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Native species valuable timber plantations in Northern Guatemalan Humid Lowlands: ecological features and silvicultural feasibility

Plantaciones con especies nativas valiosas en Tierras Bajas del Norte de Guatemala: rasgos ecológicos y viabilidad silvícola

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Abstract

The Northern Humid Guatemalan Lowlands contains a significant diversity of tree species, including some valuable-timber producers; these species are threatened by commercial overexploitation and habitat loss due to deforestation. The cultivation of these species in forest and agroforest plantations is a potentially viable option for balancing their conservation and commercial harvesting, something that has been promoted with Government Incentives in Guatemala during the past two decades. However, these species have not been widely planted, among other constraints, because knowledge on their ecological requirements and silviculture is scarce. A characterization of monoculture and mixed plantations with 14 native valuable-timber species was made in the Humid Lowlands of Northern Guatemala, analyzing for each species frequency of association and accompanying species, planted area, the main ecological features and growth rates. To gather information, we combined field observation and measurements with interviews and literature review. Based on our survey, main management challenges for cultivation of the species were identified and described. Valuable-timber native trees could potentially be sustainably cultivated in the study zone in different types of forest plantations and agroforestry schemes of coffee, cacao, cardamom and cattle; considering their suitability to fit in diversified systems, growth performance and farmer's preferences, *Swietenia macrophylla*, *Cedrela odorata*, *Tabebuia donnell-smithii*, *Calophyllum brasiliense* and *Cordia alliodora* were the species with the higher potential for inclusion in plantations. However, several unsolved problems continue restricting the cultivation of these species in plantations; therefore, is essential a careful design and management.

Keywords Biodiversity conservation, threatened native species.

Resumen

Las Tierras Bajas y Húmedas del Norte de Guatemala contienen diversidad relevante de especies arbóreas, incluyendo algunas de madera valiosa; estas especies están amenazadas por sobre explotación comercial de su madera y deforestación. El cultivo de estas especies en plantaciones forestales y agroforestales es una opción potencialmente viable para equilibrar su conservación y aprovechamiento, lo cual ha sido promovido en Guatemala durante las dos décadas pasadas. Sin embargo, estas especies no se cultivan extensivamente, entre otras limitantes, debido al escaso conocimiento sobre su ecología y silvicultura. Se caracterizaron plantaciones puras y mixtas con 14 especies nativas maderables valiosas en Tierras Bajas y Húmedas del Norte de Guatemala, analizando para cada especie, presencia de especies, superficies plantadas, rasgos ecológicos y crecimiento. Para obtener información se combinó observaciones de campo, mediciones, entrevistas, consultas de archivo y revisión bibliográfica. Se identifican y describen los principales desafíos de manejo para cultivar las especies. Las especies nativas de madera valiosa podrían potencialmente ser cultivadas de manera sostenible, en diferentes tipos de plantación forestal y agroforestal con café, cacao, cardamomo y ganadería; considerando idoneidad para encajar en sistemas diversificados, tasas de crecimiento y preferencias de productores, *Swietenia macrophylla*, *Cedrela odorata*, *Tabebuia donnell-smithii*, *Calophyllum brasiliense* y *Cordia alliodora* fueron las especies que mostraron mayor potencialidad para ser incluidas en plantaciones en la zona. Sin embargo, aún persisten diferentes aspectos no resueltos que limitan el cultivo de estas especies en plantación, requiriéndose un cuidadoso diseño y manejo.

Palabras claves: Conservación de biodiversidad, especies nativas amenazadas.

Introduction

Deforestation continues to be an unsolved problem in Guatemala; a net annual reduction of 38,500 ha of forest cover is estimated at country level, representing for the period 2006-2010 a per year decrease of 1 % of the remaining forest cover (Universidad del Valle de Guatemala, Instituto Nacional de Bosques, Consejo Nacional de Areas Protegidas [Conap], & Universidad Rafael Landívar, 2011). Land-use change and commercial over exploitation entails the loss of plant genetic material, including valuable timber trees, whose populations are being reduced and eventually depleted, to the point of being regarded as endangered or threatened species.

Different arguments justify the inclusion of native species in plantations, including the high commercial value of the wood of some of them (Montagnini & Jordan, 2005) and the increasing scarcity of these in natural forests (Onyekwelu, Stimm, & Evans, 2011). The inclusion of native species in plantations represents a conservation approach in productive systems, in which threatened tree species can be simultaneously used and conserved for their utilitarian value (Newton, 2008); restoration of biodiversity and ecological functioning require new approaches to reforestation, to enhance potential for both overcoming forest degradation and addressing rural poverty (Lamb, Erskine, & Parrotta, 2005). Native species cultivation in the tropics have been studied, examining their performance along with exotics for land restoration (Carpenter, Nichols, Pratt, & Young, 2004) in pure and mixed stands (Montagnini & Piotto, 2011).

Trials have been settled for testing groups of species survival and productivity on a particular site (Butterfield & Espinoza, 1995) or their differentiated response when planted under diverse environmental conditions (Calvo-Alvarado, Arias, & Richter, 2007; Wishnie et al., 2007) and arrangements (Manson, Schmidt, Bristow, Erskine, & Vanclay, 2013), highlighting small-scale environmental heterogeneity as a driver of tree survival and initial growth within sites (Plath, Mody, Potvin, & Dorn, 2011).

Different topics of management with tropical valuable-timber native species have been identified, including the need for sophistication of reforestation treatments, including the comparisons of mixtures with monocultures, paying attention to potential complementary effects when combining species with different shade tolerance (Hung, Herbohn, Lamb, & Nhan, 2011), the need to advance in understanding the ecosystem services and functions (Forrester, 2014; Hall, Ashton, Garen, & Jose, 2011), the balance between production and conservation roles of plantations (Lamb et al., 2005; Pryde, Holland, Watson, Turton, & Nimmo, 2015), the potential advantages that can be gained when cultivating species in carefully designed mixtures instead of monocultures (Kelty, 2006), which can lead to increases in growth rates and economic gains if proper ecological combining ability among species can be achieved (Menalled, Kelty, & Ewel, 1998), adding as well other ecological benefits (Piotto, 2008).

In Guatemala, the establishment of forest plantations has been promoted over the past 20 years, mostly through government incentives; although native species accounts for a small proportion of total planted area (Instituto Nacional de Bosques, 2017a), their relevance arises when considered their potentially high timber commercial value and the environmental roles they can play. In Guatemala there is a lack of trials with native species plantations as the ones settled in other parts of the tropics (Calvo-Alvarado et al., 2007; Manson et al., 2013; Park et al., 2010; Petit and Montagnini, 2006; Wishnie et al., 2007), to allow the testing with statistical support of species performance in response to differentiated edapho-climatic factors. However, the existence of a diverse set of plantations with valuable-timber trees, with wide variation in species composition (monocultures and different kind of mixtures), ages (dominating young and intermediates classes), degrees of success, and management approaches, and the scarce information available on species autecology and silviculture, were the drivers for this research.

Our study examines the feasibility for cultivation of valuable timber native species in the Northern Humid Lowlands of Guatemala. The aim was to identify relevant biophysical and socio-economic factors that favor or constrains their cultivation in the study zone, with the hope that our findings could eventually contribute to take better decisions for designing and manage future plantations with the species of interest.

The objectives of the research were: (i) To establish species choices preference in both monoculture and mixed stands; (ii) Identify the main environmental requirements of species and their relationship with growth rates, and (iii) Describe and analyze relevant management challenges for the different species.

Materials and methods

Selected species

From the large diversity of native tree species present in the natural forests of warm and humid areas of Mesoamerica –including their remnants in northern Guatemala– we selected a group of commercially valuable-timber ones, regarded by National Forest Service as “precious” and “semi-precious” timber species (Instituto Nacional de Bosques, 2017b). Due to habitat loss and commercial over-exploitation of their timber, the biological and economic viability of these species is classified with different levels of threat by national and international standards (the Convention on International Trade in Endangered Species of Wild Fauna and Flora -Cites-, 2017; Conap, 2009). Taxonomic information, timber commercial category, and conservation status of the chosen species is summarized in Table 1.

Study area and sampling

This research covered the humid (above 2000 mm/year of average rainfall) lowlands (below 1,000 m altitude) of northern Guatemala, which comprises a large area, located to the north and east of the Sierra Madre mountain chain, including the so-called Northern Transverse Strip (FTN), the Polochic River Valley-Izabal Lake Basin, the southern half of Petén province and the Lower Motagua River Basin (Figure 1). The area subject of study is the one with the highest rate of forest cover loss in Guatemala, which had occurred during the last four decades and is still an ongoing process due to the conversion of forests to agricultural uses, induced by different factors, including the expansion of agro-fuels cultivation, subsistence crops and cattle ranching (Universidad del Valle de Guatemala, et al., 2011). The study zone has in general a more diverse and lower productive potential soils when compared with the southern (Pacific) lowlands of Guatemala.

A combination of criteria was applied to define the sample, looking for assuring inclusion of the species of interest -in both monoculture and mixed stands-, site characteristics based mostly on physiography and altitude within the four natural regions of the study area, stage of development (based on age), and management approach; all the plantations have been established with government subsidies (Incentives Program [Pinfor]), with only one exception. The survey included 51 points (sampling units) in 33 sites. Selection of sample units was based on inclusion of the widest possible situations using the above mentioned criteria; therefore, we did not define the sample following any quantitative statistical criterion. Location by zone are summarized in Table 2 and Figure 1.

FTN zone has a higher proportion of sample because that is the region with the largest number and diversity of plantations in terms of species composition and cultivation arrangements.

In sampled stands the following information was surveyed: species composition, plantation age, and initial and current stand density, diameter at breast height, total height, sanitary status, and foliar phenology. Measurements were taken following standardized procedures (Avery & Burkhart, 2002).

Sample units were plots of either 500 or 1,000 m^2 of surface (varying in response to stands size) with rectangular shape. Some of the plots are part of the Inab permanent monitoring system for forest plantations. Interviews were carried out with land owners or managers in each farm visited and also with Inab technical personnel, both local and at national headquarters with team members of the national program of forest incentives.

According to Holdridge’s Life Zone system (Cruz de la, 1982), although most sites are within the subtropical wet forest life zone, eight samples were in the tropical wet forest and one in the subtropical moist forests (temperate) life zone; in general tree species planted face low environmental stress due to climatic condition, since the dry season entails no more than four months. The largest environmental variation and stress inducing for plantations in the study zone comes from soil condition, which is extremely variable because of the diverse origin material; soil water retention is associated with topographic position and soil texture and explains the differentiated capacity of species for survival and growth. Soil depth and rockiness might be as well limiting factors for some species.

Results

Species ecological features

Table 3 displays main ecological requirements of species -including wood density- and frequent arrangements and management challenges. Information comes from literature review and field observation.

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Table 1
Species taxonomy, timber value, and conservation status

Common Names	Scientific Name	Botanic Family	Natural Distribution	Timber Commercial Category	Cites[1] Status	Conap[2] Status
Big Leaf Mahogany	*Swietenia macrophylla* King	Meliaceae	South Mexico-Amazon Basin	Precious	II	3
Pacific Coast Mahogany	*Swietenia humilis* Zuccarini	Meliaceae	Pacific dry Mexico to Costa Rica	Precious	II	2
Spanish Cedar, Cedro	*Cedrela odorata* L.	Meliaceae	Mexico to North Argentina	Precious	III	2
Rosewood, Granadillo	*Dalbergia retusa* Hemsl	Fabaceae	Pacific Mexico-Panama	Precious	III	2
Rosul, Rosewood	*Dalbergia stevensonii* Standl	Fabaceae	South Belize, North Guatemala and South Mexico	Precious	III	2
Sericote	*Cordia dodecandra* A. DC.	Boraginaceae	Atlantic Mexico, Belize & North Guatemala	Precious		3
Jocote fraile, Jobillo, Ronrón	*Astronium graveolens* Jacq.	Anacardiaceae	South Mexico to Brasil & Bolivia	Precious		3
Chichipate	*Sweetia panamensis* Benth.	Fabaceae	South Mexico to Colombia & Venezuela	Precious		
Palo Blanco, Primavera	*Tabebuia donnell-smithii* Rose	Bignoniaceae	Pacific Mexico - Honduras	Semi-precious		
Matilisguate, Roble Sabana	*Tabebuia rosea* Bertol.	Bignoniaceae	Mexico to North South America	Semi-precious		
Santa María	*Calophyllum brasiliense* Cambess.	Clusiaceae	South Mexico to Bolivia &Brasil, including Antilles	Semi-precious		
Laurel	*Cordia alliodora* (Ruiz &Pav.) Oken	Boraginaceae	North Mexico-Argentina & Caribbean	Semi-precious		
Conacaste	*Enterolobium cyclocarpum* (Jacq.) Griseb.	Fabaceae	South Mexico-North South America, dry zones	Semi-precious		3

(Continued)

Table 1
Species taxonomy, timber value, and conservation status (Cotinuation)

Common Names	Scientific Name	Botanic Family	Natural Distribution	Timber Commercial Category	Cites[1] Status	Conap[2] Status
San Juan	*Vochysia guatemalensis* Donn Sm.	Vochysiaceae	South Mexico, Central America and Colombia	Secondary		

Note. Sources: Consejo Nacional de Áreas Protegidas (Conap), 2009; Cordero et al, 2003; Instituto Nacional de Bosques, 2017b; Kew Royal Botanic Gardens et al., 2013; Standley et al., 1977; the Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2017. [1]Conap Status: Conap stands for Guatemalan National Protected Area System Council; Category 1 for endangered of extinction species (proposed total restriction for commercial use); Category 2 for species with natural distribution restricted to one habitat (endemic species); Category 3 for species currently not in threat of extinction but that might become to be so if harvest is not regulated. Species in categories 2 and 3 can be harvested for scientific and commercial purposes if approved management plans guarantee their survival. [2]Cites List: The Convention on International Trade in Endangered Species of Wild Flora and Fauna (Cites) regulates the global trade of threatened and endangered species. The level of trade restriction for each species varies from strict to lenient, depending on the level of the threat of extinction it faces. Cites has three appendices, which establish differing levels of permit requirements for the import and export of endangered species. Appendix I lists species threatened with extinction, prohibiting international commercial trade; Appendix II lists those species not yet threatened with extinction but that may become so if trade in them is not strictly controlled and monitored to avoid exploitation incompatible with species survival; Appendix III species are listed when a party currently protects the species under its domestic laws and now seeks the further cooperation of Cites parties to control its international trade (Hunter, Salzman, & Zaelke, 2002).

Surface planted, plantations arrangement and growth

None of the studied species have been planted extensively in Guatemala. The National Forest Service (Instituto Nacional de Bosques, 2017a) reports that *T. donnell-smithii* as the native valuable timber with the highest surface planted with Government incentives during the last 20 years in the country with 6,500 ha, followed by a bunch of species with surfaces above 1,000 ha, which includes *C. odorata*, *C. brasiliense, S. macrophylla,* and *T. rosea* (Table 5); these five species were among the top 10 species in terms of surface planted and interest for cultivation in the country because of promotion made by the Forest Service and the enthusiasm of growers for planting them. However, as is the case in other tropical countries, Pines, Teak and Gmelina are the species most widely planted at national scale in humid lowlands, due to seedlings availability of reliable quality and sufficient quantities, and because their silviculture is much better known and more simple when compared with the natives.

The rest of species of interest in our project have planted surfaces with incentives below 1,000 ha, with presence in not many projects, reflecting the low interest or possibilities for their cultivation; valuable and threatened species are less common in plantations than exotics; the scarce knowledge on their ecological requirements and hence their silvicultural needs along with restrictions to access reliable and sufficient seeds, seedlings and vegetative propagules, make their commercial cultivation a difficult task. We found 13 out of the 14 species of interest for the project present in plantations in the study zone. The only species not found in plantations was *C. dodencandra*, apparently because of its slow growth and reduced market opportunities.

Official statistics show a dominant trend of monocultures (Table 3). This trend is the result of a policy implemented by Inab since the inception of the incentives program in 1997. However, we found an important number of mixed stands, which initially were planted as monocultures and in response to different cultivation challenges, which leaded to high rates of tree mortality, landowners decided to associate the surviving trees of the originally planted valuables with other species as a mean to occupy the site, becoming in mixtures (Table 3). However, official numbers indicate the original composition of stands, since species composition infor-

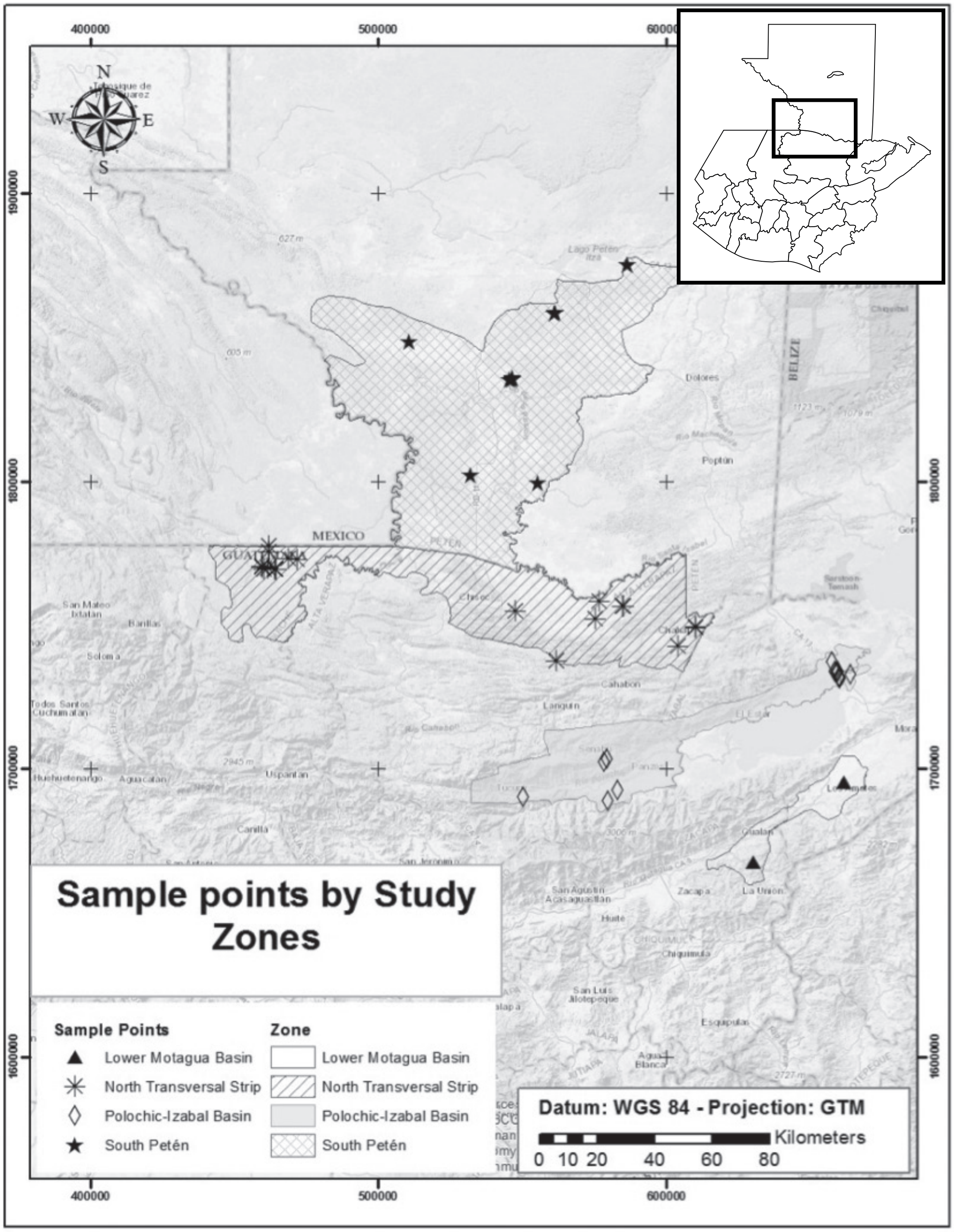

Figure 1. Study regions and sample point's location

Table 2
Sample geographic features

Natural Region	Sampled sites	Altitude m. average (range)	Physiographic region
Northern Transversal Strip (FTN)	21	192 (100-288)	Interior Lowlands of Peten; Izabal Depression; Sedimentary Highlandss
Southern Peten	11	188 (50-350)	Interior lowlands of Peten
Polochic-Izabal Basin	17	230 (18-995)	Izabal Lake depression
Lower Motagua River Basin	2	627 (570-700)	Izabal Lake depression and Crystalline lowlands

mation was never updated. Many landowners express their interest to diversify, either creating mixed stands or planting small size monocultures of different species, as a strategy to deal with biological and financial problems.

Height growth rates are displayed in Figure 2; planted surfaces as a total and in mixtures, stand proportion in terms of basal area, growth rates and plantations ages are synthesized in Table 5.

Although plantations ages varied between 5-23 years, most stands were between 10-15 years, dominating young (between 6-12 years) and intermediate (12-20 years) stages. Growth rates in height can be grouped in three categories: slow rates (below 1.0 m/year) for *S. macrophylla*, *D. retusa*, *D. stevensonii*, *A. graveolens*, *S. panamensis*, *T. rosea*, intermediate rates between 1-1.5 m/year for *S. humilis*, *C. odorata*, *T. donnell-smithii*, *C. brasiliense* and *V. guatemalensis* and finally high rate for *C. alliodora* with an average above 1.5 m/year. In the case of *E. cyclocarpum* although showed height growth slow rate, it was only one stand in the sample, with the oldest age, above 20 years, entering a mature stage, in which growth rates for height decline significantly. It is important to consider that those are average numbers, with wide spectrums in which both site conditions and genetic variability within species might lead to strong variations in growth rates.

Finally, diameter growth rates show as well high variability, with stand density as an additional inducing factor. To make more meaningful comparisons in growth and productivity rates, more in depth data is needed, restricting the number of species, site conditions and stand density management, ideally with accumulated measurements in permanent sample plots, all of which was beyond the scope of this exploratory analysis.

Plantations management in the zone

Three groups of species can be identified from a management perspective. The first one is the "traditional highly valuables", composed by historically exploited Neotropical Meliacea family species, which includes *S. humilis*, *S. macrophylla*, and *C. odorata*, characterized by their well-known valuable timber, both at national and international markets. Although commercial supplies have been yielded from natural forests and continues to being so in Guatemala, there has been a growing interest to cultivate them in plantations, resulting two of the species of this group among the top 10 trees planted with incentives during the past 20 years; shoot borer attack continues to be the most prevalent constraint for cultivation success in plantations, a biological problem difficult to be controlled. Although from the bunch of species analyzed, this group is the one which has received more attention in terms of its cultivation at international level, including their genetics (Navarro, Gillies, Wilson, & Hernandez, 2003); genetic by environment interactions (Ward & Lugo, 2003); regeneration (Grogan, Galvao, Simoes, & Verissimo, 2003; Snook, 2003) and silviculture (Francis, 2003; Negreros-Castillo & Mize, 2003), in Guatemala not much of that knowledge is readily available to producers, therefore the trial and error approach continues to be the predominant scheme when planting the Neotropical Meliaceae. The relatively large amounts of plantations with two of the three species of this group is the result of seed and seedling availability and high interest of landowners to plant them.

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Table 3
Species frequency in sample

Species	# sampled stands		
	Monoculture	Mixtures	Total
S. macrophylla	4	15	19
S. humilis	0	2	2
C. odorata	3	6	9
D. retusa	1	3	4
D. stevensonii	4	6	10
A. graveolens	0	5	5
S. panamensis	0	2	2
T. donnell-smithii	0	5	5
T. rosea	0	3	3
C. brasiliense	1	7	8
C. alliodora	0	4	4
E. cyclocarpum	1	0	1
V. guatemalensis	1	7	8

Table 4
Species ecological features, prevailing arrangements and management challenges

Species	Ecological Requirements	Wood Density g/cm^3	Prevailing arrangement & management constraints
S. macrophylla	Light demanders Long-lived pioneers Moderately fast growth *C. odorata* tolerates some shade and weed competition at seedling stage but not at sapling stage and beyond (Menalled et al., 1998)	0.45-0.55	Planted in the study area in both monoculture and mixtures Affected by shoot borer pest; low density planting (150 trees ha^{-1}) in mixtures and pruning suggested to overcome pest attack and improve growth rates (Cifuentes, 2010)
S. humilis		0.54-0.60	
C. odorata		0.34-0.66	
D. retusa	Shade intolerant (pioneer) Long-lived pioneer Moderately fast growth	0.83-0.89	Shade tree in cocoa plantations at low densities; requires continues pruning
D. stevensonii	Light demanding Slow growth; evergreen Open expanded crown	0.71-0.82	Tolerates flooded soils
C. dodecandra	Light demanding Intermediate growth Tolerates flooded soils Columnar, deciduous crown (Snook, 1993)	0.53-0.77	Very scarce in plantations

(Continued)

Table 4
Species ecological features, prevailing arrangements and management challenges (continuation)

Species	Ecological Requirements	Wood Density g/cm^3	Prevailing arrangement & management constraints
A. graveolens	Tolerates both shade and full sunlight; adapted to strong disturbance	0.76-1.09	Very scarce in plantations Shade tree in cocoa plantations, possible to plant at high densities due to columnar compact crown
S. panamensis	Deciduous, Light demanding, slow-growth	0.80	Very scarce in plantations In mixtures at low densities with mahoganies
T. donnell-smithii	Partially shade tolerant	0.38-0.53	Intermediate densities in mixtures Partial shade needed at juvenile stages Deep and well drained soils
T. rosea	Long-lived pioneer (Griscom & Ashton, 2010); tolerates both humid (seasonally flooded and riparian areas) and dry conditions; high rates of survival under low input conditions (Butterfield & Espinoza).	0.48-0.72	Deciduous, broad crown; recommended to be planted at high densities to avoid profuse branching at low heights. Grows well in fertile, alluvial and well drained soils (Cordero et al., 2003).
C. brasiliense	Partially shade tolerant; requires humid climates and not long dry season (Calvo et al., 2007); long-lived pioneer; medium to slow growth rates (Butterfield & Espinoza, 1995); evergreen foliage. Grows well in clayey, humid and acid soils even on temporary flooded condition (Cordero et al., 2003).	0.47-0.70	As a shade with cacao or cardamom and mixed plantations with *S. macrophylla*; total mortality by pests in humid Costa Rica (Calvo et al., 2007; Montagnini & Piotto, 2011;)
C. alliodora	Pioneer, light-demanding (Francis & Lowe, 2000); evergreen as a seedling, semi-deciduous in dry season as a sapling, and deciduous in wet season as a mature tree (Menalled et al., 1998).	0.33 -0.73	Nutrient (specially N) and weed sensitive (Butterfield & Espinoza, 1995; Menalled, Kelty & Ewel, 1998)
E. cyclocarpum	Intolerant to shade and flooded soils; tolerates alkaline soils;	0.30-0.50	Common tree in seasonally dry cattle farms on Pacific of Central America (Griscom & Ashton, 2011); associated in dry Pacific zone to native Meliaceae tree species, *Dalbergia* sp. and *Astronium graveolens* (Francis & Lowe, 2000).
V. guatemalensis	Shade intolerant Long-lived pioneer Fast growth (Butterfield & Espinoza, 1995); Nitrogen fixer	0.31-0.45	Endures flooded soils; high timber productivity at 15 years in Costa Rica (Montagnini & Piotto, 2011).

Note. Sources: in addition to text citations, Authors field observation and interviews; Carpenter et al., 2004; Francis & Lowe, 2000; Griscom & Ashton, 2011; Kew & MGB, 2016; Pettit and Montagnini, 2004; World Agroforestry Organization, 2017.

Table 5
Planted surface, stand proportion, growth rates and plantation ages for studied species1

Species	Planted area National level ha (mixed stands)2	Stand Proportion % b. area Mean (Range)	Growth rate Mean annual increment Mean (Range)		Age years Mean (Range)
			DBH cm year^{-1}	Height m year^{-1}	
S. macrophylla	1,002 (16)	41 (5-100)	1.19 (0.61 - 2.25)	0.98 (0.61 - 1.94)	13 (6 - 19)
S. humilis	71 (2)	16 (2 - 30)	1.35 (1.23 - 1.46)	1.17 (1.11 - 1.23)	17 (13 - 20)
C. odorata	1,404 (8)	49 (2 - 100)	1.58 (0.70 - 2.43)	1.24 (0.49 - 2.19)	14 (5 - 20)
D. retusa	87 (58)	47 (3 - 51)	1.15 (0.74 - 1.51)	0.99 (0.64 - 1.48)	14 (6 - 19)
D. stevensonii	82 (0)	48 (5 - 100)	1.0 (0.59 - 1.31)	1.0 (0.82 - 1.43)	17 (13 - 19)
C. dodecandra	300 (5)	N/A3	N/A	N/A	N/A
A. graveolens	65 (9)	21 (1 - 78)	0.68 (0.29 - 1.26)	0.68 (0.38 -1.08)	16 (13 - 19)
S. panamensis	16 (2)	34 (1 - 67)	0.87 (0.83 - 0.91)	0.73 (0.70 - 0.76)	14.5 (14 - 15)
T. donnell-smithii	6,582	30 (7 - 77)	1.74 (0.88 - 2.88)	1.38 (0.83 - 1.96)	14 (13 - 15)
T. rosea	3,473 (15)	6 (3 - 10)	1.07 (0.87 - 1.12)	0.80 (0.25 - 1.34)	14 (9 - 18)
C. brasiliense	1,522 (17)	49 (8 - 91)	1.16 (0.74 - 1.45)	1.10 (1.04 - 1.31)	12 (8 - 19)
C. alliodora	138 (1)	15 (3 - 41)	1.85 (0.80 - 3.12)	1.65 (0.88 - 2.56)	14 (5 - 19)
E. cyclocarpum	280 (1)	100	1.82	0.73	23
V. guatemalensis	993 (6)	38 (4 - 91)	1.86 (0.46 - 3.89)	1.13 (0.35 - 2.07)	15 (8 - 19)

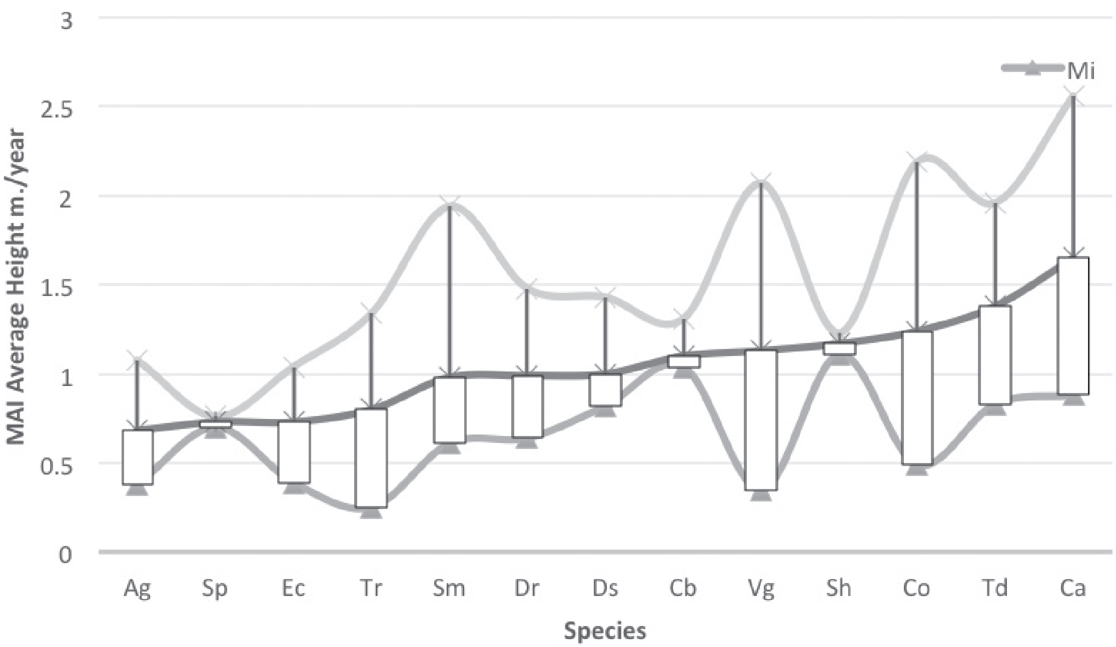

Figure 2. Height Mean Annual Increment by species. Ag: *Astronium graveolens*, Sp: *Sweetia panamensis*, Ec: *Enterolobium cyclocarpum,* Tr: *Tabebuia rosea*, Sm: *Swietenia macrophylla*, Dr: *Dalbergia retusa*, Ds: *Dalbergia stevensonii,* Cb: *Callophyllum brasiliense,* Vg: *Vochysia guatemalensis*, Sh: *Swietenia humilis*, Co: *Cedrela odorata*, Td: *Tabebuia donnell-smithii*, Ca: *Cordia alliodora.*

The second group is called "relic precious timbers", composed by *D. retusa, D. stevensonii*, *C. dodecandra, A. graveolens & S. panamensis.* The species of this group reach high prices at national and international markets, for their use in luxury crafts. The group is characterized by the scarcity of trees in natural forests, their not well-known current distribution, and the growing pressure for their exploitation, much of which is occurring illegally. Plantations surfaces and number of projects with these species are small. The two *Dalbergia* species have been included recently in the Cites Appendix as a Guatemalan initiative; is very likely that much of the current germplasm of these species in Guatemala remains in different agroforestry systems, especially throughout the northern lowlands, and the FTN zone. Not much is known regarding their genetics, autecology and silviculture.

Finally, we settle a third group, named as "semi-precious timbers", which includes *C. brasiliense, C. alliodora, E. cyclocarpum, V. guatemalensis, T. rosea & T. donnell-smithii.* Species of this group produce timber of lesser commercial value when compared with precious timber groups, although their quality still place them as widely used for cabinetry and other highly valuable applications. *E. cyclocarpum* is the only species of the group flagged with some degree of threat by the National Authority. Four of the species have been cultivated in high frequency in forest plantations with incentives, although with several unexpected problems that have leaded to species substitution after plantations establishment. Their performance in agroforestry schemes seems to be a more suitable option.

Discussion

Species preferences

In general, valuable-timber species are not the predominant choices when selecting species for commercial plantations in the Northern Humid Lowlands of Guatemala, although most of them are native to the zone. A reduced group of pioneers, fast-growing exotic species are preferred for their higher availability of seedlings of reliable origin, and knowledge on their ecological requirements and because their silviculture is much better known and simple. However, even though valuable natives have different constraints that limit their use in plantations, there is a growing interest in Guatemala to increase their use, several of the landowners of sites visited during this research, are eager to continue testing different schemes for their cultivation. A critical issue that arises is the need for exploration and assessment for ex-situ conservation of diversified and phenotypically desirable materials for these species, as a key component for their long-term conservation and utilization, as suggested by different authors (Finkeldey, 2011; Finkeldey & Hattemer, 2007).

From the species selected for the study, four were the predominant in plantations in the study zone: *T. donnell-smithii, C. odorata*, *C. brasiliense* and *S. macrophylla,* all of them among the top 10 species in terms of surface planted and interest for cultivation at country level, because of the Forest Service promotion and grower's interest. Regarding stand composition of plantations with valuable natives, there is a trend from monoculture towards mixtures, in part due to landowner's previous experiences in associating crops in agroforestry systems; biological and financial constraints make more feasible to manage plantations with valuable timber species in mixtures.

Species autecology is key for cultivation

Even though the scope of this research did not allow to go in depth on this topic, species vary in their growth rates as a result of different environmental requirements, expressed in their light, soil (humidity, nutrients), and terrain (topographic position) conditions. To gain appropriate understanding of species survival, growth rates and productivity on plantations, is essential to have sufficient knowledge of their autecological requirements (silvics), something not well known at different levels for all the evaluated species. Several of the species evaluated in our survey showed low values of productivity (below 10 m^3/ha/year) when planted in monocultures at the typical initial densities of forest stands (Cifuentes, 2010); in contrast, at equivalent densities, traditional exotics planted in Guatemala, such as Caribbean Pine, Teak or Gmelina, achieve much higher yield values.

Based on growth rates and timber value, we settle three species groups: (i) "traditional highly valuables", composed by the Neotropical Meliaceae family species *S. humilis*, *S. macrophylla*, and *C. odorata*, with a strong interest for cultivation in plantations and regarded in national and international markets as "precious timbers"; (ii) "relic timbers" composed by *D. retusa*, *D. stevensonii*, *C. dodecandra, A. graveolens & S. panamensis,* which are raising high prices at international markets for luxury craft-making. Scarcity of trees in natural forests, not well-known current distribution and increasing pressure for their exploitation characterized this group; surface and number of planted stands with them are small; (iii) "semi-precious timbers", which includes *C. brasiliense, C. alliodora, E. cyclocarpum, V. guatemalensis, T. rosea,* & *T. donnell-smithii.* Although their timber commercial value is not that high as compared with precious-timbers, their quality still places them as widely used for cabinetry and other highly valuable applications. *E. cyclocarpum* is the only species of the group flagged with some degree of threat; species are common in agroforestry systems and four of them have been planted in forest stands with high frequency although with several unexpected problems that have leaded to species substitution.

Valuable-timber plantations viability in the zone

Cultivation of native valuable-timber producer species in the Humid Lowlands of Northern Guatemala faces different environmental and socio-economic constraints that need to be addressed. From the environmental side, there is a need for better understanding on the site requirements of species (edapho-climatic conditions), and the potentially differentiated response of provenances and families (genetic variation) under contrasting environments; for long-term conservation of the species, is essential to advance in assessing and collecting for ex-situ conservation a sufficiently wide phenotypes of desirable attributes. Some biological factors are of primary relevance for cultivating some of the valuable-timber species, such as the case of the shoot-borer for the three Meliaceae family species or the need for partial shade on *T. donnell-smithii*, *C. brasiliense* and *S. panamensis.*

Regarding the socio-economic perspective, there are several challenges to cope with for advance in making sustainable the cultivation of the species; the need for cash flow, and employment generation on farm have not been well considered by Forest Service when settled forest incentives to promote plantations establishment; we noticed that landowners, especially small ones, tend to abandon stands after the six-year period of subsidy payments from government. There is no profit in selling small diameter products from stand thinning and pruning; landholders usually are not associated, which impedes the allocation of products in collection centers to reduce transportation costs and increase potential selling value. Lack of association limits as well possibilities for getting access to training, technical advisory and credit. Combining the ecological and financial issues, mixed tree species plantations and some agroforestry systems might be suitable choices for cultivating valuable-timber natives. Several successful examples of such arrangements can be found in the study zone, highlighting coffee, cacao, cardamom and cattle production.

Trials to study performance of the different species of interest at differing sites and management conditions, with adequate number of replicates are needed to gain deeper knowledge on the silviculture of species, such as the ones developed in Australia by Manson and coworkers (2013), in Panama by Oelmann and coworkers (2010), Park and coworkers (2010), Wishnie and coworkers (2007), and in Costa Rica by Montagnini and Piotto (2011), Petit and Montagnini (2006), and Redondo and Montagnini (2006).

In the field work of this research, we found several promising cultivation schemes for setting this type of trials in Northern Guatemala, which should be designed for long-term research. Valuable-timber native trees could potentially be sustainably cultivated in forest stands and the agroforestry schemes of coffee, cacao, cardamom and cattle; considering their suitability to fit in diversified systems, growth performance and farmer's preferences, *S. macrophylla*, *C. odorata*, *T. donnell-smithii*, *C. brasiliense* and *C. alliodora* should be promoted as priority species for plantations in the study zone. Careful design and management in mixtures with species associated based on their ecological requirements are essential to cope with the biological and financial constraints of such productive systems.

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