Chapter

Current and Potential Use of Timber and Non-timber Resources of the Cacao Agroforestry Systems

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Abstract

The cocoa agroforestry system (Cocoa-AFS) is a source of forest and forest non-timber resources. Forest timber resources (FTR) provide society with timber products. The most common uses for trees from the cocoa-AFS are shade for cocoa, firewood, medicinal, timber, fence posts, tool handles, ornamental, and supports and roofing for houses. Forest non-timber resources (FNTR) are those plant and animal products and services that can be obtained from the system. These resources include fruits, medicinal plants, ornamental plants, honey, and many others. Worldwide, FNTR may be the only source of personal income or food for the inhabitants of marginalized areas. Cocoa cultivation faces problems of low production and low prices. These problems induce growers to left-hand or to reduce their cocoa-AFS. Such reduction means the loss of FTR and FNTR that could complement grower incomes from the sale of cocoa. In this paper, we documented the forest tree species and determined the timber volume in cocoa-AFS in the municipality of Cardenas, Tabasco, Mexico. In addition, we determined and quantified the current use of FTR and FNTR. The emphasis of FNTR was on the associated flora and the stored carbon on aboveground biomass as environmental services by the shadow trees.

Keywords: cocoa agroecosystem, timber products, non-timber products, carbon sequestration

1. Introduction

Cocoa tree (*Theobroma cacao* L.) is cultivated in agroforestry systems (AFS) in Mexico. An AFS is a set of land management techniques that combines forest with crops, livestock, or both. It can be established simultaneously or stepwise over time and space [1]. In these systems, cocoa maintains close association with diverse tree species and other useful plants that potentially produce benefits for the families of cocoa growers [2]. In this way, cocoa-AFS possess a broad spectrum of plant associations and strong potential for production of timber, firewood, fruits, medicines, forages, oils, and ornamental plants [3]. Cocoa-AFS is possible since cocoa crop requires low radiation as a C3 plant [4]. Then, it can be established under a tree canopy [5], although in Africa, Malaysia, Peru, Colombia, and Ecuador cocoa production systems under full sunlight have been developed [6]. Having a broad diversity of tree species, cocoa-AFS contain a high diversity of plants, microfauna, and macrofauna and have an important role in the protection and conservation of biodiversity and carbon storage [7, 8]. García [9] reported that the species *Erythrina americana* Mill, *Diphysa robinoides* Benth, *Gliricidia sepium* (Jacq.) Walp, *Samanea saman* (Jacq.) Merr. and *Colubrina arborescens* (Mill.) Sarg. are the most outstanding shade trees of the cocoa-AFS in Comalcalco, which is the first municipality cocoa producer in Tabasco, Mexico. Cocoa producers also introduce other species of their preference useful by their timber (*Cedrela odorata* L.) and fruits such as *Mangifera indica* L., *Citrus* spp. and *Pouteria sapota* (Jacq.) H. E. [9, 10].

Plant diversity in cocoa-AFS can be divided into forest timber resources (FTR) and forest non-timber resources (FNTR). Some of them are shown in **Figure 1**.

FTR provide the society with environmental services (conservation of water, soil and biodiversity, atmospheric carbon sequestration, mitigation of climate change, and global warming). These aspects have not been quantified in most of the cocoa-producing regions of the world [5, 8, 11]. Tangible contributions of FTR are timber products used in the production of lumber (boards, planks, beams, and packing material), paper, veneer and plywood, and for energy (firewood).

The most common uses for trees from the cocoa-AFS are medicinal, timber, pillars for constructing houses, fence posts, tool handles, fruit production, shade for cocoa, firewood, ornamental, and roofing for houses [12]. In the function of their diameter at breast height (DBH $_{1.3\ m}$), 34% of the trees in cocoa-AFS in Costa Rica and 15% in Bolivia are used for thick boards [13, 14].

Non-timber resources are those plant and animal products and services that can be obtained from the forest [15], that is, they are the set of biological resources that include fruit, medicinal plants, ornamental plants, honey, and many others [16]. In many parts of the world, these resources are indispensable for the inhabitants of marginalized areas, who are the main extractors of these products, which may be their only source of personal income [17, 18].

In Mexico, the largest cocoa-producing states are Chiapas and Tabasco occupying an area of 58,084.8 ha, on which 47,000 growers depend. In Tabasco, the area under cocoa is 40,848 ha, which produces 17,403.8 tons of dry cocoa [19, 20]. Of this area, 96% is in the Chontalpa region and 4% in the Sierra region [21].

Figure 1.
Cocoa agroforestry system and some of their timber and non-timber resources in Tabasco, México. Up, from left to right: Calathea lutea, Mangifera indica, Citrus sinensis, and Cedrela odorata logs. Down, from left to right: Persea Americana, Alpinia purpurata, Firewood, and Capsicum annuum.

Cárdenas with an area of 10,487 ha of cocoa-AFS is the second main cocoa-producing municipality of Tabasco [20].

Cocoa cultivation faces problems of low production and prices. These problems discourage growers who no longer maintain their plantations; thus, fewer and fewer number of farmers now cultivate cocoa. The reduction in area planted in cocoa means the loss of a production system that maintains tree cover and provides FTR and FNTR that could complement grower incomes from the sale of cocoa. In this paper we are reporting the forest tree species present in the AFS and determining the timber volume in cocoa-AFS in the municipality of Cárdenas, Tabasco. Also we are determining and quantifying the current use of FTR and FNTR in the cocoa-AFS.

2. Current use of forest timber resources and forest non-timber resources from cocoa-AFS

2.1 Materials and methods

2.1.1 Study area

The study was conducted in 20 plantations (cocoa-AFS) distributed in the populations C-20 (Miguel Hidalgo y Costilla) and C-28 (Gregorio Méndez Magaña) in the municipality of Cárdenas, Tabasco (**Figure 2**). This municipality is located between 17° 15′ and 17° 40′ N and 90° 59′ and 94° 06′ W, at an altitude of 2–17 m above sea level. Climate is hot-humid with mean annual precipitation of 2643 mm and a monthly mean of 355 mm; mean annual temperature is 26°C with a maximum of 45°C [22].

2.1.2 Quantification of the current use of FTR and FNTR from the cocoa-AFS

Twenty 50 × 100 m sampling sites were established in the same number of plantations (one site per plantation). In each site, age and area of the plantation and number of FTR and FNTR plant species were recorded. Common names of the species were recorded with the aid of people who depend on the cocoa-AFS. For scientific names of the species, the appropriate literature on the vegetation of Tabasco was consulted. A specific questionnaire was given to the owners of each plantation to elicit information on destination and use of FTR and FNTR, as well as on cocoa production. Only the principal use of each species was considered. The social part of the questionnaire included information on family makeup and land ownership. The economic section comprised questions on who works in the production activities, how much is invested in the plantation, and how much is the yield per hectare. The questions relative to the destination of the FNTR of the cocoa-AFS were what products are used in the plantation and how, how much is used of each, and what income is obtained. Average income from the FNTR in the cocoa-AFS was obtained by adding the income of each of the 20 plantations and dividing by the number of plantations. Income from sale of cocoa was obtained by multiplying yield (kg ha^{-1}) by the price per kilogram and subtracting production costs per hectare.

The data were analyzed with descriptive statistics in the Statistical Package for the Social Sciences (SPSS version 20).

2.1.3 Forest timber resources and estimation of C stored in aboveground biomass

In each sampling site, total height (Th) and diameter at breast height (DBH) of each tree were recorded. A Haga pistol was used to measure Th (m), the

Figure 2.
Location of the study area: C-20 town of Miguel Hidalgo y Costilla and C-28 town of Gregorio Méndez Magaña, Cardenas, Tabasco, Mexico.

DBH was measured with a diametric circumference tape, and the result was divided by 3.1415 (π). With the variables Ht and DBH, basal area (BA, m^2) and volume with bark (vwb, m^3) were calculated for each tree. The formulas used were BA = $(DBH/2)^2 \times \pi$ and vwb = BA × ff × Ht, where ff = form factor (0.70) [23, 24]. With vwb, the volume of bark per hectare was calculated (Vwb, m^3ha^{-1}). Vwb was used to calculate the physical carbon inventory PCI, t ha^{-1}. The formula used was PCI = Vwb × FEB × FCC, where FEB is factor of expansion of biomass (1.6) and FCC is the factor of conversion of biomass to carbon (0.05).

2.2 Results and discussion

In the Cocoa-AFS sampled, a total of 3239 trees of 56 species and 27 families were recorded. The average tree density per hectare was 324, varying from 58 to 544. The families Fabaceae and Meliaceae predominate. **Table 1** shows the most frequent species. *Erythrina americana* Mill individuals (1678) account for 51.8% of the total.

FTR provide environmental services. Families obtain direct benefits, such as oxygen, lumber, fence posts, forked support posts, window and door frames, and firewood. Incomes per family reported by producers from sale of these items were US$ 155.4 a year. Of this amount, US$ 120.8 is from sale of timber for milling and US$ 34.6 from sale of firewood.

Common and scientific name		Num. trees	Percentage
Mote *Erythrina americana* Mill.	Fabaceae	1678	51.81
Cedro *Cedrela odorata* L.	Meliaceae	349	10.77
Tatuan *Colubrina arborescens (*Mill) Sarg.	Rhamnaceae	300	9.26
Chipilcohite *Diphysa robinioides* Benth	Fabaceae	188	5.80
Naranja *Citrus sinensis* (L.) Osb.	Rutaceae	188	5.80
Guácimo *Guazuma ulmifolia Lam.*	Malvaceae	87	2.69
Macuílis *Tabebuia rosea* (Bertol) *DC.*	Bignoniaceae	81	2.50
Cocoite *Gliricidia sepium (Jacq.) Kunth ex Walp.*	Fabaceae	68	2.10
Guarumo *Cecropia obtusifolia* Bertol.	Urticaceae	41	1.27
Cesniche *Lippia myriocephalus* Sch. y Cham.	Verbenaceae	36	1.11
46 other species		223	6.88
Total		3239	100

Table 1.
Most frequent forest species found in cocoa-AFS, according to the number of trees recorded.

2.2.1 Forest non-timber resources in cocoa-AFS

As FNTR, 6308 plants from 29 families and 53 species were recorded. The plants were grouped into six use categories (**Figure 3**), according to the families who depend on the cocoa-AFS in Cárdenas, Tabasco. The predominating categories were ornamental with 2719 plants, fruit tree with 1776, and vegetable with 1578 plants. Ornamental plants were more common because of their rapid growth and broad distribution. Moreover, since these types of plants do not require high solar radiation, the cocoa-AFS is an ideal habitat. The other highest use categories are those for home use: fruit, vegetable, and medicinal.

The 10 most frequent species are listed in **Table 2**. *Heliconia latispatha* Benth, considered an ornamental plant, accounted for 26.36% of total (1663 plants).

2.2.2 Use of forest and non-forest species

Of the people who depend on the cocoa-AFS, 90% have the same living conditions. They own their home, which has hard floors and concrete roofs. Three to six people live together and obtain income from sugarcane cultivation. However, 70% do not have any use for the products found in the cocoa-AFS, 20% gather them for home use, and 10% sell them. Cocoa production is the main reason for maintaining the system. What growers receive as income from the sale of cocoa is complemented with income from other crops, such as sugarcane (*Saccharum officinarum* L.), and from other activities. The 20% that use these products themselves use FTR for carpentry, supporting posts, fence posts, and roof beams, and

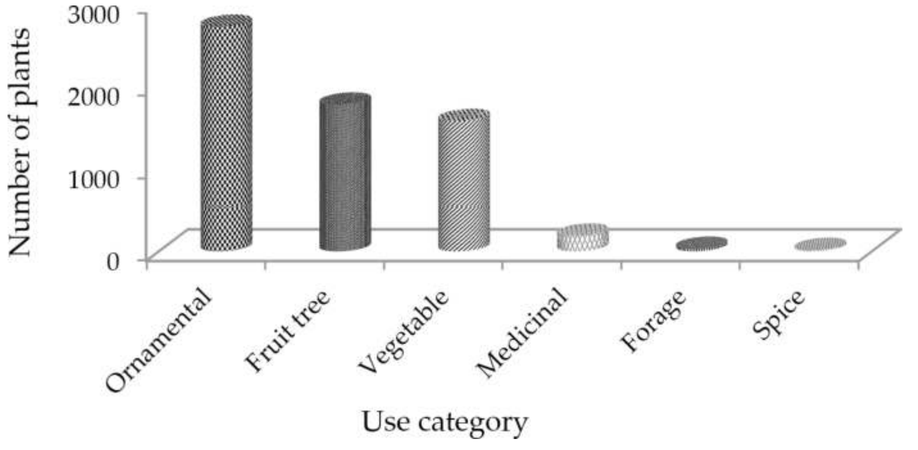

Figure 3.
Number of plants found in cocoa-AFS, in Cárdenas, Tabasco, Mexico, by use categories.

Common name	Scientific name	Num. plants	Percentage
Platanillo	*Heliconia latispatha* Benth	1663	26.36
Hoja de To	*Calathea lutea* G.F.W. Meyer	653	10.35
Platano Cuadrado	*Musa paradisiaca* L.	408	6.47
Platano Macho	*Musa balbisiana* L	386	6.12
Canna	*Canna indica* L.	351	5.56
Pitahaya	*Hylocereus undatus (*Haw.)	311	4.93
Macal	*Xanthosoma sagittifolium S.*	307	4.87
Heliconia Pie gallo	*Heliconia psittacorum* L. f	292	4.63
Hierba Mora	*Solanum tuberosum* L.	248	3.93
Papaya Silvestre	*Carica mexicana* (A.DC.)	237	3.76
43 remaining species		1452	23.02
Total		6308	100

Table 2.
Most frequent non-timber species found in cocoa-AFS.

the residues are used as fuel (firewood). It is estimated that these uses add up to a yearly average savings of US$ 197.50, which can be considered income since, if they were not obtained from the cocoa-AFS, the grower would have to pay out that amount. Some essential FNTR for home use were banana and banana leaves (*Musa* spp.), wild papaya (*Carica mexicana* A.DC.), "platanillo" (*Calathea lutea* Aubl Schult), purple maguey (*Tradescantia spathacea* Sw.), "amashito" chili (*Capsicum annuum* L.), yerba buena (*Mentha sativa* L.), arrowleaf elephant's ear (*Xanthosoma sagittifolium Schott*), Mexican cilantro (*Eryngium foetidum* L.), bitter watermelon (*Momordica charantia* L.), and achiote (*Bixa orellana* L.). Their fruits or leaves are used to prepare food. Moreover, the families save by not buying these products. Of the population that has cocoa plantations, 10% sell their FNTR at the local markets, generating incomes averaging US$ 41.9 per year. The producers that do not use products from the cocoa-AFS are interested only in the production of cocoa but not in the diversity of resources nor the uses they might have.

2.2.3 Economic value of cocoa and potential income from sale of carbon sequestration environmental services

Average cocoa yield reported by growers was 320.8 (±79.6 kg ha^{-1}) (**Table 3**). This yield provides an average net income from the sale of cocoa in pulp of US$ 456.3 ± US$ 140.1 ha^{-1}, which is not profitable since the estimated cost of production is US$ 345.8 (± US$ 135.9) ha^{-1}. The 70% of the growers reported yields above of the average.

Two growers have the highest yields and two the lowest. The former can be attributed to good management of their plantations, as the result of their participation in the ICCO-Nestle program. This program consists of training cocoa growers in good management of their cocoa plantations to ensure good yield, which is later marketed by the same program. The lowest yields can be attributed to two factors.

Plantation number	Production [a] (kg.ha^{-1})	Net income cocoa (US$ ha^{-1})	AGB C[b] (t ha^{-1})	Income[c] from C payments (US$ ha^{-1})
1	500	833	143.29	1074.67
2	333	417	87.92	659.41
3	233	417	86.57	649.30
4	333	667	122.07	915.53
5	267	500	111.90	839.27
6	200	333	148.98	1117.37
7	233	417	215.75	1618.13
8	333	417	165.79	1243.41
9	200	333	165.18	1238.83
10	333	417	122.45	918.36
11	500	667	117.46	880.98
12	333	417	99.85	748.87
13	333	417	115.29	864.70
14	333	500	160.98	1207.37
15	367	417	33.04	247.81
16	333	583	77.83	583.69
17	333	417	115.53	866.49
18	333	333	91.42	685.65
19	250	208	105.39	790.46
20	333	417	120.27	902.03
Media	320.8	456.3	120.38	902.6
D. E.	79.6	140.1	39.34	295.1
C. V	24.8	30.7	32.69	32.69

Source: Questionnaire given to cocoa growers 2014.
[a]*Dry cocoa.*
[b]*Carbon in aboveground biomass.*
[c]*Estimated price of a ton of C = US $ 7.5.*

Table 3.
Income (US $) from sale of cocoa in pulp and potential sale of carbon, from cocoa-AFS, in Cárdenas, Tabasco, Mexico.

First, these growers attach little importance to their plantations because they depend mainly on other crops such as sugarcane, while their cocoa-AFS is only an additional option. The second factor causing low yields is the moniliasis disease caused by the fungus *Moniliophthora roreri*, which attacks the cocoa pods directly and can cause 20–80% yield losses.

The average estimated production of carbon (C) in cocoa-AFS was 120.35 t ha^{-1}. At a price of US$ 7.50 per ton of C, average incomes were calculated at US$ 914.3 h^{-1}. Thus, sale of environmental services would provide 50% more income than cocoa production. Moreover, payment for C sequestration involves conserving trees, mainly young trees since protecting them increases the amount of C captured by the cocoa-ASF. However, because payment of environmental services is a slow process, an option for cocoa growers is to sell FTR and FNTR to obtain more income from their cocoa-AFS.

Cocoa-AFS have been caught up in a vicious cycle since 2005 when moniliasis came to Mexico depleting the cocoa production. When the grower considers only cocoa production and obtains low yields (and incomes), he stops investing in his plantation (time invested in its management decreases). With little or no care of the plantation (less pruning, little or no disease control, less or no fertilization), crop yield is reduced. The average yield in dry weight estimated in this study is below the national average (430 kg ha^{-1}) [20] and that of the Ivory Coast (550 kg^{-1}), the largest cocoa producer in the world [25].

3. Timber trees from the cocoa-AFS and their potential use

3.1 Materials and methods

3.1.1 Study area and sampling sites

The study was conducted in 20 cocoa-AFS in different localities of the municipality of Cárdenas, Tabasco. Experimental plots (50 × 100 m) were set up on Eutric Fluvisols (FLeu) and Eutri-gleyic Fluvisols (FLeugl). These soils are the typical soils of the study area and of the cocoa-AFS [26]. The cocoa-AFS for sampling were defined by interviews to local authorities in order to contact cooperating producers.

3.1.2 Tree sampling and taxonomic identification

For each one of the 20 cocoa-AFS, the age and surface were recorded before the tree sampling. Trees were numbered by painting on them; then they were identified taxonomically and located with a Global Positioner System (GPS, Garmin model GSmap60csx ®) [27]. Tree sampling consisted on record the variables: diameter at breast height ($DBH_{1.3\ m}$, cm) measured with a diametric tape, total height (Th, m), and commercial height (Ch, m) measured with a Haga® Pistol. Basal area (BA, m^2) was estimated with the equation $BA = (DBH/2)^2 \times \pi$. Total and commercial volume (TV, CV, m^3) were estimated with the equation $V = BA \times ff \times H$, where ff = form factor (0.70) and H = total or commercial height [23, 24].

3.1.3 Canopy classification and potential use of trees

Tree canopy was classified based on height [28]: <5 m high (very low stratum), ≥5–<15 m (low), ≥15–<25 m (medium), and ≥25 m high (high stratum). DBH data of trees was classified by categories (1–10 cm, 10–20, 20–30 cm, etc.) to calculate the frequency per class [14, 27]. The potential use per tree was defined in function of DBH [29]: DBH < 5 cm (without use), ≥5–<10 cm (firewood), ≥10–<15 cm (posts), ≥15–<30 cm (narrow boards), and DBH ≥30 cm (thick boards).

3.2 Results and discussion

The total surface sampling was 10 out of 36.5 ha of cocoa-AFS visited. The mean surface per cocoa-AFS was 1.8 ha, varying from 0.5 to 5 ha, which indicate that cocoa-AFS belongs to smallholder producers. In Ref. [13], a mean surface of 1.3 ha per cocoa plantation, varying from 0.25 to 15 ha, is reported in Talamanca, Costa Rica.

3.2.1 Tree flora composition

In the 10 ha of cocoa-AFS sampled, 2856 forest trees were found, belonging to 67 species, 58 genera, and 28 families. In another work [12], 6 ha in Tabasco Mexico were sampled and 38 species, 35 genera, and 24 families were found. Also in Tabasco, [9] recorded 40 species of 19 families in a survey of 72 producers, while [5] in the Soconusco region in Chiapas, Mexico, recorded 790 trees belonging to 23 families, 38 genera, and 47 species in 7.2 ha. In our study, we recorded more tree families and species than that reported in [9, 5]. In contrast, [30] in Brazil recorded 2514 trees belonging to 293 species and 52 families, i.e., less trees and more diversity than ours. It could be attributed to the cleared rainforests areas where cocoa-AFS were located or due to the larger sampling (15 ha). Besides, [31] in Nigeria reported 487 trees belonging to 45 species and 24 families in 1.3 ha sampled.

The mean number of species per hectare was 14, ranging from 6 to 35. The most common species were *E. americana* and *C. odorata*. For Bolivia, [14] reported the species Mahogany (*Swietenia macrophylla*), Brazilian firetree (*Schizolobium parahyba*), and Roble (*Amburana cearensis*) as the more frequent per hectare.

In our study, we found 286 trees ha^{-1}, ranging from 96 to 618 trees ha^{-1}, as mean density. Fabaceae and Meliaceae were the most frequent families. Somarriba et al. [32, 33] recorded 278 trees ha^{-1} in Panamá and Costa Rica; in Venezuela 300 trees ha^{-1} were reported [34], while in Brazil 47–355 trees ha^{-1} were reported [30]. Results obtained from our study are in agreement with four previous studies mentioned here concerning tree density per hectare, and that Fabaceae is the most commonly used tree family for shading cocoa.

3.2.2 Frequency of tree species by cocoa-AFS age

The age of cocoa-AFS sampled varied from 6 to 35 years old. In this entire range of ages, *Moté* (*E. americana*), Spanish cedar (*C. odorata*), and *Cocoite* (*G. sepium*) were outstanding (**Table 4**). These results agree with [10] who stated *E. americana* (25% of the shade trees) in Cárdenas, Tabasco, but differ with the same author for *G. sepium* (75% of the shade trees). It was cited for Brazil [30] that *Schefflera morototoni* (Aubl.) Maguire (8%) and *Artocarpus heterophyllus* Lam. (7%) are the most common shading species in cocoa. In Nigeria the tree species *Elaeis guineensis* Jacq., *Cola nítida* (Vent.) Schott et Endl., *C. sinensis, Mangifera indica, Anacardium occidentale* L., *Psidium guajava* L., *Persea americana* Mill., *Ricinodendron heudelotii* Muell. Arg., *Citrus reticulata* L., and *Cocos nucifera* L. summed 76% of the scored trees [31]. In Talamanca, Costa Rica, *C. alliodora, Citrus* spp., *C. nucifera*, *Inga* spp. and *C. odorata* were outstanding [13], but in Bolivia, the outstanding species were *S. macrophylla, S. parahyba*, *A. cearensis*, *Centrolobium ochroxylum*, and *C. odorata* [14]. Comparing our results with those of such studies, we found that

Common and scientific name of the species	Number of trees	Frequency (%)
Moté, *Erythrina americana* Mill	812	28.4
Spanish cedar, *Cedrela odorata* L.	573	20.1
Cocoite, *Gliricidia sepium* (Jacq.) Walp	247	8.7
Tatúan, *Colubrina arborescens* (Mill.) Sarg.	246	8.6
Chipilcohite, *Diphysa robinioides* Benth	188	6.6
62 other species	790	27.6
Total	2856	100.0

Table 4.
Amount and frequency of the most common trees in cocoa-AFS from 6 to 35 years old in Cardenas, Tabasco, Mexico.

species are similar, but tree density is different. It is because the shading species in the cocoa-AFS vary among countries and among regions into the same country.

In 6, 20, and 25-year-old cocoa-AFS, *C. odorata* was the most frequent shading tree species at 78.0, 41.9, and 15.1% frequencies, respectively. In 15- and 20-year-old cocoa-AFS, the most common species was *G. sepium* (35.1 and 27.1%). At 18-, 25-, and 30-year-old cocoa-AFS, the most frequent species was *Erythrina americana* (46, 45.4, 56.6%, respectively). In 18- and 35-year-old cocoa-AFS, *Tabebuia rosea* was the most frequent species (15.2 and 15.8%). *Diphysa robinioides* with 47.8 and 38.5% frequencies was the most common species in 27- and 33-year-old cocoa-AFS, whereas *C. arborescens* with 17.5, 12.8 and 16.9% frequencies was the most common shading tree species in 30-, 33-, and 35-year-old cocoa-AFS (data not tabulated).

3.2.3 Species with greater basal area by age of cocoa-AFS

The main tree species by the largest BA in cocoa-AFS from 6 to 35 years old were *E. americana* with 6 m^2 ha^{-1}, *E. poeppigiana* 3.8 m^2 ha^{-1}, and *C. odorata* with 1.6 m^2 ha^{-1}. Each one of the other 64 species had ≤1 m^2 ha^{-1} of BA. By age, the smallest BA (12.2 m^2 ha^{-1}) and the largest BA (22.7 m^2 ha^{-1}) were recorded on the 20- and 25-year-old cocoa-AFS, respectively (**Figure 4**).

In 6- and 20-year-old cocoa-AFS with 15.7 and 2.2 m^2 ha^{-1}, respectively, a main species by BA was *Cedrela odorata*. In 6- and 18-year-old cocoa-AFS with 0.6 and 1.9 m^2 ha^{-1}, respectively, the main species was *Guazuma ulmifolia*. In 15-, 25-, and 30-year-old cocoa-AFS, with 7.8, 9.1, and 1.9 m^2 ha^{-1}, respectively, a main species was *E. poeppigiana*. In 15-, 20-, and 35-year-old cocoa-AFS with 4.3, 2.7, and 3.5 m^2 ha^{-1}, respectively, the main species was *Gliricidia sepium*. In 15-, 18-, 25-, and 30-year-old cocoa-AFS with 3.3, 8.3, 8.2, and 14 m^2 ha^{-1}, respectively, the main species was *E. Americana*. *Mangifera indica* was the main species in 18-, 30-, and 33-year-old cocoa-AFS with 1.4, 0.9, and 2.6 m^2 ha^{-1} BA. *Samanea saman* in 25- and 33-year-old cocoa-AFS with 1.7 and 7 m^2 ha^{-1} BA was the main species. *Diphysa robinioides* with 3.5, 2.5, and 1 m^2 ha^{-1} BA was the main species in 27-, 33-, and 35-year-old cocoa-ASF (**Figure 4**).

The mean basal area (BA) of all the scored trees was 18.5 m^2 ha^{-1} and a range of 8.3–34.6 m^2 ha^{-1}. In Cárdenas, Tabasco [12] stated 48.2 m^2 ha^{-1} as average BA and *S. saman* with 12 m^2 ha^{-1}, *D. robinoides* 7.8 m^2 ha^{-1} and *G. ulmifolia* with 5.6 m^2 ha^{-1} as the main species. Such BA values are greater than ours because their reported species have higher frequency and bigger diameter, e.g., *S. saman*.

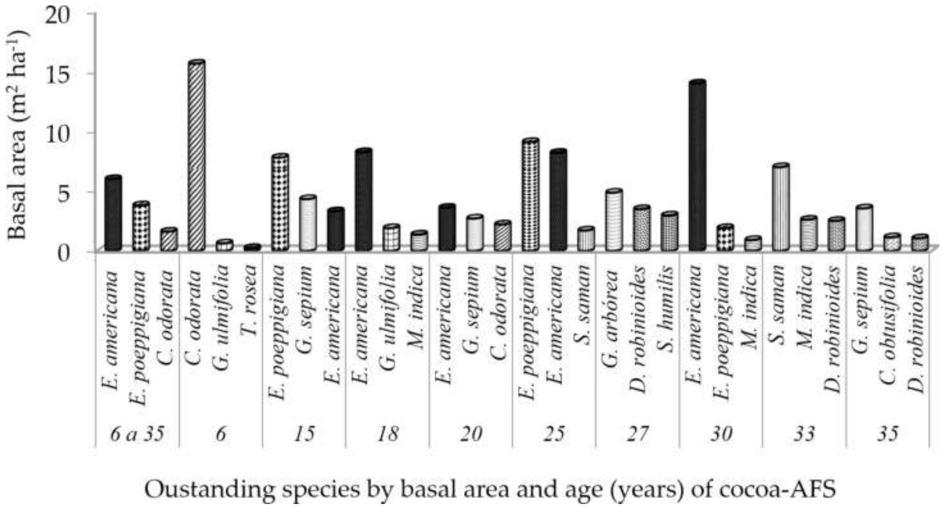

Figure 4.
Tree species with the largest basal areas (m^2 ha^{-1}) in cocoa-AFS of different ages in Cardenas, Tabasco, Mexico.

In Panamá, a mean of 11 m^2 ha^{-1} was reported; the species *C. alliodora* (12 m^2 ha^{-1}), *T. ivorensis* (11 m^2 ha^{-1}), and *T. rosea* (10 m^2 ha^{-1}) had the largest BA [32]. In Lima, Peru, a mean BA of 5.71 m^2 ha^{-1} was reported; the species with the largest BA were *Inga* sp., *Citrus nobilis*, and *Piptadenia favia* [35]. In Costa Rica, Somarriba and Domínguez [36] reported 4.1 m^2 ha^{-1} of mean BA; *T. ivorensis* with 52 m^2 ha^{-1}, *T. rosea* 4.5 m^2 ha^{-1}, and *C. alliodora* with 2.8 m^2 ha^{-1} were the main species. By the way, [37] stated 4.8 m^2 ha^{-1} of mean BA in Honduras. Our recorded BA values are higher than those of the four previous authors cited maybe because their sampled trees were younger and smaller on diameter.

3.2.4 Total timber volume and commercial volumes (TV, CV)

There is a large quantity of timber in cocoa-AFS that can and should be used in a sustainable way. A TV of 1923.8 m^3 in logs was found in the 20 sampled sites. The average TV was 192.4 m^3 ha^{-1}. It ranged from 70.4 to 619.86 m^3 ha^{-1}. Ten species accounted for 87.4% of the TV; the outstanding species were *E. poeppigiana* 33.5% (64.4 m^3 ha^{-1}), *E. americana* 20.9% (40.3 m^3 ha^{-1}), and *C. odorata* 8.1% (15.5 m^3 ha^{-1}) (**Figure 5**). In Panama, the species *C. alliodora* (90 m^3 ha^{-1}), *T. ivorensis* (81 m^3 ha^{-1}), and *T. rosea* (46 m^3 ha^{-1}) were reported as having larger volumes than those of our study [32], as they were established preferentially for shade. The values were similar to those reported in Honduras for the species *Cordia megalantha* 118 m^3 ha^{-1}, *Tabebuia donnell-smithii* 33.9 m^3 ha^{-1}, *Cojoba arborea* 33.5 m^3 ha^{-1}, and *Vitex gaumeri* 31.6 m^3 ha^{-1} [37]. In Costa Rica, *Terminalia ivorensis* with 35 m^3 ha^{-1}, *Cordia alliodora* with 21 m^3 ha^{-1}, and *Tabebuia rosea* with 19 m^3 ha^{-1} TV were reported [36].

In the 20 cocoa-AFS sampled, we recorded 526.29 m^3 log of CV; the mean was 52.6 m^3 ha^{-1} varying from 21.9 to 146.7 m^3 ha^{-1}. The ten main species summed 82.9% of CV; among such species, *E. poeppigiana*, *E. americana*, and *C. odorata* with 27.4% (14.4 m^3 ha^{-1}), 18.7% (9.9 m^3 ha^{-1}), and 11.9% (6.1 m^3 ha^{-1}), respectively, were the most outstanding species (**Figure 6**). For cocoa-AFS in Costa Rica, the species *C. alliodora* was stated with the greatest CV (31 m^3 ha^{-1}), which is due to its preference for shading tree; in the same study, the species with smaller CV was *Cedrela odorata* [38], which is in agreement with our results.

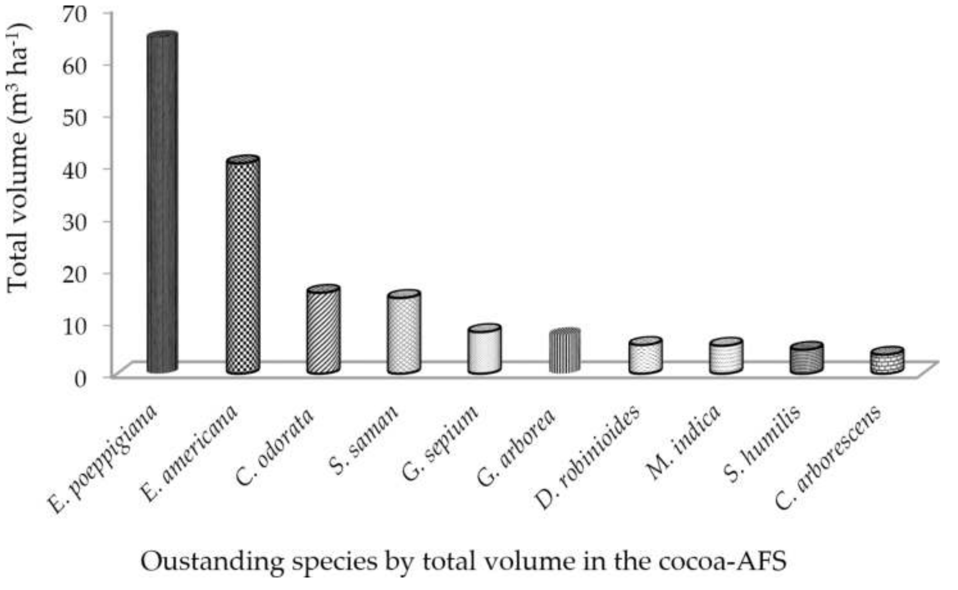

Figure 5.
Tree species with the highest timber volumes ($m^3\ ha^{-1}$) in cocoa-AFS in Cardenas, Tabasco, Mexico.

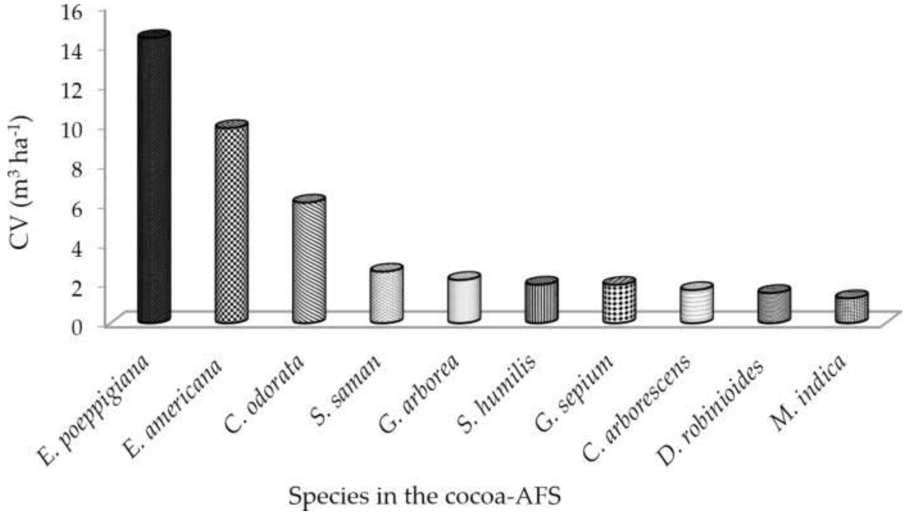

Figure 6.
Main tree species by commercial volume (CV, $m^3\ ha^{-1}$) in the cocoa-AFS, in Cardenas, Tabasco, Mexico.

3.2.5 Classification of tree canopy by height

A mean total height of 10.1 m varying from 2 to 35.5 m was registered for trees in the cocoa-AFS sampled. In the very low stratum, the 5.8% of trees were classified. These trees were *C. odorata*, *T. rosea*, and *C. arborescens* young plants. The low canopy stratum included 84.2% of trees, whereas the high canopy included 1% of trees (**Figure 7**). This 1% grouped species such as *E. poeppigiana* (Erythrina), *S. saman* (Samán), and *A. altilis* (Chestnut). In Cárdenas, Tabasco, some trees of 36 m, mainly of the species *S. saman, G. ulmifolia*, and *C. arborescens,* were reported [12], evidencing that cocoa-AFS contains tree species of similar height to those found in the tropical rainforests. In Talamanca, Costa Rica, up to 30 m for the upper canopy of cocoa-AFS is reported [13]. In Panama and Honduras, average heights of 17 and 13 m have been reported [32, 37]; such heights are higher than those recorded in our study.

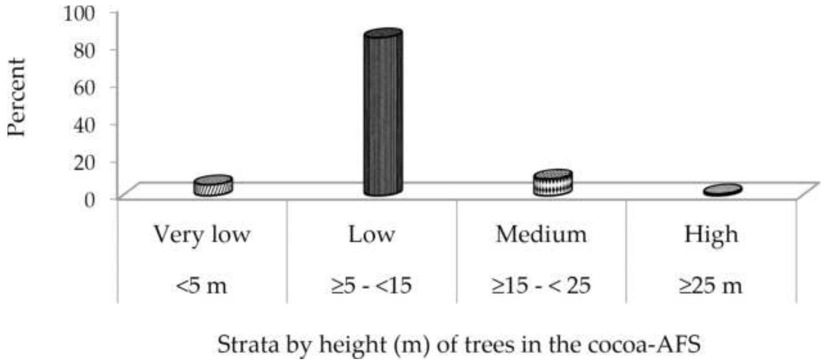

Figure 7.
Trees distribution by height (m) in cocoa-AFS in Cardenas, Tabasco, Mexico.

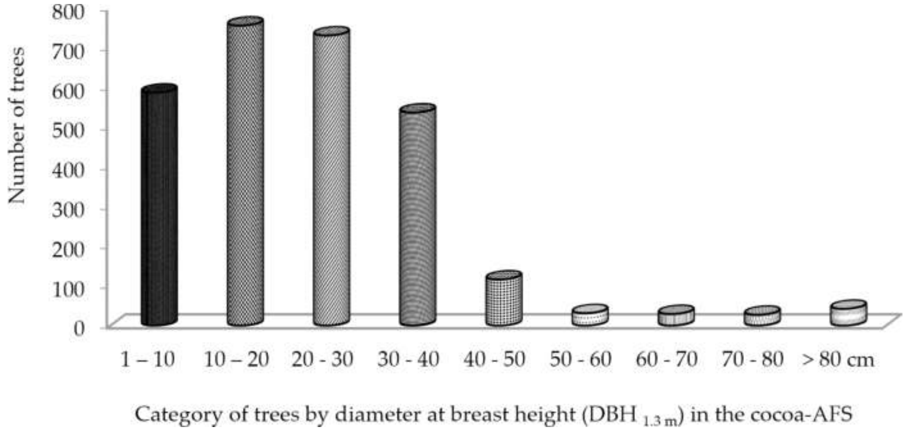

Figure 8.
Categories of trees by diameter at breast height ($DBH_{1.3m}$) of the cocoa-AFS in Cardenas, Tabasco, Mexico.

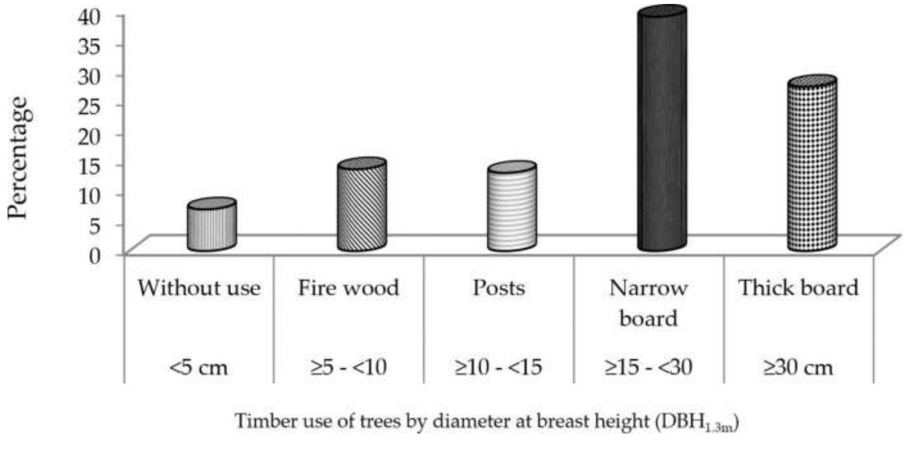

Figure 9.
Potential timber use by diameter at breast height ($DBH_{1.3m}$) of trees from the cocoa-AFS in Cardenas, Tabasco, Mexico.

3.2.6 Tree classification by diameter at breast height and potential use

The mean diameter at breast height ($DBH_{1.3\ m}$) was 23 cm varying from 1 to 146 cm. The 91% of the 2856 scored trees had a DBH of between 1 and 40 cm. Among these trees, 53% had 10–30 cm DBH (**Figure 8**). In Bolivia, 45% of the trees in cocoa-AFS had DBH of between 10 and 20 cm [14], while a maximum DBH of 137 cm for some species was reported in Cárdenas, Tabasco [12]. In Panamá [32] and Honduras [37], average DBH of 25 and 28 cm were reported, which are larger than those found in our study, probably because the authors averaged only three timber species, while we averaged all the timber species found in the cocoa-AFS.

According to the DBH, the main timber uses of the registered trees were narrow and thick boards, 39 and 27.4%, respectively, and 6.9% of the trees were recorded without any use (**Figure 9**) because they were reforestation species established in areas without shade. Use varies with species, age, diversity, and culture, among other factors. In Talamanca, Costa Rica, 34% of the trees with use for thick boards were registered [13], and in Bolivia 15% with this use were reported.

4. General conclusions

Cocoa agroforestry systems are made up of a large number of timber and non-timber resources. From cocoa-AFS in Cárdenas, Tabasco, Mexico, information on current use was obtained, and species were quantified. The most common species used as shade trees are *E. americana*, *C. odorata*, *G. sepium*, *C. arborescens*, and *D. robinioides*. The species with the largest timber volumes are *E. poeppigiana*, *E. americana, C. odorata, S. saman*, and *G. sepium*. This timber resource can be used sustainably in different ways. The principal uses of these timber resources were in making narrow boards and thick boards, a function of their diameter at breast height ($DBH_{1.3\ m}$).

Non-timber resources included 6308 plants belonging to 53 species grouped in 29 families. The 53 species were classified by use into five groups: ornamental, fruit, vegetable, medicinal, and forage. Seventy percent of the people do not use the cocoa-AFS resources; 20% use them in their homes, and only 10% sell them. The products of the cocoa-AFS that are used or sold are square banana and plantain, arrowleaf elephant's ear, banana leaves, papaya, platanillo, Moses in the cradle, amashito chili, yerba buena, parsley, bitter melon, achiote, and firewood. Cocoa production is complemented with income obtained from the sale of forest timber and non-timber resources. Income from the sale of environmental services could be up to 50% higher than income from cocoa production.

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Conflict of interest

The authors declare that they have no conflict of interest.

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