Whitmore 1989) and occur naturally in later stages of natural forest development.

Knowledge about secondary forest succession is largely confined to early stages of forest development, while less is known about older successional stands and the ecology of their dominant species (Guariguata 2000). To date, most work has concentrated on early successional vegetation and the short-lived pioneer species that dominate it (Finegan 1996). Due to the relative management complexity of enrichment planting basic information about the species ecology is fundamental to select potential species and predict their response to management activities. Likewise, the performance of planted native timber woods within natural forests must be known to precisely prescribe appropriate species for enrichment planting.

This paper presents results of growth performance of 24 native tree species in the Caribbean lowlands of Costa Rica. Species were planted in different habitats in order to seek information that can be useful for reforestation projects and enrichment plantations in the zone and other regions with similar conditions. This paper also attempts to provide silvicultural guidelines for the cultivation of tropical wood species and production systems.

MATERIALS AND METHODS

Site description

The study was carried out in cooperation with local farmers in the Sixaola River valley in Talamanca, Limón, Costa Rica. The area is located in south-eastern Costa Rica at 9° 33′ N and 82° 40′ W (Figure 1), 50 m asl, with a mean annual temperature between 24 and 27 °C, a mean annual precipitation between 2200 and 2400 mm year^{-1}, a potential evapotranspiration of 1565–1710 mm year^{-1} and a mean daily sunshine of 4.5 hours (Herrera 1985). The rain distribution through the seasons is particularly uniform, although the humid climate has some seasonality with a short drier season from September till October. The natural vegetation is classified as lowland tropical moist forest with the overall topography being flat and uniform. The alluvial Inceptisols are classified as Tropeptic Eutropepts with slow drainage. Soil pH is medium acid to neutral. Its fertility ranges from moderate to high.

Plantation establishment

The plantations in the study were established between 1989 and 1992 on private lands that belong to a small farmers' association called ASACODE (Asociación San Migueleña de Conservación y Desarrollo). Twenty-four native species locally desired for timber value or well known for wildlife use were planted in single species plots in three different habitats, namely, open pasture, young secondary forest and mature forest. Due to the availability of planting material, it was not possible to plant all species in three treatments. Twenty species were planted in all habitats, two species in two different habitats and only two species in open pasture. Table 1 includes the list of species with their ecology, uses and treatments where they were planted.

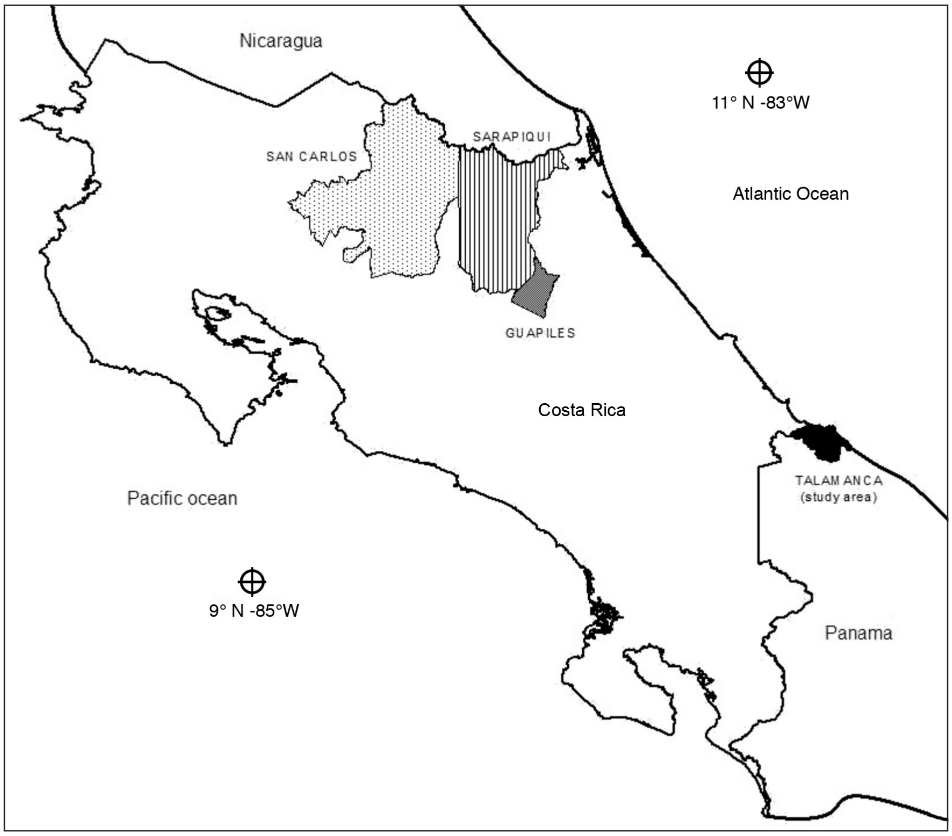

Figure 1 Map of Costa Rica showing the study area location and other sites where experimental trials with the same native tree species were conducted

The planting material was produced in the ASACODE's nursery under a conventional polyethylene nursery bag system. Seeds were collected from selected trees in the region. Initial spacing was at 3 × 3 m and each plot was 24 × 24 m with a total of 64 trees per plot. In the center of each 64-tree single species plot a 36-tree plot (6 × 6 trees) was defined as the measurement plot in order to avoid edge effects (Vásquez 1986). Weeding was the main maintenance activity after field planting of trees in open pasture. Enrichment planting sites (10-year-old secondary forest and mature forest) were prepared without causing major disturbances on natural vegetation. The cutting of lianas was conducted in the first year. Herbicides or fertilizers were not used.

Planting treatments

The vegetation in the experimental site varied between mature forest (old growth forest), 10-year-old secondary forest and open pasture, providing a set of habitats that was used to test the growth of native tree species.

The plots were established in three different treatments:

(1) open pasture previously used for cattle ranching with full sunlight radiation;

(2) 10-year-old secondary forest regenerated on abandoned pastureland with a basal area of 11 m^2/ha, an average of 570 stems/ha with a distribution of tree stem diameter showing low coefficient of variation (diameter at breast height (dbh) > 10 cm), uneven canopy with small gaps and absence of large trees; and

(3) mature forest or old growth forest with a basal area of 25 m^2/ha and an average of 85 stems/ha with a distribution of tree stem diameter showing a high coefficient of variation (dbh > 30 cm). The canopy reaches 40 m high with some large and emergent trees that can reach more than 50 m high, e.g. *Ceiba pentandra*. The most important species are *Carapa guianensis*, *Virola* spp., *Dipteryx panamensis*, *Prioria copaifera* and *Pentaclethra macroloba*.

Table 1 Ecology and uses of 24 species planted in open pasture, young secondary forest and mature forest in the Caribbean lowlands of Costa Rica

Species	Ecology	Uses*
Abarema idiopoda (Blake) Barneby & Grimes	Long-lived pioneer	T, F, C
Brosimum alicastrum Sw	Non-pioneer, shade-tolerant	T, F, M, W
Carapa guianensis Aubl.	Long-lived pioneer, canopy tree, seedlings grow rapidly with high insolation, seedlings are probably shade tolerant	T, F, C, M, W
Cordia alliodora (Ruiz & Pavón) Oken	Long-lived pioneer, seedlings appear in the first year of pioneer succession, this tree is a light-gap species	T, F, C, M
Dalbergia glomerata Hemsl.	Non-pioneer, subcanopy, shade-tolerant, seedlings grow rapidly with high insolation	T
Dipteryx panamensis (Pittier) Record and Mell	Long-lived pioneer	T, F, C, W
Genipa americana L.	Long-lived pioneer, shade intolerant	T, M, W
Hieronyma alchorneoides Allemao	Non-pioneer, subcanopy tree	T, M, W
***Inga coruscans* Humb. & Bonpl. ex Willd.	Short-lived pioneer, shade intolerant	F, W
Manilkara zapota (L.) van Royen	Non-pioneer, canopy tree, shade tolerant	T, C, M, W
Minquartia guianensis Aubl.	Non-pioneer, canopy tree, shade tolerant	T, W
***Pentaclethra macroloba* (Willd.) Kuntze	Non-pioneer, canopy tree, dominant, shade-tolerant, saplings survive and even grow in the dense primary forest	T, F, M
Prioria copaifera Griseb.	Non-pioneer, canopy tree, shade tolerant	T, C, M, W
Quararibea asterolepsis Pittier	Non-pioneer, shade tolerant	T, W
Rollinia microsepala Standl.	Long-lived pioneer	T, W
Sickingia maxonii (Standl.) Standl.	Non-pioneer, subcanopy tree, shade-tolerant is probably a better description than shade-loving	T, W
Symphonia globulifera L.f.	Long-lived pioneer	T, F, M, W
Tabebuia rosea (Bertol.) DC.	Long-lived pioneer	T, F, C, M
****Terminalia amazonia* (J.F. Gmel) Exell	Long-lived pioneer, canopy tree	T
Terminalia oblonga (Ruiz & Pavón) Steud.	Long-lived pioneer, canopy tree	T
Virola koschnyi Warb.	Non-pioneer, canopy tree, seedlings are shade tolerant but respond vigorously to canopy opening	T, M, W
Virola sebifera Aubl.	Non-pioneer, canopy tree, seedlings are shade tolerant but respond vigorously to canopy opening	T, W
*****Vitex cooperi* Standl.	Long-lived pioneer	T
Zanthoxylon riedelianum Engl.	Long-lived pioneer	T

Sources: Cordeiro and Boshier 2003, Clark and Clark 1992, Denslow 1987, Janzen 1983
* Timber (T), Firewood (F), Crafting (C), Medicinal (M), Wildlife (W)
** planted only in open pasture
*** planted only in mature forest and open pasture
**** planted only in young secondary forest and mature forest

Data analysis

On each plot, dbh and total height were measured for each tree, not including bordering trees, in 1992, 1993, 1996 and 1998. The averages of total height, dbh, basal area, volume and survival were calculated for each plot. For volume calculation a form factor of 0.5 was used (Newbould 1967). Mean annual increment in volume (MAIV) was used to compare species productivity. The plantings were not replicated at the plot level, therefore, it was not possible to estimate variation in growth rates.

RESULTS

Tree survival

In general, tree survival in open pasture was high. Among all species planted eight species exhibited survival below 70% (Table 2). Mortality in open pasture occurred a few months after planting for all species with low survival mainly because of grass competition. The species with the highest survival were *D. glomerata*, *A. idiopoda*, *T. amazonia,* among others, with more than 90% of the trees initially planted still living in the last measurement. The species with the lowest survival were *B. alicastrum*, *S. globulifera* and *V. sebifera* with less than 45% of the trees initially planted still living in the last measurement. Only *M. guianensis* presented full mortality.

Tree survival in the 10-year-old secondary forest was satisfactory. Among the 21 species planted only six species exhibited survival less than 70% (Table 2). Mortality in this secondary forest occurred continuously during the plantation development for all species with extreme shade intolerance. The species with the highest survival were *D. glomerata*, *D. panamensis*, *M. zapota*, among others, with more than 90% of the trees initially planted still living in the

Table 2 Age, survival, height and mean annual increment in volume (MAIV) at the last measurement of native tree species planted in open pasture, young secondary forest and mature forest in the Caribbean lowlands of Costa Rica

Species	Open pasture					10-year-old secondary forest					Mature forest				
	Age (month)	Survival (%)	Height (m)	Dbh (cm)	MAIV (m^3/ha/year)	Age (month)	Survival (%)	Height (m)	Dbh (cm)	MAIV (m^3/ha/year)	Age (month)	Survival (%)	Height (m)	Dbh (cm)	MAIV (m^3/ha/year)
A. idiopoda	98	94	14.03	14.19	20.0	98	89	8.74	7.07	5.5	90	39	1.00	-	-
B. alicastrum	89	33	7.22	6.18	0.7	99	86	4.00	2.48	0.2	97	78	1.01	-	-
C. guianensis	99	92	12.03	12.01	9.3	99	53	2.45	2.27	0.1	97	8	0.87	-	-
C. alliodora	87	86	11.59	11.71	10.6	87	72	12.62	10.30	12.5	24	0	-	-	-
D. glomerata	92	100	10.85	10.97	8.4	92	97	8.11	5.88	2.0	90	69	3.54	2.66	0.2
D. panamensis	92	86	15.56	11.01	11.9	92	97	7.65	4.42	1.6	90	36	1.00	-	-
G. americana	98	67	10.85	10.36	5.4	98	92	4.28	3.24	0.4	96	75	0.48	-	-
H. alchorneoides	78	72	11.30	10.44	6.9	87	72	9.58	6.64	4.1	79	50	8.49	5.83	1.5
I. coruscans	82	64	16.25	12.47	14.4	-	-	-	-	-	-	-	-	-	-
M. zapota	87	89	9.34	9.03	4.6	87	97	4.13	2.84	0.3	86	67	1.83	1.78	0.01
M. guianensis	53	0	-	-	-	68	36	1.94	1.28	0.1	67	64	1.26	-	-
P. macroloba	80	61	8.82	8.95	3.7	-	-	-	-	-	-	-	-	-	-
P. copaifera	99	94	9.51	11.80	7.6	99	92	2.95	2.20	0.1	97	89	1.23	-	-
Q. asterolepsis	65	58	1.73	1.74	0.01	80	0	-	-	-	79	44	1.93	1.99	0.01
R. microsepala	96	94	19.20	16.41	33.3	96	81	11.30	8.87	8.3	74	0	-	-	-
S. maxonii	99	86	10.42	11.20	6.2	99	97	5.75	4.69	0.9	96	97	1.09	-	-
S. globulifera	90	28	6.33	5.19	0.4	87	78	3.09	1.83	0.1	86	50	0.68	-	-
T. rosea	99	94	8.71	9.34	4.3	87	42	3.59	3.22	0.1	86	8	1.41	1.00	0.01
T. amazonia	89	100	11.74	13.06	13.9	-	-	-	-	-	90	64	1.37	1.24	0.01
T. oblonga	89	94	11.65	11.21	10.2	87	86	9.58	7.82	4.6	86	3	0.77	-	-
V. koschnyi	89	83	16.13	16.90	24.4	87	78	7.23	5.55	1.5	90	28	1.07	-	-
V. sebifera	65	44	5.05	4.95	0.7	75	67	4.21	4.40	0.7	79	67	6.18	4.90	1.1
V. cooperii	-	-	-	-	-	80	83	3.53	2.45	0.2	79	47	2.21	1.52	0.01
Z. riedelianum	65	53	2.94	3.99	0.2	75	61	3.01	2.76	0.1	26	0	-	-	-

last measurement. The species with the lowest survival were *M. guianensis* and *T. rosea* with less than 45% of the trees initially planted still living in the last measurement. Only *Q. asterolepsis* presented full mortality.

In general, tree survival in mature forest was very low. Among 21 species planted, only five species exhibited survival above 70% (Table 2). Mortality in mature forest occurred continuously during the plantation development for all species with low survival. The species with the highest survival were *S. maxonii* and *P. copaifera* with more than 89% of the trees initially planted still living in the last measurement.

Tree growth and productivity

Great differences were found in dbh and height between species in open pastures. The largest dbh growth was observed for *V. koschnyi*, *R. microsepala* and *A. idiopoda*. The largest height growth was observed for *R. microsepala*, *I. coruscans* and *V. koschnyi*. The lowest height was observed for *M. guianensis*, *Q. asterolepsis*, *V. sebifera* and *Z. riedelianum* (Table 2). *Rollinia microsepala*, *V. koschnyi*, *A. idiopoda* and *T. amazonia* plots showed basal area above 15 m^2/ha in the last measurement. The most productive species in open pasture were *R. microsepala* (MAIV = 33.3 m^3/ha/year), *V. koschnyi* (MAIV = 24.4 m^3/ha/year), *A. idiopoda* (MAIV = 20.0 m^3/ha/year), *Inga coruscans* (MAIV = 14.4 m^3/ha/year) and *T. amazonia* (MAIV = 14.0 m^3/ha/year).

In enrichment planting of young secondary forest the largest dbh growth was observed for *C. alliodora*, *R. microsepala* and *T. oblonga* (Table 2). The largest height growth was observed for *C. alliodora*, *R. microsepala* and *T. oblonga*. Although *C. alliodora*, *D. glomerata* and *T. oblonga* had shown high early growth these species had not maintained growth rates, showing low growth in the last measurement. The most productive species were *C. alliodora* (MAIV = 12.5 m^3/ha/year), *R. microsepala* (MAIV = 8.3 m^3/ha/year), *A. idiopoda* (MAIV = 5.5 m^3/ha/year) and *T. oblonga* (MAIV = 4.6 m^3/ha/year).

Tree growth in enrichment planting in mature forest was poor. The largest dbh and height growth were observed for *H. alchorneoides*, *V. sebifera* and *D. glomerata*. All the other species presented extremely low dbh and height growth (Table 2). *Hieronyma alchorneoides*, *V. sebifera*, *D.*

glomerata and *V. cooperi* had shown reasonable early growth. These species did not sustain growth rates, showing low growth in the last measurement, except for *H. alchorneoides* that maintained annual increments in height above 1 m. All plots showed extremely low productivity. The maximum basal area was achieved by *H. alchorneoides* and *V. sebifera*. However, the values found for basal area and volume can be considered modest in terms of timber production.

Comparison of species survival and growth between habitats

The results showed differences in survival between treatments. Different responses were expected since the seedlings of tree species differ in shade tolerance (Swaine & Whitmore 1988). Three mortality patterns were observed: (1) high mortality in the mature forest, medium mortality in the 10-year-old secondary forest and low mortality in open pasture; (2) low mortality in open pasture and in the 10-year-old secondary forest and high mortality in the mature forest; and (3) similar mortality in all conditions or high mortality in open pasture and low mortality in the 10-year-old secondary forest and in the mature forest.

Mostly, species presented high survival rates under relatively high availability of incident radiation, but high mortality under the deep shade conditions of the mature forest (Figure 2). Species exhibiting this pattern were *A. idiopoda*, *C. alliodora*, *M. zapota*, *D. glomerata*, *D. panamensis*, *R. microsepala*, *T. oblonga*, *V. koschnyi* and *Z. riedelianum*. Most of the species that exhibited this pattern are classified as long-lived pioneer (see Table 1), with the exception of *M. zapota*, *D. glomerata* and *V. koschnyi*.

Carapa guianensis and *T. rosea* exhibited low tolerance to shade with high survival under sunny conditions. Survival decreased in the 10-year-old secondary forest and it was negligible in the mature forest (Figure 3).

Some species did not exhibit variation in mortality among treatments (Figure 4). These species were *G. americana*, *H. alchorneoides*, *P. copaifera*, *Q. asterolepsis* and *S. maxonii*. It is important to point out that *Q. asterolepsis* showed low survival under all conditions. In contrast *H. alchorneoides*, *P. copaifera* and *S. maxonii* exhibited high survival under all conditions indicating that seedlings of these species can tolerate shade for quite long. Other shade tolerant species identified in this study were *B. alicastrum*, *M. guianensis*, *S. globulifera* and *V. sebifera* which had higher survival in the mature forest and in the 10-year-old secondary forest than in open pasture.

Growth results also showed different species responses among treatments. Three growth patterns was observed: (1) high growth in open pasture and low growth in the 10-year-old secondary forest and in the mature forest; (2) high growth in open pasture, medium growth in the 10-year-old secondary forest and low growth in the mature forest; and (3) similar growth under all conditions.

Most species exhibited relatively high growth rates under sunny conditions. Growth tended to decrease under the 10-year-old secondary forest and it was poor in the mature forest (Figure 5). Species with this growth pattern included *A. idiopoda*, *B. alicastrum*, *D. glomerata*, *D. panamensis*, *G. americana*, *R. microsepala*, *S. globulifera*, *S. maxonii*, *T. rosea*, *T. amazonia*, *T. oblonga*, *V. cooperi* and *V. koschnyi*. *Cordia alliodora* was the only species that exhibited high growth rates in open pasture and in the 10-year-old secondary forest; it showed poor growth in the mature forest.

Three species exhibited high growth rates under sunny conditions, but extremely poor growth in the 10-year-old secondary forest and in the mature forest (Figure 6). These species were *C. guianensis*, *P. copaifera* and *M. zapota*.

Some species grew equally well, or equally poorly, under all conditions (Figure 7), e.g. *H. alchorneoides*, *V. sebifera*, *Q. asterolepsis* and *Z. riedelianum*. *Quararibea asterolepsis* and *Z. riedelianum* showed poor growth in all conditions. In contrast, *H. alchorneoides* and *V. sebifera* exhibited good growth in all conditions. *Minquartia guianensis* was the only species that grew better in the mature forest compared with 10-year-old secondary forest and open pasture, although showing poor growth in all conditions.

DISCUSSION

Potential species for reforestation in the humid lowlands of Costa Rica

Although several species did not express good productivity in reforestation (open pasture), some of them, which had high productivity, can become an interesting alternative for timber production in the region.

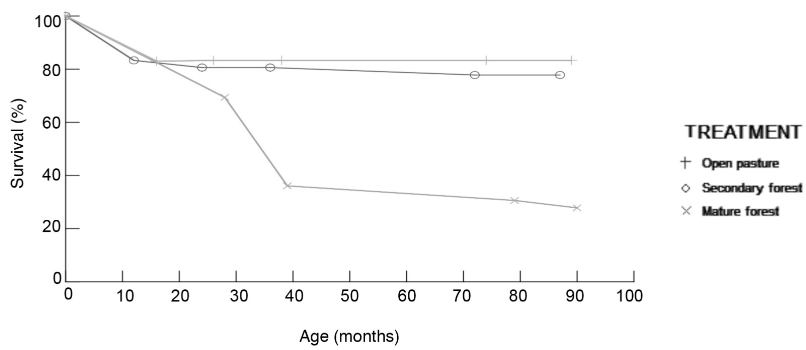

Figure 2 Example of species with better survival in open pasture and secondary forest (*Virola koschnyi*)

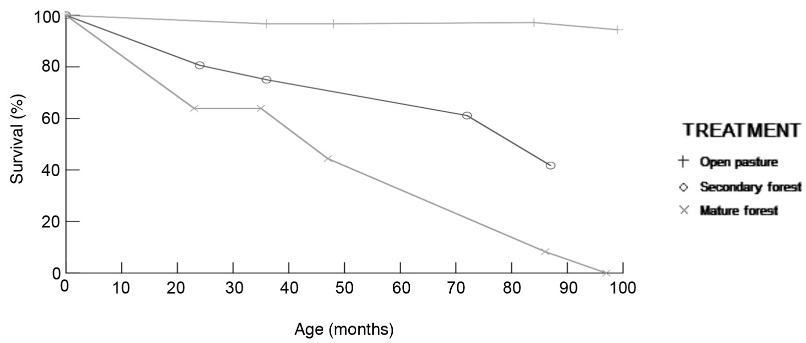

Figure 3 Example of species with better survival in open pasture (*Tabebuia rosea*)

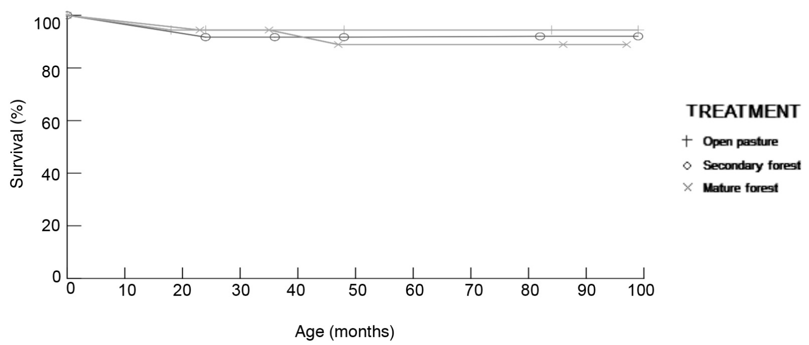

Figure 4 Example of species with similar survival in all habitats (*Prioria copaifera*)

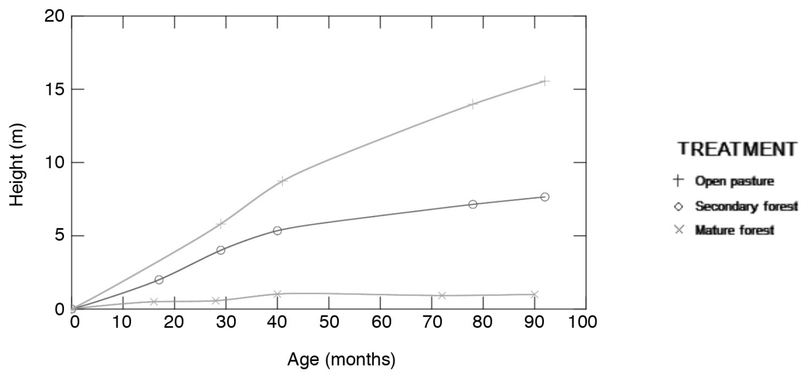

Figure 5 Example of species with high growth in open pasture, medium growth in 10-year-old secondary forest and low growth in mature forest (*Dipteryx panamensis*)

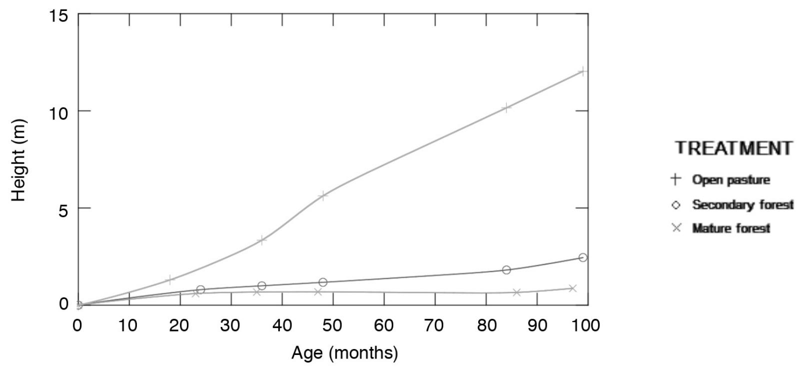

Figure 6 Example of species with high growth in open pasture and low growth in 10-year-old secondary forest and in mature forest (*Carapa guianensis*)

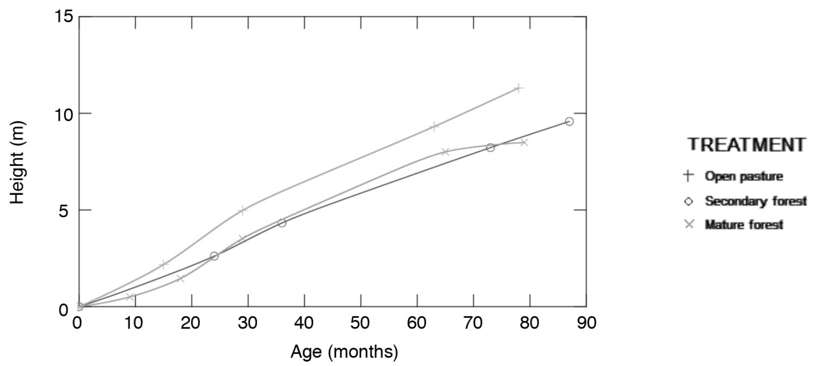

Figure 7 Example of species with similar growth in all conditions (*Hieronyma alchorneoides*)

Rollinia microsepala exhibited high survival and good growth with increments in dbh greater than those found for other species. Survival for this species in the present study was much higher than the 69% reported by Haggar *et al.* (1998) for plantations in the same region of Costa Rica for 72 months. Annual height increments were slightly greater than those reported by Butterfield (1995). The volumetric increment of 33 m^3/ha/year found for this species was superior to several exotic species commonly used in reforestation in the tropics (Wadsworth 1997).

Virola koschnyi exhibited good growth with increments comparable with those reported by Piotto *et al.* (2003a) in pure plantations in Sarapiqui at 10 years of age and by Russo (2002) in pure plantations in Guapiles at nine years and superior to those reported by Redondo-Brenes (2007) in San Carlos at 11 years of age.

Abarema idiopoda, *T. amazonia* and *C. guianensis* showed high survival and productivity, with increments in dbh greater than those reported in Sarapiqui by Butterfield (1990, 1995) at three years of age and by Haggar *et al.* (1998) in mixed plantations at six years.

Comparing growth data from different sources for the native species used in this study, it was observed that there were abrupt differences in survival and growth for some species in different locations. This suggests the importance of considering genetic differences and species requirements before deciding which species should be used in reforestation projects. However, some species such as *R. microsepala* and *V. koschnyi* showed the same growth rates in different locations. These species could apparently sustain high growth rates in a variety of sites. Thus, they can be recommended for broad use in reforestation.

Manilkara zapota, *P. copaifera* and *S. maxonii* exhibited increments in height greater than 1 m/year. For these species there is no literature on growth in plantations, but the results of this study indicated that they can be promising species for reforestation in the region.

Potential species for enrichment planting

Some species planted in secondary forest presented good growth, indicating their ability to deal with competition for growing space. *Dalbergia glomerata* showed high growth in the secondary forest, comparable with increments in mixed stands in Sarapiqui reported by Butterfield (1995) and Haggar *et al.* (1998).

Genipa americana and *D. panamensis* also presented increments comparable with those found by Montagnini *et al.* (1995) and Butterfield (1995) in mixed plantations. Although both species did not respond well when planted in mature forest, these species can be suitable in mixed plantations or in enrichment of young secondary forest.

Comparing the results on growth and survival in different environments here with screening trials conducted by Butterfield (1995) in Sarapiqui, it is notable that *H. alchorneiodes* and *D. glomerata* presented similar growth response under different light conditions. However, *C. guianensis* showed a different response compared with Butterfield (1995) in terms of survival and growth. This species presented high survival in open pasture and low survival in secondary forest and mature forest, in contrast with that found in Sarapiqui. The growth under shade conditions found in this study indicated that it might not be economically viable to plant *C. guianensis* as value timber species within forested areas.

Hieronyma alchorneoides performed well in all planting treatments. Planted in mature forest, this species was the most promising, but with an annual growth inferior to the results reported in other studies of pure and mixed plantations conducted in the same region (González & Fisher 1994, Butterfield & Espinoza 1995, Montagnini *et al.* 1995). The results here suggested that *H. alchorneoides* could respond well if planted in overexploited natural forests in the Caribbean lowlands. It is also recommended for mixed plantations. Planted in secondary forest, it presented growth increments compatible with those found in other studies with mixed plantations conducted in the same region. Moreover, it is important to point out that this species can be multi-purpose, producing food and habitat for wildlife, seeds for reforestation programmes and timber products (Flores 1993).

Virola sebifera also presented good growth in the mature forest treatment. This species can also be used in enrichment planting for conservation purposes. Threatened and rare tree species or those that are important for conservation programmes should be more often used for enrichment plantings.

Management considerations for reforestation and enrichment planting

Plots in full sunlight required intensive management during the plantation establishment. Some species with fast growth and large crown size could rapidly close the canopy, suppressing weed competition. Slow growth species needed more time to close the canopy which incurred in high establishment costs due to the necessity for constant weeding.

Species with fast growth must be thinned a few years after planting because the growing space is rapidly filled at early ages. Also, species with form problems required intensive management during the plantation development, such as pruning, to guarantee higher quality stems for final harvest (e.g. *A. idiopoda*, *H. alchorneoides*). There has been relevant silvicultural information about several native tree species in the zone, e.g. growth curves and equations (Petit & Montagnini 2004), thinning responses (Piotto *et al.* 2003b) and allometric models (Montero & Kanninen 2003). These recent advances in native tree plantation management could make the use of many species more common in tropical landscapes.

High initial growth for many species planted in the secondary forest was observed. Species with fast growth could reach the canopy at early ages and maintain relatively high growth for many years. However, the secondary forest was growing at the same time, increasing competition between natural and planted trees. It was observed that growth in diameter and height was delayed in the early ages of secondary forests when compared with the same species growing in open pasture. Considering that the performance of the studied species was generally bad in shade conditions, canopy removal may be necessary for sustaining tree growth and survival in enrichment planting, especially for those species that presented little capacity to develop under shade (e.g. *R. microsepala*, *C. guianensis* and *P. copaifera*). This may indicate the necessity for application of silvicultural treatments, e.g. liberation, at early ages until the planted trees can reach a privileged canopy position. However, it would incur high costs of maintenance for enrichment planting especially if used for slow growth species.

CONCLUSIONS

Results from the study described in this paper provide insights about the use of some species for reforestation and enrichment planting in pastureland, secondary forests and overexploited mature forests in the Caribbean lowlands of Costa Rica and in other areas in the region with similar conditions. Long-term studies testing high priced wood or species with high environmental and social value for local communities must be conducted to provide silvicultural guidelines for species selection and management activities on enrichment planting in neotropics. Economic research would also play an important role in comparing different management options for secondary and overexploited forests. Furthermore, studies focused on responses of silvicultural treatments in enrichment planting would provide valuable information to maximize the growth and survival of trees planted beneath the forest canopy.

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