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Tree plantations on farms: Evaluating growth and potential for success

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A B S T R A C T

Interest in native species is growing across the tropics as reforestation of degraded lands becomes more widespread. In this study four tree species native to Panama – *Cedrela odorata*, *Pachira quinata*, *Samanea saman*, and *Tabebuia rosea* – were grown on rural farms at two dry tropical sites in Panama for up to five years. Survivorship and growth data at these "on-farm" trials are compared to data recorded from nearby experimental or "species selection" trial sites and evaluated in terms of soil fertility and management. Participant farmers were also asked about their interest in planting trees in general as well as their interest in 61 species grown in the species selection trial.

Although, on-farm survivorship was variable and generally lower than that found on the species selection trial, one species (*S. saman*) experienced high and consistent survivorship. High survivorship combined with growth data from farms at both sites for this species suggests it would be a good candidate for extension projects working with rural farmers. Survivorship of other species appears more sensitive to farmer management and/or local site conditions. Generally lower growth on the Los Santos farms as compared to the species-selection trial is attributed to the lower soil fertility (plant available P) at the on-farm sites compared to the species selection trial. In contrast, only one species – *P. quinata* – had a growth variable found to be significantly lower between the on-farm and species selection trial sites in Rio Hato. *C. odorata*, *P. quinata T. rosea* can all be used in on-farm conditions with consideration to specific site and management conditions.

By 2009, approximately 80% of the farmers planting trees still wished to participate in tree planting activities. All of the farmers no longer wishing to continue with the project expressed slow growth rates of trees as a principal reason. All but one of these farmers had growth rates for his/her trees markedly below those of the species selection trial nearby. Some farmers wishing to continue had very high mortality rates (>70% for all species), suggesting non-tangible benefits for participating in project activities. Other species that were not tested on-farm but grew well in the species-selection trials and were of interest to local farmers are discussed.

As long as specific site and management conditions are carefully considered, data from species selection trials can be useful in informing tree planting projects with rural farmers; however, care should be taken to manage expectations.

1. Introduction

Tropical ecologists, conservationists, and policy makers have long recognized the environmental problems associated with tropical deforestation (Laurance, 1999; Steffen et al., 1998). However, while deforestation continues (Asner et al., 2009; Curran et al., 2004; Laurance et al., 2001), in many countries there is a countertrend towards abandonment of agricultural lands as people migrate to cities to seek jobs and improve their overall socioeconomic status (Chazdon, 2008; Páres-Ramos et al., 2008; Wright and Muller-Landau, 2006;). At the same time, as cities are burgeoning with recent arrivals, others seek a better life on the agricultural frontier (Wright and Samaniego, 2008).

The arrival of the 21st century has brought with it an increased awareness of the linkages between the plight of people and forests in the most remote areas of the world and the environmental

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well being and economic status of those living in the industrialized world (Millennium Ecosystem Assessment, 2005; Pagiola et al., 2005). As governments, institutions, and individuals in the developed world struggle to minimize their global environmental footprints (Hertwich and Peter, 2009), significant effort is also being expended to seek creative ways to improve rural livelihoods and impact environmental quality from local to global scales. Activities range from managing agricultural fallows for livelihoods and biodiversity (Diemont and Martin, 2009; Vieira et al., 2009 for a restoration perspective), improving farm productivity by incorporating a vast diversity of trees and shrubs (Murgueitio et al., 2011), planting trees in coffee and cocoa plantations to reduce management costs and increase productivity (Ruf and Schroth, 2004; Somarriba et al., 2004), managing to improve agricultural pollination (Tscharntke et al., 2008), to encouraging tree cover for timber production and carbon sequestration (Plath et al., 2010). In addition to these management interventions that provide tangible local and concurrent global benefits, the concept of Payment for Environmental or Ecosystem Services, where payments are made for changes in land management practices that produce benefits far beyond the individual farm, has been developed (Bulte et al., 2008; Pagiola et al., 2005).

Given the emphasis on increasing and protecting native biodiversity across the landscape as a conservation goal, interest in reforestation with native species is not surprising (Haggar et al., 1998; Hooper et al., 2002; Montagnini et al., 1995). Recently a number of studies have been undertaken to overcome one of the biggest barriers to reforestation with native species—basic silvicultural knowledge (Condit et al., 1993). These include studies to understand basic seed biology (Sautu et al., 2006), species screening trials to test growth performance under varied or specific conditions (Butterfield, 1995; Carpenter et al., 2004; Haggar et al., 1998; Otsamo et al., 1997; Shono et al., 2007; Stewart and Dunsdon, 1994; Wishnie et al., 2007), and experiments to improve tree growth through enhanced nutrient cycling (Nichols et al., 2001; Siddique et al., 2008). However, it is equally true that a lack of knowledge of the social norms and customs that govern how people use and value land and natural resources can lead to the failure of tree planting projects (Garen et al., 2009).

This manuscript reports on a research project initiated in 2004 working with rural land owners in Panama. The project was set up as a companion to the Native Species Reforestation Project (PRORENA) species selection trial described by Wishnie et al. (2007) and van Breugel et al. (2011), a trial set up with the objective of screening a large number of species for optimal growth over broad rainfall and soil fertility gradients. Agricultural researchers have long known that, because of the unique biophysical, management, and social conditions associated with trials conducted on research stations, crops grown with farmers – "on-farm" – often grow differently than those grown on the station (Love, 2008). Thus, the research project reported on herein was set up to test survival and growth performance of a subset of well known tree species on farms surrounding two of the four sites of the PRORENA species selection trial. In addition, the project sought to learn about the real world challenges faced by farmers planting native tree species as well as their motivations for doing so (Garen et al., 2009).

The overall goal of this study is to understand biophysical and social opportunities for and constraints to planting trees with rural farmers in two different sites in Panama in order to inform the design and implementation of tree planting projects here and elsewhere. The specific ecological hypothesis tested is that there is a difference in growth and survivorship between trees planted with rural farmers and those planted in the PRORENA species selection trial. Results are evaluated in terms of differences in soil fertility and management. Data on farmer interest over time are evaluated to help understand the prospects for success and pitfalls of larger scale projects to improve ecosystem services. Finally, growth performance of and farmer interest in 61 species grown at the PRORENA species selection trial at these sites are discussed to inform tree planting projects in the dry forests of Central America, one of the most highly threatened forest biomes of the world (Griscom and Ashton, 2011; Janzen, 1988; Murphy and Lugo, 1986).

2. Methods

2.1. Overall experimental set-up

The research described here was possible due to collaboration with the US Peace Corps. Between 2004 and 2006 Peace Corps volunteers in both Los Santos and Rio Hato recruited 34 farmers, two technical schools and a local community to plant trees in monoculture blocks (2004 and 2005) and mixtures (2006) where the basic plantation establishment (seedling source, site preparation, fertilization and control for insects) followed methods used to establish the PRORENA species selection trial (see Wishnie et al., 2007; van Breugel et al., 2011). Logistical and experimental constraints limited the initial offering to four species – *Cedrela odorata*, *Pachira quinata*, *Samanea saman*, and *Tabebuia rosea* – from which farmers chose species to plant. Farmers provided approximately half of the funds and all of the labor required to establish and manage the plantations (Love, 2008). Once established, the actual plantation management was the farmer's responsibility. They were encouraged to clean the plantations at the same frequency as the PRORENA species selection trials but farmers made their own decisions as to whether or not to interplant crops within the plantation and when to let animals in with their trees. Farmers received regular visits from Peace Corps volunteers and/or an extension forester and were also invited to regular workshops on plantation management.

Trees grown in mixtures can affect the growth or their neighbors through competition, facilitation, or complementary use of resources (e.g., Haggar and Ewel, 1997; Nichols et al., 2006; Piotto, 2008; Potvin and Gotelli, 2008; Ewel and Mazzarino, 2008). As no replication exists for mixtures established with farmers, data from these plots are difficult to evaluate. Thus, no mortality and growth data from farms established in 2006 (all mixtures) is presented here.

2.2. Study site

The study took place in the provinces of Los Santos and Coclé, Panama. All on-farm sites are within 20 km of the species selection trial sites (Garen et al., 2009). The Rio Hato district (Coclé) is located in the dry arc of Panama and receives approximately 1450 mm of rainfall per year, with a single dry season (December–April) averaging 4.6 months in length. In Los Santos farms were spread out across the districts of Tonosi and Pedasi (Garen et al., 2009). The area receives approximately 1690 mm of rainfall a year with a dry season (December–April) of approximately 4.6 months (Table 1; van Breugel et al., 2011).

Soils across the dray arc of Panama are broadly classed as Cambisols (FAO/EC/ISRIC, 2003). Park et al. (2010) describe the terrain at the Rio Hato species selection trial site as flat or generally sloping with substantial patches having undergone sheet erosion while the Los Santos selection trial site is characterized by hilly terrain with moist swales, with some plots being seasonally inundated. This description also holds for the terrain at the on-farm plots at the two sites with the exception that no farm plots were on land that is seasonally inundated. In keeping with the Cambisol designation, soil textures across both the species selection and on farm sites are fine, generally ranging from loams to clays. In general soils of the Los Santos species selection site are fertile, deep, and well

Table 1
Climate and soil characteristics at the PRORENA Los Santos and Rio Hato species selection and on-farm trial sites, Panama.

	Species selection trials		On-farm trials	
	Los Santos	Rio Hato	Los Santos	Rio Hato
Climate[a]				
Mean annual rainfall (mm/year ± S.E.)	1691 ± 62	1451 ± 70	–	–
Mean no. of months < 100 mm rainfall	4.6 ± 0.3	4.6 ± 0.2		
Soil properties[b] (mean ± S.E.)				
pH	6.30 ± 0.06	5.65 ± 0.24	6.10 ± 0.44	5.77 ± 0.20
Plant available P (ppm)	7.52 ± 0.92	1.86 ± 0.15	1.61 ± 0.26	1.44 ± 0.38
K (ppm)	58.07 ± 12.79	47.22 ± 7.40	73.43 ± 27.74	71.20 ± 9.25
Ca (ppm)	2373 ± 302.2	599.40 ± 52.59	3554.71 ± 837.26	566.23 ± 93.56
Mg (ppm)	562.33 ± 15.74	99.82 ± 6.38	610.73 ± 98.66	104.07 ± 12.21

[a] Rio Hato, 2005 (PRORENA, unpublished data). All other data: Empresa de Transmisión Eléctrica S.A. (ETASA) unpublished data. Los Santos: Pedasi and Tonosi stations, 2003–2009; Rio Hato: Rio Hato station, 2003, 2004, 2006–2009.

[b] pH was determined in water using a digital pH meter. Los Santos and Rio Hato species selection soil data from Wishnie et al. (2007) where plant available P and cations were extracted using Mehlich I. On-farm plant available P extracted by resin; base cations extracted using barium chloride method. Data for plant available P excludes one on-farm site in Rio Hato with exceedingly high P believed to be due to the addition of fertilizer; with this farm included mean and standard error are 8.20 ± 15.37.

drained. Those at the Rio Hato species selection site are infertile, highly weathered, and rocky or highly compacted in patches.

For this study, soils from on-farm plots were collected and processed as in the species selection trial (Wishnie et al., 2007), the soils with which they are compared. Soils from participant farmers were analyzed for plant available phosphorus (resin extraction, Turner and Romero, 2009), base cations (barium chloride method, Sumner and Miller, 1996) and pH in water (Table 1) at the Smithsonian Tropical Research Institute, Panama soils lab. Although the Mehlich I extraction used for plant available P in the species selection trial can give higher values than those obtained by resin extraction, the differences would only be minor and would not lead to the greater than fourfold differences in magnitude obtained between Los Santos species selection and on farm-sites (Turner, personal communication). The two methods used for cation extraction have been found to give comparable values on similar soils in Panama for potassium, calcium, and magnesium (Turner, personal communication).

2.3. Overall status of experiment in 2009

The original on-farm trials included 37 participants, including farmers (34), technical schools (2), and town associations (1). In 2006 one technical school in Rio Hato, that originally joined the project in 2004, converted its farm to other land uses. By the time of this study in 2009, one Los Santos farmer had left the project, as cattle had breached his fences, and one Rio Hato farmer had lost all of her trees, but still expressed interest in planting trees and considered herself a participant. Due to exceedingly high mortality and logistical constraints, six of the 34 remaining plantations, still maintaining trees and participating in the trials in 2009, were not measured. Four of these farms (1 Los Santos, 3 Rio Hato) had mortality rates estimated at >70% (Slusser, personal observation). One farm in Los Santos was inaccessible at the time of the study and one farm in Rio Hato was overlooked as the farmer had ceased cleaning in 2006 and trees were completely overtopped by competing herbs and shrubs (Slusser, personal observation). Thus, growth and mortality data are presented for 26 farms, one technical school, and one town association.

2.4. Tree measurement methods

At the end of the wet season in 2009, survivorship, basal diameter, and tree height were measured in the on-farm plots. At this measurement, trees within a 6 m × 7 m central block (42 individuals) were counted and measured, and trees outside this block were considered as buffer trees experiencing edge effects. Tree height was measured with a 15 m extendable pole. Survivorship in 2009 was calculated from the percentage of live trees within the central block. Data are not considered in this analysis for plots that disappeared between the time of plantation establishment and measurement in 2009.

2.5. Farmer interviews

All 33 participant farmers interviewed by Garen et al. (2009) were re-interviewed, regardless of whether or not they continued to maintain trees, in 2009. Data on farmer preferences were derived from a questionnaire in which farmers were asked if they would be interested in planting additional trees and if so, if they were interested in planting any of the 61 species tested in the PRORENA species selection trial sites in Rio Hato and Los Santos. All questions were read aloud and verbal responses recorded. A detailed discussion of the methodology is presented in Garen et al. (2009).

2.6. Statistical analyses

The extreme conditions in climate and soil conditions are known to result in different survivorship and growth performance for the species assessed herein between the Los Santos and Rio Hato study sites (see van Breugel et al., 2011). For the purposes of these analyses, values of mean annual increment for height (MAIH) and basal diameter (MAIBD) were calculated for all trees on farms within a site and compared to the PRORENA species selection trials. Data comparing growth performance within species and between farmer sites and the species selection trials were compared in an ANOVA format using Ecosim (Gotelli and Entsminger, 2001). The randomization test in Ecosim accommodates data that are not normally distributed and with unequal variances and is less sensitive to unbalanced designs than conventional ANOVA (Gotelli and Entsminger, 2001). Within site survivorship was compared using the ANOVA procedure in Ecosim. A difference was considered statistically significant at alpha = 0.05.

3. Results

3.1. Survival

With the exception of *S. saman* which established well in both Los Santos and Rio Hato, survivorship within species and sites was highly variable (Table 2). A significant difference in species mean percent survival was only detected between farms and within years for trees planted in Rio Hato in 2005 (Table 2, Rio Hato 2005 $p = 0.04600$ for comparison between *P. quinata* and *T. rosea*).

Table 2
Mean percent survival for trees planted in monoculture plots with farmers (On-farm) and in the species selection trials of PRORENA in Los Santos and Rio Hato, Panama after 4 (2005) and 5 (2004) years. Where only one plot survived, no survivorship data are shown. n = number of plots.

Species	Los Santos on-farm						Rio Hato on-farm						Species selection[a]					
	2004[b]			2005			2004			2005			Los Santos		Rio Hato			
	Percent	SD	n	Percent	SD	n	Percent	SD	n	Percent	SD	n	Percent	SD	Percent	SD	n	
Cedrela odorata	46.9	41.9	4	48.4	44.9	4	28.6	13.5	3	83.3		1	100	0	73.3	25.2	3	
Pachira quinata	76.7	11.3	5	81.5	22.0	4	60.7	26.8	4	70.2	15.6	3	100	0	90	10	3	
Samanea saman	75.2	12.2	5	91.0	5.7	5	91.3	8.4	3	95.2		1	100	0	70	30	3	
Tabebuia rosea	85.1	20.3	4	51.1	55.6	2	32.5	29.8	3	45.2	13.3	3	96.7	5.8	90	17.3	3	

[a] Means are calculated as percent of trees alive per plot after five years where 50% of trees were thinned at year two.
[b] Year of plantation establishment.

With the exception of a single farm in Rio Hato, mean survivorship for *C. odorata* was poor – below 50% – at both sites and across planting years. In contrast, mean percent survival of *S. saman* was high and generally compared favorably to percent survival in the PRORENA species selection trials. In Los Santos, one farmer experienced higher than 85% survival for all four of the species planted in 2004 and 2005. One farmer in Rio Hato experienced over 80% survival for both *P. quinata* and *S. saman* planted in 2004. With the exception of plots established in Los Santos in 2004, overall survival of *T. rosea* was low as compared to the PRORENA species selection trials (Table 2).

3.2. Growth

With the exception of MAIBD growth of *P. quinata* ($p = 0.04940$), no significant differences were found in growth within species between the on-farm trials and the species selection trials in Rio Hato (Fig. 1a and b). In contrast, ANOVA randomization tests showed significant differences in growth performance for at least one variable in three of the four species grown with farmers and in the species selection trial in Los Santos. *P. quinata* exhibited significantly higher MAIH ($p = 0.00290$) and MAIBD ($p = 0.00340$) in the species selection trial than in the on-farm trials, as did *S. saman* (MAIH $p = 0.03820$; MAIBD $p = 0.00230$). *C. odorata* grown in the species selection trial exhibited a significantly higher MAIBD ($p = 0.00570$) than when grown with farmers.

3.3. Farmer species preferences

Approximately three quarters of the farmers participating in the farm-trials (75% LS; 80% RH) indicated they would be interested in planting additional trees. Of the 61 species planted in the PRORENA species selection trial, all interested farmers interviewed in both Los Santos and Rio Hato (100%) reported that they would like to plant 15 species, 13 of which are known to have some rural use and 10 are known to produce timber (Table 3). A majority of the farmers said they would be interested in planting 39 of the 61 species in the trial, of which 29 are known to have rural uses, 18 are used for timber, and 25 have been highlighted for restoration uses. While the overwhelming trend was for farmers in both regions to show a preference for the same species, some curious exceptions were found. For example, while 86.7% of the farmers in Los Santos expressed an interest in planting *Trichilia hirta*, only 8.3% of the farmers in Rio Hato expressed an interest in this species. However, only 33% of Rio Hato participants recognized the species. In contrast, 91.7% of the farmers interviewed in Rio Hato expressed an interest in planting *Astronium graveolens*, while only 13.3% of the farmers showed an interest in planting this species in Los Santos. *A. graveolens* is a valuable timber species native to Los Santos but 89% of the farmers did not recognize it by name. Lack of interest in *T. hirta* in Rio Hato and *A. graveolens* in Los Santos may be due to the lack of recognition of the local name used in the survey rather than lack of interest in the species.

3.3.1. Timber species

In Los Santos, all farmers were interested in planting 13 different timber species and a further 6 timber species were of interest to over half of those interviewed. The majority of Los Santos farmers did not exhibit an interest in planting two of the five timber species with the highest MAIH (the exotic *Acacia mangium* and *Schizolobium parahyba*) and three of the five timber species with the highest MAIBD (*A. mangium*, *Hura crepitans*, and *S. parahyba*) in the PRORENA selection trial (Table 3). No farmers expressed an interest

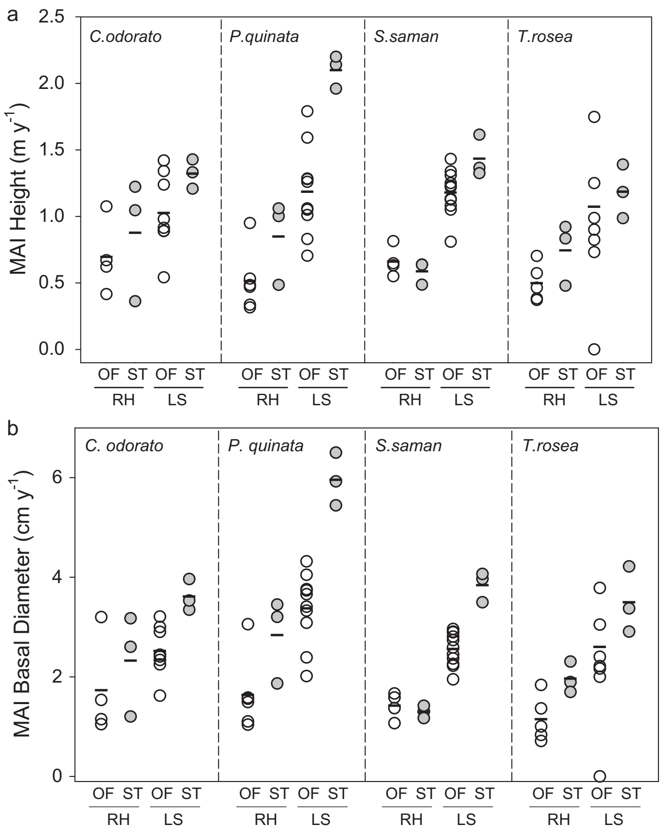

Fig. 1. (a) Mean annual increment height (MAIH) growth for four species grown in the PRORENA on farm and species selection trials in the provinces of Los Santos and Cocle, Panama. RH, Rio Hato; LS, Los Santos; OF, on-farm; ST, species selection trial; dots denote mean values for individuals of the species farms (on farm) or plots (species selection trials). (b) Mean annual increment basal diameter (MAIBD) growth for four species grown in the PRORENA on farm and species selection trials in the provinces of Los Santos and Cocle, Panama. RH, Rio Hato; LS, Los Santos; OF, on-farm; ST, species selection trial; dots denote mean values for individuals of the species farms (on farm) or plots (species selection trials).

Table 3
Percentage of farmers in Los Santos (LS, $n = 15$) and Rio Hato (RH, $n = 12$), Panama interested in planting, mean annual increment basal diameter (MAIBD, cm/year) and mean annual increment height (MAIH, m/year) of individual species grown in the PRORENA species selection trials. Use categories for each species are also indicated. SD, standard deviation; NA, not asked.

Scientific name	Los Santos					Rio Hato					Use category		
	%LS	MAIBD	SD	MAIH	SD	%RH	MAIBD	SD	MAIH	SD	Timber	Rural	Rest.
Acacia mangium	40	5.81	1.03	3.17	0.67	100	4.48	0.09	2.13	0.08	×	×	
Albizia adinocephala	80	3.13	0.13	2.17	0.34	33	1.05	0.17	0.87	0.1	×		
Anacardium excelsum	100	4.47	1.01	1.69	0.43	100	2.29	0.58	0.43	0.19	×	×	×
Anacardium occidentale	100	4.08	0.90	1.29	0.27	100	2.87	0.64	0.7	0.15		×	×
Astronium graveolens	13	2.27	0.85	1.14	0.57	92	1.96	1.29	0.72	0.44	×	×	
Brosimum alicastrum	13	0.85	0.14	0.41	0.12	17	0.46	0.08	0.07	0.05	×		×
Byrsonima crassifolia	100	2.49	0.59	1.47	0.29	100	4.03	0.99	0.8	0.25	×	×	
Calophyllum brasiliensis	93	1.03		0.56		83	0.80	0.34	0.31	0.16	×	×	
Calycophyllum candidissimum	100	2.61	0.62	1.35	0.22	83	0.61	0.10	0.1	0.04		×	×
Cassia grandis	87	4.15	1.92	1.85	0.89	67	0.83	0.31	0.12	0.06		×	×
Cassia moschata	0	3.85	0.99	1.59	0.45	17	1.02	0.37	0.38	0.13			×
Cedrela odorata	100	3.62	0.32	1.32	0.11	100	2.33	1.01	0.88	0.45	×	×	
Cedrela tonduzii	0	3.57	0.87	1.94	0.59	0			0.36	0.16			×
Chrysophyllum cainito	100	1.71	0.62	0.64	0.26	100	1.01	0.25	0.32	0.14		×	×
Colubrina glandulosa	60	3.15	0.91	1.37	0.33	33	1.78	0.33	1.06	0.07		×	×
Copaifera aromatic	87	2.11	0.42	0.77	0.08	83	0.60	0.25	0.26	0.1			×
Cordia alliodora	100	3.97	0.80	2.41	0.43	100	1.42	0.84	0.82	0.62	×	×	×
Dalbergia retusa	100	4.51	0.67	2.04	0.4	67	3.17	0.92	1.08	0.32	×	×	
Diphysa americana	100	2.77	0.63	1.35	0.07	100	1.48	0.19	0.62	0.11		×	
Dipterys oleifera	13	1.41	0.03	1.12	0.09	33	0.53	0.04	0.18	0.17	×		
Enterolobium cyclocarpum	100	4.80	0.46	1.46	0.19	100	1.25	0.05	0.42	0.06	×	×	
Erythrina fusca	27	7.75	1.83	2.03	0.52	17	1.76	0.34	0.43	0.19		×	×
Gliricidia sepium	100	6.19	0.80	2.26	0.1	100	1.20	0.14	0.63	0.05		×	×
Gmelina arborea	53	7.34	1.50	2.84	0.88	17	3.00	0.95	0.87	0.26	×	×	
Guazuma ulmifolia	100	4.16	0.51	1.75	0.39	83	1.95	0.35	0.74	0.2		×	×
Gustavia superva	53	0.92	0.48	0.39	0.19	83	0.35	0.20	0.04	0.05		×	×
Hieronyma alchorneoides	0	1.83	0.62	0.76	0.24	8	1.55	0.35	0.16	0.08	×		×
Hura crepitans	47	5.46	1.28	1.33	0.39	17	3.03	1.02	0.54	0.23	×	×	×
Hymenaea courbaril	100	1.80	0.46	0.66	0.21	92	0.80	0.18	0.2	0.06	×	×	×
Inga punctata	100	2.90	0.28	1.06	0.12	92	2.05	1.02	0.58	0.46		×	×
Inga sp.	100	2.95	0.78	1.12	0.29	92	1.86	0.46	0.48	0.16		×	×
Lacmellea panamensis	0					33	0.45	0.02	0.1				×
Luehea seemannii	80	5.21	0.28	1.52	0.07	58	2.21	1.73	0.91	0.53			×
Manilkara zapota	100	1.15	0.39	0.58	0.24	92	0.74	0.06	0.2	0.09	×	×	×
Muntingia calabura	60	6.29	0.70	2.7	0.45	67	2.65	0.54	0.76	0.22		×	
Ochroma pyramidale	93	5.66		2.32		50	3.59	1.36	1.53	0.54			×
Ormosia macrocalyx	60	1.92	0.58	0.84	0.32	50	1.85	0.38	0.55	0.14	×	×	×
Pachira quinata	100	5.96	0.53	2.1	0.12	100	2.84	0.85	0.85	0.32	×	×	
Peltogyne purpurea	13	0.25		0.13		33	0.28	0.09	0.12	0.05	×		
Pithecellobium mangense	47	2.50	0.53	0.85	0.24	50	1.78	0.61	0.45	0.14	×		
Platymiscium pinnatum	73	2.49	0.54	1.15	0.14	67	1.87	0.39	1.19	0.17	×	×	×
Protium tenuifolium	0	1.48	0.22	0.91	0.23	0	0.70	0.15	0.28	0.09			×
Pseudosamanea guachapele	0	3.33	0.25	1.27	0.06	0	2.05	0.79	0.99	0.38		×	
Pterocarpus officinalis	40	1.81	0.48	0.66	0.03	83	1.61	0.48	0.63	0.23			×
Samanea saman	93	3.84	0.30	1.43	0.16	100	1.30	0.13	0.59	0.09		×	
Sapindus saponaria	33	2.35	0.56	1.19	0.25	8	0.90	0.34	0.27	0.2			×
Sapium glandulosum	93	6.03	1.17	2.7	0.72	58	1.79	0.70	0.49	0.28			×
Schizolobium parahyba	0	5.39	0.53	4.46	0.29	17	2.38	1.25	0.56	0.65	×		×
Spondias mombin	100	5.90	0.78	2.31	0.3	100	1.56	0.15	0.44	0.15		×	×
Sterculia apetala	100	2.91	0.27	1.11	0.22	100	2.00	0.18	0.47	0.09	×		×
Swietenia macrophylla	100	2.48	0.48	1.32	0.26	100	1.83	0.91	0.87	0.39	×	×	
Tabebuia guayacan	100	2.03	0.53	1.22	0.33	100	2.12	0.92	0.88	0.03	×	×	
Tabebuia impetiginosa	40	2.05	0.34	1.01	0.18	50	1.38	0.74	0.61	0.33			×
Tabebuia rosea	93	3.50	0.66	1.19	0.2	92	1.97	0.31	0.74	0.23	×	×	
Tectona grandis	100	5.47	1.12	2.47	0.34	100	3.42	1.10	1.67	0.59	×		
Terminalia amazonia	7	2.65	0.15	1.43	0.43	17	1.61	0.89	0.96	0.64	×		
Trichilia hirta	87	2.91	0.61	1.51	0.3	8	1.14	0.35	0.43	0.28			×
Vitex cooperi	0	4.30	0.82	1.63	0.23	17	1.07	0.21	0.16	0.1	×		
Vochysia ferruginea	0	2.88		0.93		0	0.85	0.19	0.35	0.17	×		×
Vochysia guatemalensis	NA	2.58		1.12		NA	1.81	0.21			×		
Xylopia frutescens	60	2.24	0.61	1.18	0.2	92	0.65	0.26	0.4	0.15			×

in planting *S. parahyba*, a species native to Panama but apparently not to the region, which had exceptional growth in the PRORENA species selection trial (Table 3). In Rio Hato, the majority of farmers were interested in planting the species with the highest MAIH and MAIBD, with the exception of *Terminalia amazonia* (high MAIH) and *H. crepitans* (high MAIBD). Few farmers recognized *T. amazonia* (13% in Rio Hato and 6% in Los Santos), an evergreen species common to moist forest in Panama.

3.3.2. *Species with rural or restoration use*

Given that the local uses of many species are varied, including fruit production, fuel wood or other products, or use in living fences (Garen et al., 2009; Love and Spaner, 2005), simply comparing growth rates of these species may be of little value. It is, however, worth noting that of the 22 species for which all farmers in Los Santos expressed an interest in planting, only two are not known to have a rural use. Similarly, only 9 of the 39 species for which 50% of those interviewed in Los Santos expressed an interest in planting are not listed as having a rural use. In Rio Hato, only 2 of 17 of the species that all farmers showed an interest in planting and 10 of 40 species for which 50% of the farmers expressed an interest had no known rural use (Table 3). Given that timber species and those for which farmers have local uses can be used to restore a forest, virtually all species listed in Table 3 have some restoration use. Six of the species planted in the PRORENA species selection trial for which at least 50% of those interviewed from either Los Santos or Rio Hato apparently have no other use than land restoration.

4. Discussion

4.1. Trial status and prospects for planting trees

The results presented herein highlight both the opportunities and challenges of undertaking tree planting projects with local people. Even with a sustained extension effort afforded by Peace Corps Volunteers and foresters, approximately 20% (7 of 34) of the farmers had lost 70% or more of their trees (5 farmers) or dropped out of the project (2 farmers) by 2009. Land sales, farmer death and insufficient growth due to poor management decisions or high expectations all contributed to reasons for farmers not wishing to plant additional trees (Garen et al., 2009). On the other hand, the fact that even farmers with plots experiencing high mortality and slow growth still identified with the PRORENA project shows that tree planting projects can engage individuals and provide both recognizable and non-tangible benefits.

4.2. Survival and growth

4.2.1. Overall patterns

The species assessed in the PRORENA on-farm trials are all well known to and desired by an overwhelming majority of the farmers participating in these trials (Table 3; Garen et al., 2009). Three of these species (*C. odorata*, *P. quinata*, and *T. rosea*) are considered high value timber species while the fourth (*S. saman*) is a nitrogen fixing tree desirable for fodder production (Love and Spaner, 2005).

Overall survival was lower in the on-farm trials than the species selection trials (Table 2, but also see two year mortality for *C. odorata* in van Breugel et al., 2011). Most species specific growth variables in Rio Hato were not significantly different from those obtained for the species selection trial, although there was a trend towards lower growth rates in the on-farm plantations. In contrast, with the exception of *T. rosea*, most of these variables were significantly lower for species grown with farmers than in the species selection trial in Los Santos. Using regression tree analysis for three sites in the PRORENA species selection trial, Park et al. (2010) found a significant separation in growth for three of the four species studied here (*C. odorata*, *P. quinata*, and *T. rosea*) between the more fertile and moist sites of Los Santos and Soberania and the site with the lowest fertility and lowest precipitation, Rio Hato. Growth splits for *S. saman* were related to soil variables at these sites. Comparing growth of 49 species in all four sites of the PRORENA species selection trials, van Breugel et al. (2011) found that most species did not show significantly different growth between high and low fertility or between wet and dry sites when the variable not tested (moisture when fertility was tested and fertility when moisture was tested) was not controlled. Nevertheless, they found that three of the four species grown with farmers here (*C. odorata*, *P. quinata*, and *T. rosea*) showed significantly higher growth on fertile than on infertile sites. Thus the differences for these species noted by Park et al. (2010) are likely related to fertility rather than differences in moisture. Differences in fertility are likely responsible for growth differences found for *C. odorata* and *P. quinata* in Los Santos between on-farm and species selection trials.

4.2.2. Site specific species survival and growth

C. odorata has a wide Neotropical distribution and is a member of the mahogany family (Meliaceae). It has long been known to suffer from shoot borer (*Hypsipyla grandella* (Zeller)) attack when grown in monocultures (Cornelius and Watt, 2003; Perez-Salicrup and Esquivel, 2008). In areas with a pronounced dry season, its relatively shallow roots at the seedling stage have also been cited as the cause of high mortality (Piotto et al., 2004). Thus its relatively poor to variable survival in the on-farm trials should not be unexpected (Table 2; also see Plath et al., 2010). Its high survival at the one site in Rio Hato where it was planted in 2005 is likely related to management. Providing exceptional attention to his trees, including building small catchments around their bases to capture water, this farmer has consistently been singled out as a model tree farmer for the area. Regular die back due to *Hypsipyla* attack likely masked any differences in MAIH that might have been found. However, as discussed above, the differences in MAIBD within the Los Santos site can be attributed in part due to the differences in plant available P (Table 1). While for most variables measured there was no significant difference between the on-farm trials and trees grown in the species selection trial, this is not a species that should be grown in monocultures.

P. quinata is a deciduous timber tree that is well known in markets of Panama and other Central American countries (Pérez-Cordero et al., 2003). Pérez-Cordero et al. (2003) point out that this species is known to grow better on fertile than infertile sites. Thus differences in MAIH and MAIBD found for this species in Los Santos between the on-farm and species selection trial are likely due to differences in soil fertility (plant available P) as suggested above. In contrast, the differences in MAIBD observed in Rio Hato may be related to farmer's reduced ability to tend their trees to the degree PRORENA did in the species selection trial. Site conditions as well as management objectives and constraints should be evaluated before considering this species for use with rural farmers.

T. rosea has a widespread distribution across Latin America and also produces a wood that is valuable (Plath et al., 2010). Although it grew reasonably well in the PRORENA species selection trial at these (Fig. 1a and b, Table 3) and other sites, it can suffer from insect attack where large portions of the leaves are consumed (Hall, personal observation). Poor survivorship in Rio Hato on-farm participant plantations suggests this species may not be appropriate for extension projects in this area. Working in an area with almost 1/3 more precipitation than the Los Santos site, Plath et al. (2010) observed good, although variable, growth over a two-year period and recommended its use in tree planting schemes working with local people. They also report this species performs better on wetter plots in plantation trials. However, van Breugel et al. (2011) found this species to show a significant response in growth to soil fertility while no differences were found in growth between the wet and dry infertile sites. Thus, managers should proceed with caution when considering this species for extension projects in this region.

Overall *S. saman* exhibited high survival with a low variability across all on-farm trials. Survivorship and growth appeared similar (survival) or greater (MAIH) in Los Santos for both the on-farm and the species selection trial to those reported for the northern pacific region of Costa Rica by Piotto et al. (2004), while those of the much drier Rio Hato site are markedly lower. *Samanea saman* 's particularly high survival coupled with indistinguishable growth between on-farm and species selection trials in moisture and fertility stressed sites of Rio Hato, support the recommendation made by Wishnie et al. (2007) that it may be a considered for use in on-farm systems. Similarly, although it grew significantly better in the species selection as compared to the on-farm trial, it nonetheless maintained consistent, good growth on farms in Los Santos. Its overall survival and growth coupled with the facts that it produces desirable, if not high value, wood with a relatively high wood density (Wishnie et al., 2007), is preferred as a fodder species (Love and Spaner, 2005), and fixes nitrogen (Durr, 2001), suggest a variety of uses from improving farm production to potential carbon sequestration schemes in drier areas.

4.3. Assessing growth of species preferred by rural farmers

Most trees planted by rural farmers, including those planted in this study, have a multitude of uses (Table 3; Aguilar and Condit, 2001; Love and Spaner, 2005; Garen et al., 2009). Because farmers have different motivations for planting trees (Garen et al., 2009; Love and Spaner 2005), it is difficult to recommend species for planting beyond broad categories, such as timber, multiple use, or trees planted for biodiversity related purposes (e.g., Butterfield, 1995; Haggar et al., 1998; Piotto et al., 2003, 2004; Wishnie et al., 2007). Even within the relatively clear category of timber species, products extracted may have markedly different values over time, making comparisons challenging (see. e.g., Montagnini and Mendelsohn, 1997; Piotto et al., 2009; Pérez-Cordero et al., 2003).

Data from the PRORENA species selection trial can be used to identify species that may grow well in farm conditions. They can also be used to identify potential pitfalls by identifying species that farmers wish to grow but that perform poorly in selection trials. Foresters and other land managers should verify that site conditions at the trial site reflect conditions under which the trees will be grown (e.g., high plant available P of Los Santos PRORENA species selection trial vs low plant available P in soils of farms in the area) and test species with farmers under different conditions (Love et al., 2009). In 2007 nearly all farmers (78% LS, 100% RH) interviewed by Garen et al. (2009) expressed an interest in continuing to plant trees with PRORENA. However, by 2009, three farmers at each of the two PRORENA on-farm sites had changed their mind. All six farmers reported the slow growth rates of trees as a principal reason for their lack of interest and only one of them had growth rates on his/her farm comparable to the PRORENA species selection trial. Data reported in Park et al. (2010) and van Breugel et al. (2011) for the PRORENA species selection trial underscore the importance of edaphic factors impacting the growth of the four species grown with farmers here. The extent to which farmers were expecting their trees to grow as well as those on the PRORENA species selection trial coupled with their own site conditions may help explain the current lack of enthusiasm of this subset of farmers. However, the wide variability in farmer's ability and motivation to actively manage their plantations (Garen et al., unpub. data), is also a factor.

With the caveats noted above in mind, some conclusions are apparent. Three species (*Hymenea courbaril*, *Manikara zapota*, and *Chrysofilum cainito*) that all respondents in Los Santos expressed an interest in planting had such low mean annual increments (MAIH and MAIBD well below 1 m per year and 2 cm per year, respectively) that it is hard to imagine them being worth the effort to plant and tend in plantations at either site. Other popular species with poor growth can be identified in Table 3.

Several species showed high potential for planting success, although they were not well-recognized by the farmers. No farmer interviewed in Los Santos showed an interest in planting the species with the highest MAIH in the species selection trial, *S. parahyba* (Table 3). This is likely due to the fact that it is apparently not native to this part of Panama. Piotto et al. (2004) noted excellent growth of this species in the dry forest of Costa Rica but in contrast to the PRORENA species selection trial (97% five year survival), experienced high mortality. The species with the next highest MAIH here (both exotics: *A. mangium* and *Gmelina arborea*) also ranked low in terms of farmer interest. Given the extreme invasiveness and potential growth problems of the *A. mangium* (Daehler, 1998), careful consideration should be given before encouraging farmers to plant this species. Farmer interest was also low (47%) in the timber species exhibiting the fifth ranked MAIBD, *H. crepitans*. This may be due to the belief by farmers here that this species depletes water resources in streams (Griscom et al., 2011).

The top three growing native high quality timber species in Los Santos (as ranked by MAIH) include *Cordia alliodora*, *P. quinata*, and *Dalbergia retusa*, all species desired by 100% of survey respondents. With the exception of *C. alliodora*, all species exhibited high survivorship at this site (see van Breugel et al., 2011). Both *P. quinata* and *D. retusa* have been noted by other authors for their growth and/or value in plantations in dry areas (Piotto et al., 2004) but *D. retusa* can exhibit very poor form (Craven et al., in press). High ranked (top 20 MAIH) native multi-use species that fix nitrogen include *Gliricidia sepium*, *D. retusa*, and *Erythrina fusca*. Love and Spaner (2005) report that cattle farmers in the province of Herrera, Panama, purposefully retain *G. sepium* and *E. fusca* for fodder while Wishnie et al. (2007) highlight the restoration potential of the former due to its rapid crown development.

The top two growing species in Rio Hato as determined by MAIH were both exotic timber species. Issues related to *A. mangium* are discussed above and much is known about the silviculture of Teak (*Tectona grandis*) in Panama (Ugalde Arias and Gomez-Flores, 2006). Of the top three native high quality timber species as ranked by MAIH (*Platymiscium pinnatum*, *D. retusa*, and *T. amazonia*), *D. retusa* also had a high MAIBD. As in this study, *P. pinnatum* has been shown to exhibit relatively low diameter growth in sites with a pronounced dry season (Piotto et al., 2004).

High ranked (top 20 MAIH) native multi-use species that fix nitrogen include *D. retusa*, and *Pseudosamanea guachapele*. Although it did not grow as well as the their very best growing species, Piotto et al. (2004) also found *P. guachapele* to grow well as compared to other species grown in their site. Craven et al. (2011) found this species to be highly drought resistant; Wishnie et al. (2007) recommend this species for on-farm systems.

5. Conclusions

While a single site species selection trial can help identify promising species for a given area, environmental conditions may not necessarily be representative of the broader region or lands that farmers are willing to make available for tree planting, particularly as these are often of marginal productivity. The growth data presented herein underscores the need to expand species selection trials within a given region for this reason. Further, the management conditions of trees planted with rural farmers can be far from those on species selection trials.

Even though survival and growth may not have been as high as they may have hoped, farmers participating in the PRORENA on-farm trial project have maintained a high degree of motivation and continued interest in participation. Thus it is clear that tree planting efforts – whether to improve the income of rural farmers, reinforce biological corridors and plant buffer zones, or develop schemes to improve the sequestration of carbon across the rural landscape – can be successful. However, expectations should be managed.

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References

Aguilar, S., Condit, R., 2001. Use of native tree species by an Hispanic community in Panama. Economic Botany 55, 223–235.

Asner, G.P., Rudel, T.K., Aide, T.M., Defries, R., Emerson, R., 2009. A contemporary assessment of change in humid tropical forests. Conservation Biology 23, 1386–1395.

Bulte, E.H., Lipper, L., Stringer, R., Zilberman, D., 2008. Payments for ecosystem services and poverty reduction: concepts, issues, and empirical perspectives. Environmental Development and Economics 13, 245–254.

Butterfield, R., 1995. Promoting biodiversity: advances in evaluating native species for reforestation. Forest Ecology and Management 75, 111–121.

Carpenter, L.F., Doland Nichols, J., Sandi, E., 2004. Early growth of native and exotic trees planted on degraded tropical pasture. Forest Ecology and Management 196, 367–378.

Chazdon, R.L., 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science 320, 1458–1460.

Condit, R., Hubbell, S.P., Foster, R.B., 1993. Identifying fast-growing native trees from the neotropics using data from a large, permanent census plot. Forest Ecology and Management 62, 123–143.

Cornelius, J.P., Watt, A.D., 2003. Genetic variation in a *Hypsipyla*-attacked clonal trial of *Cedrela odorata* under two pruning regimes. Forest Ecology and Management 183, 341–349.

Craven, D., Braden, D., Dent, D., Ashton, M.S., Berlyn, G.P., Hall, J.S., 2011. Seasonal variability of photosynthetic characteristics influences growth of eight tropical tree species at two sites with contrasting precipitation in Panama. Forest Ecology and Management 261, 1643–1653.

Craven, D., Cedeño, N., Mariscal, E., Deago, J., Wishnie, M.H., Hall, J.S., in press. Amelioration of Growing Conditions in Mixed Species Plantation of *Terminalia amazonia* and Nitrogen-fixing *Dalbergia retusa*. In: Montagnini, F., Finney C. (Eds.), Restoring degraded landscapes with native species in Latin America. Nova Science Publishers, New York.

Curran, L.M., Trigg, S.N., McDonald, A.K., Astiani, D., Hardiono, Y.M., Siregar, P., Caniago, I., Kasischke, E., 2004. Lowland forest loss in protected areas of Indonesian Borneo. Science 303, 1000–1003.

Daehler, C.C., 1998. The taxonomic distribution of invasive angiosperm plants: ecological insights and comparison to agricultural weeds. Biological Conservation 84, 167–180.

Diemont, S.A.W., Martin, J.F., 2009. Lacandon Maya ecosystem management: sustainable design for subsistence and environmental restoration. Ecological Applications 19, 254–2766.

Durr, J., 2001. The biology, ecology, and agroforestry potential of the raintree, *Samanea saman* (Jacq.) Merr. Agroforestry Systems 51, 223–237.

Ewel, J.J., Mazzarino, M.J., 2008. Competition from below for light and nutrients shifts productivity among tropical species. Proceedings of the National Academy of Sciences United States of America 105, 18836–18841.

FAO/EC/ISRIC, 2003. World Soil Resources., http://www.fao.org/ag/agl/agll/wrb/wrbmaps/htm/soilres.htm.

Garen, E.J., Saltonstall, K., Slusser, J.L., Mathias, S., Ashton, M.S., Hall, J.S., 2009. An evaluation of farmers' experiences planting native trees in rural Panama: implications for reforestation with native species in agricultural landscapes. Agroforestry Systems 76, 219–236.

Gotelli, N.J., Entsminger, G.L., 2001. EcoSim: Null Models Software for Ecology. Version 7.0. Acquired Intelligence Inc. & Kesey-Bear, http://homepages.together.net/~gentsmin/ecosim.htm.

Griscom, H., Connelly, A.B., Ashton, P.M.S., Wishnie, M.H., Deago, J., in press. The structure and composition of a tropical dry forest landscape after land clearance, Azuero Peninsula, Panama. Journal of Sustainable Forestry.

Griscom, H.P., Ashton, M.S., 2011. Restoration of dry tropical forests in Central America: a review of pattern and process. Forest Ecology and Management 261, 1564–1579.

Haggar, J.P., Briscoe, C.B., Butterfield, R.P., 1998. Native species: a resource for the diversification of forestry production in the lowland humid tropics. Forest Ecology and Management 106, 195–203.

Haggar, J., Ewel, J.J., 1997. Primary productivity and resource partitioning in model tropical ecosystems. Ecology 78, 1211–1221.

Hertwich, E.G., Peter, G.P., 2009. Carbon footprint of nations: a global, trade-linked analysis. Environmental Science and Technology 43, 6414–6420.

Hooper, E., Condit, R., Legendre, P., 2002. Responses of 20 native tree species to reforestation strategies for abandoned farmland in Panama. Ecological Applications 12, 1626–1641.

Janzen, D.H., 1988. Tropical dry forests, the most endangered major tropical ecosystem. In: Wilson, E.O. (Ed.), Biodiversity. National Academy Press, Washington, DC, pp. 130–137.

Laurance, W.F., 1999. Reflections on the tropical deforestation crisis. Biological Conservation 91, 109–117.

Laurance, W.F., Cochrane, M., Bergen, S., Fearnside, P., Delamonica, P., Barber, C., D'Angelo, S., Fernandes, T., 2001. The future of the Brazilian Amazon. Science 291, 438–439.

Love, B., 2008. Characterization and evaluation of tree, maize, and upland rice genetic resources in the Azuero region of Panama. PhD. thesis, University of Alberta, Edmonton, Canada.

Love, B.E., Bork, E.W., Spaner, D., 2009. Tree seedling establishment in living fences: a low-cost agroforestry management practice for the tropics. Agroforestry Systems 77, 1–8.

Love, B., Spaner, D., 2005. A survey of small-scale farmers using trees in pastures in Herrera Province, Panama. Journal of Sustainable Forestry 20, 37–65.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Montagnini, F., González-Jiménez, E., Porras-Salazar, C., Rheingans, R., 1995. Mixed and pure forest plantations in the humid neotropics: a comparison of early growth, pest damage and establishment costs. Commonwealth Forestry Review 74, 306–314.

Montagnini, F., Mendelsohn, R.O., 1997. Managing forest fallows: improving the economics of swidden agriculture. AMBIO 26, 118–123.

Murgueitio, E., Calle, Z., Uribe, F., Calle, A., Solorio, B., 2011. Native trees and shrubs for the productive rehabilitation of cattle ranching lands. Forest Ecology and Management 261, 1654–1663.

Murphy, P.G., Lugo, A.E., 1986. Ecology of tropical dry forest. Annual Review of Ecology and Systematics 17, 67–88.

Nichols, J.D., Bristow, M., Vanclay, J.K., 2006. Mixed species plantations: prospects and challenges. Forest Ecology and Management 233, 383–390.

Nichols, J.D., Rosemeyer, M.E., Carpenter, F.L., Kettler, J., 2001. Intercropping legume trees with native timber trees rapidly restores cover to eroded tropical pasture without fertilization. Forest Ecology and Management 152, 195–209.

Otsamo, A., Adjers, G., Hadi Tjuk, S., Kuusipalo, J., Vuokko, R., 1997. Evaluation of reforestation potential of 83 tree species planted on *Imperata cylindrica* dominated grassland. New Forests 14, 127–143.

Pagiola, S., Arcenas, A., Gunars, P., 2005. Can payments for environmental services help reduce poverty? An exploration of the issues and evidence to date from Latin America. World Development 33, 237–253.

Páres-Ramos, I.K., Gould, W.A., Aide, T.M., 2008. Agricultural abandonment, suburban growth, and forest expansion in Puerto Rico between 1991 and 2000. Ecology and Society 13, http://www.ecologyandsociety.org/vol13/iss2/art1/.

Park, A., van Breugel, M., Ashton, M.S., Wishnie, M., Mariscal, E., Deago, J., Ibarra, D., Cedeno, N., Hall, J.S., 2010. Local and regional environmental variation influences the growth of tropical trees in selection trials in the Republic of Panama. Forest Ecology and Management 260, 12–21.

Perez-Salicrup, D.R., Esquivel, R., 2008. Tree infection by *Hypsipyla grandella* in *Swietenia macrophylla* and *Cedrela odorata* (Meliaceae) in Mexico's southern Yucatan Peninsula. Forest Ecology and Management 255, 324–327.

Pérez-Cordero, L.D., Kanninen, M., Ugalde-Arias, L.A., 2003. Stand growth scenarios for *Bombacopsis quinata* plantations in Costa Rica. Forest Ecology and Management 174, 345–352.

Piotto, D., 2008. A meta-analysis comparing tree growth in monocultures and mixed plantations. Forest Ecology and Management 255, 781–786.

Piotto, D., Craven, D., Montagnini, F., Alice, F., 2009. Silvicultural and economic aspects of pure and mixed native tree species plantations on degraded pasturelands in humid Costa Rica. New Forests, doi:10.1007/s11056-009-9177-0.

Piotto, D., Montagnini, F., Ugalde, U., Kanninen, M., 2003. Performance of forest plantations in small and medium-sized farms in the Atlantic lowlands of Costa Rica. Forest Ecology and Management 175, 195–204.

Piotto, D., Víquez, E., Montagnini, F., Kanninen, M., 2004. Pure and mixed forest plantations with native species of the dry tropics of Costa Rica: a comparison of growth and productivity. Forest Ecology and Management 190, 359–372.

Plath, M., Mody, K., Potvin, C., Dorn, S., 2010. Do multipurpose companion trees affect high value timber trees in a silvopastoral plantation system? Agroforestry Systems, doi:10.1007/s10457-010-9308-9.

Potvin, C., Gotelli, N.J., 2008. Biodiversity enhances individual performance but does not affect survivorship in tropical trees. Ecology Letters 11, 217–223.

Ruf, F., Schroth, G., 2004. Chocolate forests and monocultures: a historical review of cocoa growing and its conflicting role in tropical deforestation and forest conservation. In: Schroth, G., de Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L., Izac, A.M.N. (Eds.), Agroforestry and Biodiversity Conservation in Tropical Landscapes. Island Press.

Sautu, A., Baskin, J.M., Baskin, C.C., Condit, R., 2006. Studies on the seed biology of 100 native species of trees in a seasonal moist tropical forest, Panama, Central America. Forest Ecology and Management 234, 245–263.

Shono, K., Davies, S.J., Kheng, C.Y., 2007. Performance of 45 native tree species on degraded lands in Singapore. Journal of Tropical Forest Science 19, 25–34.

Siddique, I., Engel, V.L., Parotta, J.A., Lamb, D., Nardoto, G.B., Ometto, J.P.H.B., Martinelli, L.A., Schmidt, S., 2008. Dominance of legume trees alters nutrient relations in mixed species forest restoration plantings within seven years. Biogeochemistry 88, 89–101.

Somarriba, E., Harvey, C.A., Samper, M., Anthony, F., Gonzalez, J., Staver, C., Rice, R.A., 2004. Biodiversity conservation in Neotropical Coffee (*Coffea arabica*) plantations. In: Schroth, G., de Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L., Izac, A.M.N. (Eds.), Agroforestry and Biodiversity Conservation in Tropical Landscapes. Island Press.

Steffen, W., Noble, I., Canadell, J., et al., 1998. The terrestrial carbon cycle: implications for the Kyoto Protocol. Science 280, 1393–1394.

Stewart, J., Dunsdon, A., 1994. Performance of 25 Central American dry zone hardwoods in a pantropical series of species elimination trials. Forest Ecology and Management 65, 183–193.

Sumner, M.E., Miller, W.P., 1996. Chapter 40: cation exchange capacity and exchange coefficients. In: Sparks, D.L. (Ed.), Methods of soil analysis, part 3: chemical method. Soil Science Society of America and American Society of Agronomy, Madison, WI, USA, pp. 1201–1229.

Tscharntke, T., Sekercioglu, C.H., Dietsch, T.V., Sodhi, N.S., Hoehn, P., Tylianakis, J.M., 2008. Landscape constraints on functional diversity of birds and insects in tropical agroecosystems. Ecology 89, 944–951.

Turner, B.J., Romero, T.E., 2009. Short term changes in extractable inorganic nutrients during storage of tropical rainforest soils. Soil Science Society of America Journal 73, 1972–1979.

Ugalde Arias, Gomez-Flores, M., 2006. Perspectivas económicas y ambientales de las plantaciones de teca bajo manejo sostenible, en Panamá. In: Published report prepared for United States Agency for International Development and the National Environmental Authority of Panama.

van Breugel, M., Hall, J.S., Craven, D.J., Gregoire, T.G., Park, A., Dent, D.H., Wishnie, M.H., Mariscal, E., Deago, J., Ibarra, D., Cedeño, N., Ashton, M.S., 2011. Early growth and survival of 49 tropical tree species across four sites differing in soil fertility and rainfall. Forest Ecology and Management 261, 1580–1589.

Vieira, D.L.M., Holl, K.D., Peneireiro, F.M., 2009. Agro-successional restoration as a strategy to facilitate tropical forest recovery. Restoration Ecology 17, 451–459.

Wishnie, M.H., Dent, D.H., Mariscal, E., Deago, J., Cedenno, N., Ibarra, D., Condit, R., Ashton, P.M.S., 2007. Initial performance and reforestation potential of 24 tropical tree species planted across a precipitation gradient in the Republic of Panama. Forest Ecology and Management 243, 39–49.

Wright, S.J., Muller-Landau, H.C., 2006. The future of tropical forest species. Biotropica 38, 287–301.

Wright, S.J., Samaniego, M.J., 2008. Historical, demographic, and economic correlates of land-use change in the Republic of Panama. Ecology and Society 13, http://www.ecologyandsociety.org/vol13/iss2/.