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Shade trees composition and diversity in cacao agroforestry systems of southern Pará, Brazilian Amazon

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Abstract Agroforestry systems (AFS) are important agricultural land use in synergy with socio-environmental aspects, especially with cacao (*Theobroma cacao* L.) crop, a commodity mainly produced by smallholders in the humid tropics. In southern Pará, Brazilian Amazon, farmers manage native shade trees growing with cacao, but species selection may be not appropriate to AFS maintenance over time. The objective of this study was to understand the shade trees transition between successional management phases of cacao-AFS, considering its initial shade (IS) and secondary shade (SS). It was sampled 10 plots in each situation (20,000 m^2 in total) identifying individuals with CBH $\geq$ 15 cm. As expected, floristic composition was different and SS had greater species richness and diversity than IS, where only 17% of species were the shared among them. *Musa* sp. and *Carica papaya* L. were found only in IS and were dominant species, representing almost a half of the individuals. Although there was increase of late succession species from IS to SS, this still keeps high abundance of early succession species, such as *Cecropia* sp. The result shows an unexploited potential products and gap of services provision, such as N-fixing. The conclusion highlights the necessity of long-term succession planning and management practices to guarantee cacao crop maintenance and improve diversification with other income sources, such as fruits and wood. The role of biodiversity conservation, provided by shade trees, should be the target of political strategies to encourage its maintenance, such as payment for ecosystems services or other economic incentives.

Keywords Cacao · Cocoa · Agroforestry · Diversity · Shade tree · Eastern Amazon

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Introduction

Cacao (*Theobroma cacao* L.) crop is a commodity usually grown in agroforestry systems (AFS) by smallholders in the humid tropics (Vaast and Somarriba 2014). Some of these systems can have a complex structure and botanical composition, which has been described by literature around the world (Salgado-Mora et al. 2007; Sambuichi and Haridasan 2007; Jagoret et al. 2011; Deheuvels et al. 2012; Vebrova et al. 2014; Sonwa et al. 2014; Adou Yao et al. 2015). The tree component of AFS, known as shade trees, has an essential role to promote land cover with greater biomass and biodiversity than other conventional land uses (Schroth et al. 2004; McNeely and Schroth 2006; Saj et al. 2013, 2017). Besides, there are other functions related to AFS as nitrogen fixing, nutrient cycling, pollination, dispersion, etc. (Tscharntke et al. 2011).

Shade trees are used as a strategy to keep low cacao production costs, reducing inputs and increasing food security and other non-profit environmental benefits (Franzen and Mulder 2007; Useche and Blare 2013; Cerda et al. 2014; Jagoret et al. 2014; Utomo et al. 2015; Abou Rajab et al. 2016; Saj et al. 2017). They can also diversify production and provide oil, timber, seeds or fruits (Rice and Greenberg 2000; Somarriba and Beer 2011; Cerda et al. 2014), improve carbon stocks (Somarriba et al. 2013; Silatsa et al. 2016) and support high species richness and diversity (Clough et al. 2011; Deheuvels et al. 2014; Vebrova et al. 2014). On the other hand, the intensification of cacao production, while reducing the density and diversity of shade trees, would have a negative impact on livelihoods sustainability and on its capacity to contribute to landscape connectivity and adaptation to climate change (Tondoh et al. 2015; Tscharntke et al. 2011; Vaast and Somarriba 2014; Saj et al. 2017).

Identifying native shade tree species appropriate for cacao crop has been found to be a necessity. Schroth et al. (2004). Clough et al. (2011) and Deheuvels et al. (2014) pointed the importance of proper design of shade component and research to intensify cacao's association with shade tree products. Cerda et al. (2014) also related the need for further research to intensify cacao-AFS's synergy with highly diverse-dense systems. Other authors also realized the lack of knowledge about the multifunctionality of shade trees and highlighted the need for additional investigations about cacao-AFS structure and diversity (Tscharntke et al. 2011; Deheuvels et al. 2012; Bieng et al. 2013).

Botanical composition and structural diversity in cacao-AFS are unique in each system, although some vegetation patterns can be found and structural types can be differentiated (Deheuvels et al. 2012). This heterogeneity varies according to technical recommendations, natural regeneration, seeding availability, social behavior, species economical value, management capacity and specific practices. In the Brazilian Amazon, specifically in southern Pará, cacao has been cultivated typically under native shade trees (Schroth et al. 2016). The association of some factors—international market, environmental policies and environmental conditions—increased cultivation of cacao in the last decades (Schroth et al. 2016).

At São Félix do Xingu, a municipality where deforestation was among the higher rates in Brazil at middle 2000s, the cacao-AFS is highlighted because of its potential of forest conservation. Besides, it is an important crop for rural economy and as livelihood alternative to family farming smallholders (Schroth et al. 2016). After cacao begins to produce, management practices are adopted for the crop establishment, changing shade trees composition. However, the species selection may be not appropriate to AFS long-term maintenance, or not favorable to native trees. There is no scientific record of shade tree species composition and diversity in cacao-AFS in this study site. The objective of the study was to understand the transition of tree species composition and diversity in cacao-AFS, considering native or exotic, and if this composition could support a shade tree succession that guarantees the maintenance of AFS. We hypothesized that: (1) initial and secondary shade have low floristic similarity; (2) secondary shade has greater species richness and diversity than initial shade, and (3) composition of secondary shade has few late successional species. We also described the potential use of these species and some management recommendations.

Methods

Study area

The municipality of São Félix do Xingu (Fig. 1) is located in southern Pará, Brazil (06°38′41″South and 51°59′42″West). As described by Schroth et al. (2016), the massive deforestation and economic development of this region started around the 1990s, after the arrival of roads and cattle ranching. At 2011, most of cacao plantations were young and not productive, indicating the recent crop expansion (Schroth et al. 2016). The study site comprises the Tancredo and Xadá cacao growing regions, cultivated mainly by smallholder's family farmers, where livestock is the most important rural activity. Vegetation is of the Amazon rainforest, classified as tropical moist forest, dense upland forest, including open forest.

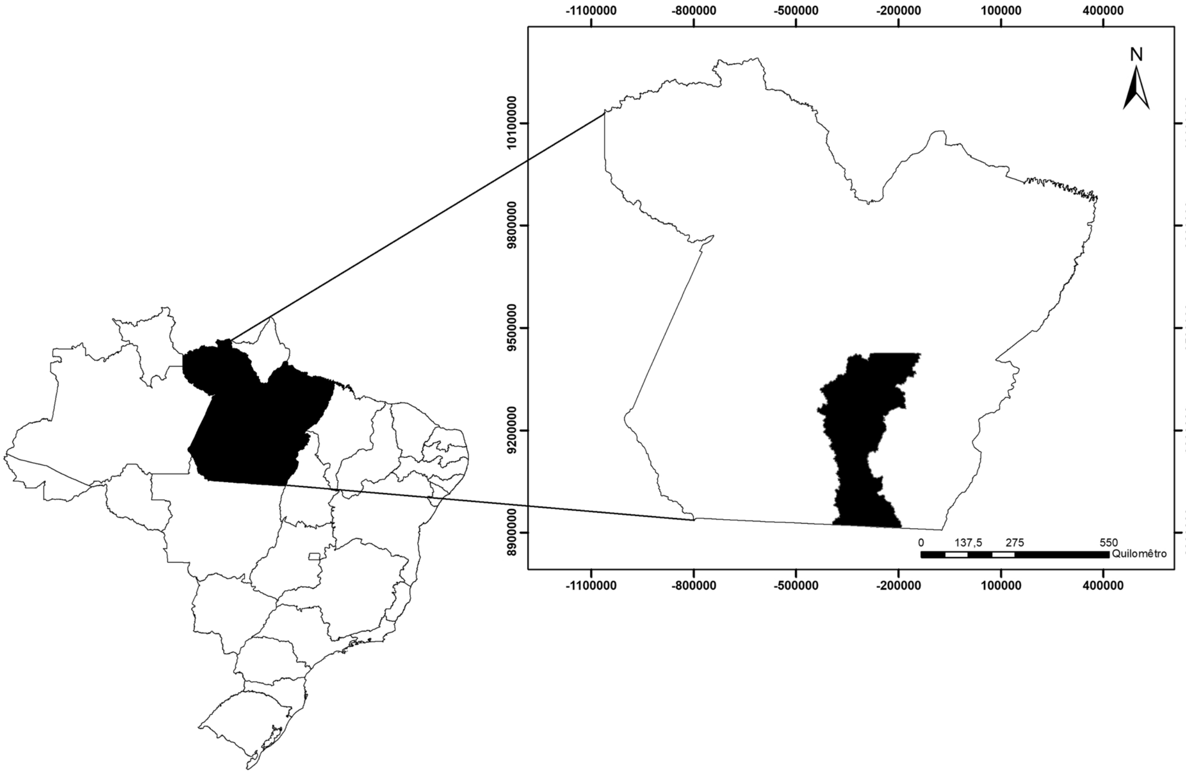

Fig. 1 São Felix do Xingu municipality, state of Pará, Brazil

According to IBGE (2002), the climate is warm moist equatorial with three dry months. According to São Félix do Xingu conventional meteorological station data, since 2003–2013, the area recorded around 2000 mm of annual rainfall, minimum and maximum temperatures of 16.4 and 36 °C, respectively, and 25.4 °C in average.

Fig. 2 Cacao-AFS IS, 3 years old

Land use descriptions and shade management

Cacao-AFS Initial Shade (IS): The sites have cacao trees of 3–5 years old (Fig. 2), planted after 3–13 years of pasture, with cacao intercropped with other annual crops, such as maize and cassava, and semi-perennial crops, as banana and papaya. After the third year, when cacao started to produce, the farmers reduce banana and papaya density and start to manage the natural regeneration for shade. When the natural regeneration is higher than cacao, generally after 5 years, they start to remove the perennial crops and let selected trees grow, initiating the next shade phase.

Cacao-AFS Secondary Shade (SS): The sites have cacao trees of 6–13 years old (Fig. 3), some planted after 4 years of annual crops use, others after 3–15 years of pasture use. Secondary shade is the second phase of cacao-AFS strategy management, composed of natural regeneration of young native shade trees. These trees are not economically exploited and are irregularly distributed.

Fig. 3 Cacao-AFS SS, 13 years old

Sampling and data collection

The described management and environmental conditions can be found in cacao growing landscape of southern Pará. Sampling choices considered Somarriba et al. (2001), with adaptations for the approach of this research and according to study site conditions. Shade management was distinguished in IS and SS, characterized by cacao age and botanical composition, considering the predominance of banana/papaya or trees/palms. Data was collected during September–November 2012. It was sampled IS and SS in areas indicated by farmers and local technicians. Cacao sites use to have 1–5 ha and the data on vegetation composition and diversity were collected in plots of 10 × 100 m, oriented according to the shape of each site. Two sample plots were installed inside each site, at least 15 m far from the site edge, in a total of 5 sites for IS and 5 sites for SS. All shade trees individuals with circumference at the breast height (CBH) $\geq$ 15 cm were considered. It was collected herbarium specimens for further identification, which were done at "Emilio Goeldi Museum" and checked at Flora do Brasil 2020 (2014) and SpeciesLink (2014) Virtual Herbarium websites.

Interviews with farmers were made to obtain information about management practices, species use, commercialization and biological behavior. Associated to this, secondary data and field notes were used to categorize species by: (1) successional behavior: early; late and; early–late (species with fast growing in open sites and long life, which occurs in early succession and can keep to late succession); (2) products: fruit, timber, oil, medicinal and charcoal and; (3) services: nitrogen fixing and fauna attractive (zoochoric plants).

Analysis

PAST 3 software was used to generate diversity analysis (rarefaction curve, Species richness (S) and Chao, Shannon (H′), Pielou (J′) and Sorensen indexes). The R 3.1.1 with Vegan package was used for dissimilarity index and cluster analysis (applying vegdist function and chao index as method) and Microsoft Excel 2013 to manage worksheet, tables and graphic editions, such as venn diagram for species richness and curves of relative abundance of species by systems. It was calculated the index of importance value (IVI), which includes relative density (Dr), relative frequency (Fr) and relative dominance by basal area (Dor).

Results

In the area sampled (20,000 m^2), it was inventoried a total of 1238 plants from 71 species in 26 identified families (CBH $\geq$ 15 cm), being 440 trees and the remaining 818 of *Musa* sp. and *Carica papaya* (Table 1). Out of the total number of the species, it was identified 7 species (10%) only to genus and 15 species (21%) to morphospecies level. The highest total species richness belongs to the families: Fabaceae (18 species/66individuals), Moraceae (5/26), Meliaceae (4/10), Euphorbiaceae (3/8), Arecaceae (3/3) and Sapotaceae (3/18). The other families are represented just by one or two species (Table 1).

The most abundant families (> 50 individuals) are represented only by one species: Musaceae (*Musa* sp.), Caricaceae (*Carica papaya*), Urticaceae (*Cecropia* sp.) and Cannabaceae (*Trema micrantha*). The first two occurred just in IS, and the other two occurred in both systems (Table 1).

Identified families in IS were 15 of which the greater relative species richness belongs to Fabaceae (19.23%) and Meliaceae (7.69%), while the greater relative abundance belongs to Musaceae (50.08%), Caricaceae (24.55%) and Cannabaceae (5.66%). Identified families in SS were 22 and represents an increase of 47%, with greater relative species richness in Fabaceae (31.58%) and Moraceae (8.77%), while the greater relative abundance were shown by Urticaceae (24.19%), Fabaceae (21.77%) and Rhamnaceae (8.06%).

Table 1 Number of species (S) and individual abundance (A) of botanical families for IS, SS and total

Family	Total		IS		SS	
	A	S	A	S	A	S
Fabaceae	66	18	12	5	54	18
Moraceae	26	5	18	1	8	5
Meliaceae	10	4	8	2	2	2
Euphorbiaceae	8	3	1	1	7	3
Arecaceae	3	3	1	1	2	2
Sapotaceae	18	3	0	0	18	3
Hypericaceae	12	2	1	1	11	1
Malvaceae	9	2	1	1	8	2
Rutaceae	4	2	0	0	4	2
Sapindaceae	2	2	0	0	2	2
Anacardiaceae	9	1	9	1	0	0
Annonaceae	1	1	0	0	1	1
Apocynaceae	1	1	0	0	1	1
Bignoniaceae	14	1	5	1	9	1
Cannabaceae	57	1	56	1	1	1
Caricaceae	243	1	243	1	0	0
Clusiaceae	1	1	0	0	1	1
Ebenaceae	9	1	0	0	9	1
Lauraceae	1	1	0	0	1	1
Lecythidaceae	5	1	0	0	5	1
Melastomataceae	1	1	0	0	1	1
Musaceae	575	1	575	1	0	0
Myrtaceae	20	1	2	1	18	1
Rhamnaceae	20	1	0	0	20	1
Rubiaceae	1	1	1	1	0	0
Urticaceae	103	1	43	1	60	1
NI	19	11	14	6	5	5
Total	1238	71	990	26	248	57

Families in descending order of total richness

Floristic composition and species abundance could distinguish IS from SS (Fig. 4). The majority of plots in IS was close grouped by these variables, presenting some homogeneity, while SS were more diverse and heterogeneous. Nevertheless, there were two IS plots (belonged to same site) which had these similarity variables far from the other IS plots. These were the only IS plot management without *Musa* sp. and with higher abundance of *Carica papaya.*

Diversity, richness and equitability were greater in SS than IS (Table 2), besides SS had greater probability for greater species numbers if more individuals were sampled than IS (Fig. 5). Two species (C. *papaya* and *Musa* sp.) were restricted to IS and they greatly influenced this system by the high proportion of individuals).

Exclusive species number in SS were almost three times greater than IS (Fig. 6), while only 12 species occurred in both systems (17% of total richness): *Handroanthus serratifolius* (Vahl) S.Grose; *Psidium guajava* L.; *Apuleia leiocarpa* (Vogel) J.F. Macbr.; *Cassia fastuosa* Willd. ex Benth.; *Ceiba pentandra* (L.) Gaertn.; *Croton urucurana* Baill.; *Maclura tinctoria* (L.) D. Don ex Steud.; *Senegalia polyphylla* (DC.) Britton & Rose; *Senna multijulga* (Rich.) H.S. Irwin & Barneby; *Zanthoxylum rhoifolium* Lam.; *Trema micrantha* (L.) Blume and *Cecropia* sp.

The most important species (IVI $\geq$ 10) also varied in both systems (Table 3), where *Cecropia* sp. was the only one which occurred in both. The *Musa* sp. occurs only in IS plots and is remarkably the most important specie, mainly because of its high abundance and dominance values. Except *Handroanthus serratifolius* (Vahl) S.Grose and *Pouteria macrophylla* (Lam.) Eyma, the higher values of IVI does not include late successional species.

The relative abundance curves (Fig. 7) show that both communities had few species with high number of individuals, whereas the majority of species occurred in low densities. Therefore, curves comparison show the diversity difference between IS and SS systems.

The majority of species were native from the regional Amazon forest, only 3 were considered as exotic (Table 4), where IS and SS had 89/17 and 98/93% of richness/abundance with native species, respectively. Early, early–late and late successional behaviors of identified species represented 55, 25 and 20% in IS and 48, 10 and 42% in SS, respectively (Table 5).

For both systems, the main potential products were fruit and timber, followed by charcoal and medicinal use (Table 6). In IS the species were well distributed by product, representing almost the same proportion, except by oil. Of the SS identified species, 16, 21 and 10% can provide fruits, timber and charcoal, while only 8 and 2% species can provide medicinal and oil products, respectively. Both systems had around 50% of their identified species to fauna attractive function,

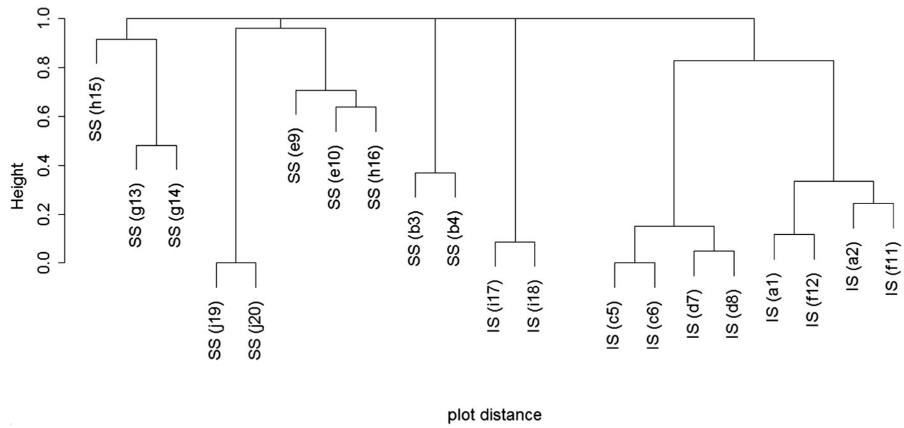

Fig. 4 Dissimilarity matrix of floristic composition (Chao index) by clusters of each plot (numbers) per site (letters "a" to "j"), considering 10 plots in IS and 10 plots in SS

Table 2 Diversity comparison between IS and SS. Species richness (S), Chao index, Shannon index (H′), Pielou index (J′) and Sorensen index

	IS	SS
S	27	57
Chao-1	31.50	81.00
H′	1.35	3.18
J′	0.41	0.79
Sorensen	0.289	

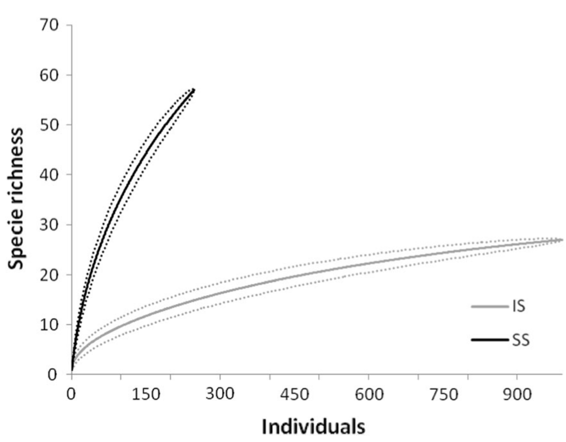

Fig. 5 Species accumulation curves (95% confidence) of cacao agroforestry with initial shade (IS) and secondary shade (SS)

although SS has 9% N-fixing species, while IS had only 3%.

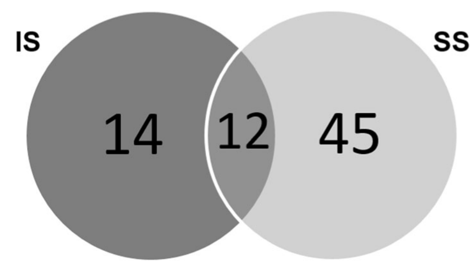

Fig. 6 Shared shade trees species found in cacao-AFS (IS and SS)

Discussion

Our results highlight the differences between two cacao-AFS (IS and SS) that are the result of management practices adopted by farmers. It was found that cacao-AFS can be distinguished by its shade trees composition and diversity in two successional phases (IS and SS), which were characterized by management strategies. The results are in accordance with related literature about cacao-AFS in tropical forests of America. In Central America and Mexico, Shannon diversity index (H′) and species richness (S) varied 0.8–2.99 and 22–104 (Salgado-Mora et al. 2007; Deheuvels et al. 2012). In Amazon and Atlantic Forest biomes, there are AFS's with variation of number of families (11–45), S (13–180), H′ (1.37–2.73) and Pielou equitability (J′) (0.44–0.79) (Santos et al. 2004; Sambuichi and Haridasan 2007; Vebrova et al. 2014). In terms of forest comparison, available literature in São Félix do Xingu and surrounding regions, showed tree species richness varying from 85 to 433, diversity (H′) between 3.66 and 5.28 and equability (J′) in rang

Table 3 Most important species (IVI ≥ 10) (descending order) in IS and SS. Relative density (Dr), relative frequency (Fr), relative dominance by basal area (Dor) and index of importance value (IVI)

Species	Sucessional behavior	Dr (%)	Fr (%)	Dor (%)	IVI (%)
IS					
Musa sp.	Early	58	17	88	163
Carica papaya L.	Early	25	10	5	40
Trema micrantha (L.) Blume	Early	6	9	1	15
Cecropia sp.	Early	4	9	1	14
SS					
Cecropia sp.	Early	24	6	17	46
Colubrina glandulosa Perkins	Early	8	2	15	25
Psidium guajava L.	Early	7	4	4	15
Pouteria macrophylla (Lam.) Eyma	Late	6	6	3	14
Schizolobium parahyba var. amazonicum (Huber ex Ducke) Barneby	Early	1	2	8	12
Vismia baccifera (L.) Triana & Planch.	Early	4	2	4	11
Handroanthus serratifolius (Vahl) S.Grose	Late	4	3	3	10

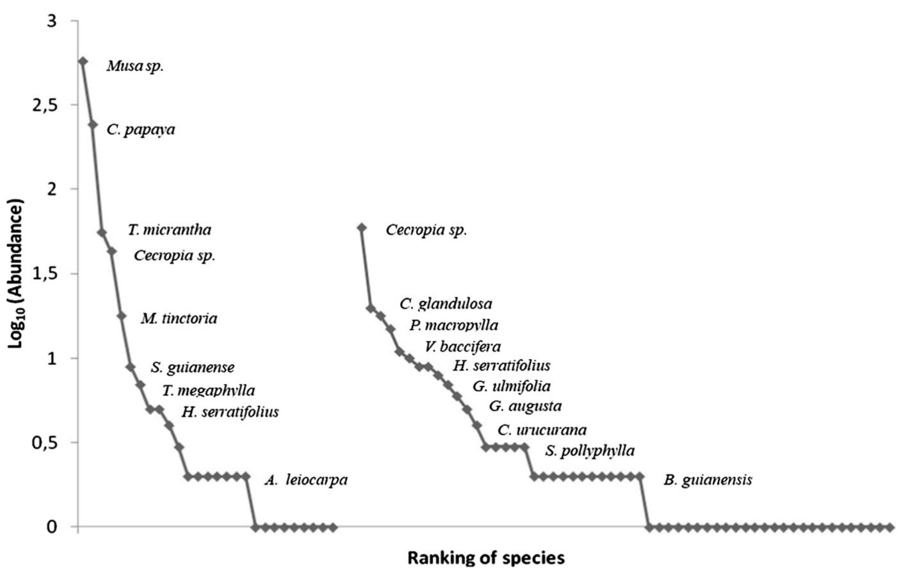

Fig. 7 Relative abundance curves for shade tree species found in IS (left) and SS (right)

of 0.79–0.91 (Salomão et al. 1998, 2007; Ribeiro et al. 1999; Carneiro et al. 2012).

In IS, diversity index and rarefaction curve were strongly influenced by the high abundance of *Musa* sp. and *Carica papaya*, representing 58 and 24% of total abundance in this system. Pielou equitability index (J′) confirms this result: SS had almost double the value of IS. Even though, simulations without these two species do not change the results of greater diversity of SS. Banana and papaya are not woody but have the important function to provide shade to cacao plants during the first years, while giving income to farmers. Deheuvels et al. (2012) described some cacao-AFS categories for Costa Rica, including a differentiation to systems with high *Musa* sp. density, which looks similar to IS system in the study.

Table 4 Species composition and abundance by IS and SS

Species	Family	IS	SS	Native	SB	PP	Serv.
Annona exsucca DC.	Annonaceae		1	N	Late	F; T	FA
Apuleia leiocarpa (Vogel) J.F. Macbr.	Fabaceae	2	1	N	Late	T	–
Astrocaryum aculeatum G.Mey.	Arecaceae		1	N	Late	F; O	FA
Astrocaryum vulgare G. Mey.	Arecaceae		1	N	Late	F; O	FA
Bagassa guianensis Aubl.	Moraceae		2	N	Early	F; T	FA
Bauhinia cupulata Benth.	Fabaceae		3	N	Early	C; M	–
Bauhinia sp.	Fabaceae		8	N	Early	C	–
Brosimum acutifolium Huber	Moraceae		2	N	Late	M	FA
Carica papaya L.	Caricaceae	243		E	Early	F; M	FA
Cassia fastuosa Willd. ex Benth.	Fabaceae	5	2	N	Early	T; M	–
Cecropia sp.	Urticaceae	43	60	N	Early	M	FA
Ceiba pentandra (L.) Gaertn.	Malvaceae	1	1	N	Early–late	T	–
Cenostigma tocantinum Ducke	Fabaceae		1	N	Early–late	T	–
Chrysophyllum cuneifolium (Rudge) A. DC.	Sapotaceae		2	N	Late	T; F	FA
Colubrina glandulosa Perkins	Rhamnaceae		20	N	Late	T	FA
Croton urucurana Baill.	Euphorbiaceae	1	4	N	Early	M	–
Cupania latifolia Kunth	Sapindaceae		1	N	Late	T	FA
Diospyros carbonaria Benoist	Ebenaceae		9	N	Late	C	FA
Erythrina verna Vell.	Fabaceae		3	N	Early	M	FA; N
Ficus sp.	Moraceae		1	N	Late	C; T	FA
Garcinia brasiliensis Mart.	Clusiaceae		1	N	Late	F	FA
Genipa americana L.	Rubiaceae	1		N	Early–late	F	FA
Guarea guidonia (L.) Sleumer	Meliaceae	1		N	Early–late	M; T	FA
Guazuma ulmifolia Lam.	Malvaceae		7	N	Early	C; F; M	FA
Gustavia augusta L.	Lecythidaceae		5	N	Late	T	FA
Handroanthus serratifolius (Vahl) S.Grose	Bignoniaceae	5	9	N	Late	T; M	FA
Inga bourgonii (Aubl.) DC.	Fabaceae		1	N	Early	F	FA; N
Inga edulis Mart.	Fabaceae		3	N	Early	F	FA; N
Inga laurina (Sw.) Willd.	Fabaceae		1	N	Early	F	FA; N
Inga sp.	Fabaceae		3	N	Early	F	FA; N
Lacmellea arborescens (Müll. Arg.) Markgr.	Apocynaceae		1	N	Late	C	FA
Maclura tinctoria (L.) D. Don ex Steud.	Moraceae	18	1	N	Early–late	F	FA
Margaritaria nobilis L.f.	Euphorbiaceae		2	N	Early	T	–
Mauritia flexuosa L.f.	Arecaceae	1		N	Late	F	FA
Metrodorea flavida K. Krause	Rutaceae		2	N	Late	T	–
Musa sp.	Musaceae	575		E	Early	F	FA
Perebea guianensis Aubl.	Moraceae		2	N	Late	T	FA
Persea sp.	Lauraceae		1	N	Late	T	FA
Pouteria macrophylla (Lam.) Eyma	Sapotaceae		15	N	Late	F	FA
Pouteria pariry (Ducke) Baehni	Sapotaceae		1	N	Late	F; T	FA
Psidium guajava L.	Myrtaceae	2	18	E	Early	F	FA
Samanea tubulosa (Benth.) Barneby & J.W.Grimes	Fabaceae		1	N	Early–late	F	FA; N
Sapium glandulosum (L.) Morong	Euphorbiaceae		1	N	Early–late	T	–
Schizolobium parahyba var. *amazonicum* (Huber ex Ducke) Barneby	Fabaceae		3	N	Early	T	–
Senegalia polyphylla (DC.) Britton & Rose	Fabaceae	2	2	N	Early	C	N
Senna multijuga (Rich.) H.S. Irwin & Barneby	Fabaceae	2	2	N	Early	C	–
Spondias mombin L.	Anacardiaceae	9		N	Early–late	F; M; T	FA
Stryphnodendron guianense (Aubl.) Benth.	Fabaceae		10	N	Early	T	FA; N

Table 4 continued

Species	Family	IS	SS	Native	SB	PP	Serv.
Stryphnodendron sp.	Fabaceae		2	N	Early	–	N
Swietenia macrophylla King	Meliaceae	7		N	Late	T	–
Talisia megaphylla Sagot ex Radlk.	Sapindaceae		1	N	Late	T	FA
Trema micrantha (L.) Blume	Cannabaceae	56	1	N	Early	M; C	FA
Vismia baccifera (L.) Triana & Planch.	Hypericaceae		11	N	Early	C	FA
Vismia sp.	Hypericaceae	1		N	Early	–	FA
Zanthoxylum rhoifolium Lam.	Rutaceae		2	N	Early	T	FA
Zanthoxylum sp.	Rutaceae	1	6	N	Early	–	FA
NI_2	Meliaceae		1	N	–	–	–
NI_3	Unknown		1	N	–	–	–
NI_4	Unknown		1	N	–	–	–
NI_5	Unknown		1	N	–	–	–
NI_6	Unknown		1	N	–	–	–
NI_7	Unknown		1	N	–	–	–
NI_10	Unknown	4		N	–	–	–
NI_11	Unknown	2		N	–	–	–
NI_12	Unknown	2		N	–	–	–
NI_13	Unknown	2		N	–	–	–
NI_14	Unknown	1		N	–	–	–
NI_15	Unknown	3		N	–	–	–
NI_18	Fabaceae		2	N	–	–	–
NI_19	Meliaceae		1	N	–	–	–
NI_20	Melastomataceae		1	N	–	–	–

Native (N) or exotic (E). Succession Behavior (SB). Potential Products (PP): Fruit (F); Timber (T); Oil (O); Charcoal (C); Medicinal use (M). Services (Serv.): Fauna attractive (FA); N fixing (N)

The "–" symbol in the "SB" column indicates the lack of classification because the individuals are not identified at the species level. In column "PP" indicates that the species do not offer the categorized potential products. In the "Serv." column, it indicates that the species do not offer the categorized services

Greater species richness and diversity of SS in association with low floristic similarity by the two systems show the potential transition from IS to SS in this kind of cacao-AFS management. The most abundant (> 50 individuals) and rich (> 2 species) botanical families found in IS were distinct from SS, except by Fabaceae, which is the main family represented for both systems. *Cecropia* sp., a fast sunlight growing species, short life span, small shade and big leaves (farmers complain about its leaves because when they fall are held in cacao branches), was the most common species occurring in both systems, which shows that management practices are necessary for the maintenance of AFS in near future.

Table 5 Number of individuals and sucessional behavior in IS and SS

Cacao-AFS	Early	Early–late	Late
IS	11	5	4
SS	23	5	20

The floristic composition and species abundance heterogeneity of SS (Fig. 4) can be related to the greater variation of management practices adopted by farmers in this phase than in IS. As observed in Souza et al. (2012), the variation in floristic composition among sites indicates greater gamma-diversity in SS than IS. This diversity is composed predominantly of native trees, of which percentage abundance improves almost 6 times from IS to SS, indicating AFS's importance for native species conservation and maintenance of local knowledge about native plants, once farmers are keeping them instead of being replaced by

Table 6 Number of species per products and services categories in IS and SS

Cacao-AFS	Fruit	Timber	Oil	Medicinal	Charcoal	Zoocoric	N-fixing
IS	5	6	0	7	3	13	1
SS	15	20	2	8	10	33	9

exotic species, a contradictory result reported by Thijs et al. (2015).

More than half of identified species belonged to early successional group in SS and it can be recommend shifting them to late successional species, not only in order to increase the conservation potential (Valencia et al. 2016), but also for long term maintenance of the cacao crop. This shift should occur gradually and carefully, selecting species appropriate to cacao crop, taking into consideration the growing architecture until their functionality, services and products. Of the two services listed, both systems were well represented by fauna attractive shade trees, but had few N-fixing species richness and abundance, which would be important to improve cacao yields (Bos et al. 2007; Dechert et al. 2005).

Cacao-AFS has great potential to conserve floristic diversity, mainly with management practices improvement (Deheuvels et al. 2012), generating social and environmental benefits in synergy with crop production (Frazen and Mulder 2007; Clough et al. 2011; Schroth et al. 2016). As shown by literature, well-planned shade trees do not negatively influence cacao yield and, depending on management, it is possible to improve net income or other economic benefits (Bos et al. 2007; Somarriba and Beer 2011; Utomo et al. 2015; Vanhove et al. 2016; Jagoret et al. 2017). Besides, shade trees play an essential role in nutrient cycling (Hartemink 2005; Asase and Tetteh 2016), pest and disease control (Schroth et al. 2000; Sperber et al. 2004; Bos et al. 2007), biomass production and carbon stocks (Saj et al. 2013; Somarriba et al. 2013; Abou Rajab et al. 2016; Silatsa et al. 2016; Asase and Tetteh 2016).

Considering that species richness and diversity are related to those services (Hooper 1998) and the shade tree composition found in São Félix do Xingu, it is strongly recommended the proper species selection and its strategic spatial distribution, with high diversity of shade trees. Based on farmers report and secondary data (about tree species architecture and its products and services) there are some native species which could be adequately used to compose cacao-AFS from secondary shade to the next phase of shade. These are: *Apuleia leiocarpa* (Vogel) J.F. Macbr., *Bagassa guianensis* Aubl., *Pouteria macrophylla* (Lam.) Eyma, *Erythrina verna* Vell., *Pouteria pariry* (Ducke) Baehni, *Chrysophyllum cuneifolium* (Rudge) A. DC., *Perebea guianensis* Aubl., *Spondias mombin* L., *Colubrina glandulosa* Perkins, *Cenostigma tocantinum* Ducke, *Annona mucosa* Jacq., *Handroanthus serratifolius* (Vahl) S.Grose, *Inga edulis* Mart. and *Samanea tubulosa* (Benth.) Barneby & J. W. Grimes.

Besides *Cecropia* sp., other species should have their population reduced (not necessarily eliminated) during SS to prepare the cacao-AFS to the next shade phase and these are: *Psidium guajava* L.; *Cassia fastuosa* Willd. ex Benth.; *Croton urucurana* Baill.; *Senegalia polyphylla* (DC.) Britton & Rose; *Senna multijulga* (Rich.) H.S. Irwin & Barneby; *Vismia baccifera* (L.) Triana & Planch. and *Trema micrantha* (L.) Blume.

Potential products offered by shade trees can be important for income diversification, promoting greater economic security for farmers (Tscharntke et al. 2011; Ofori-Bah and Asafu-Adjaye 2011; Sonwa et al. 2014). In our systems, we identified five products that can be currently harvested, mainly timber and fruits, 45 and 36% of total identified species, respectively. The first one has high economic value added, but financial return comes in medium to long term. For this purpose, tree harvest has to be well thought, aiming to reduce the impacts on cacao crop. In the other hand, fruit trees can be permanently on the site and provide products once or twice annually.

Due to the multiple socioeconomic and environmental benefits that AFS-cacao offers, it could have an important role to biodiversity conservation when used as a tool for rehabilitation of deforested lands in southern Pará, as showed by Schroth et al. (2016). Incentives should be addressed, mainly to smallholders, to stimulate the important role of shade trees in cacao-AFS for biodiversity conservation and other services, creating a program backed by stakeholders and government to finance payment for ecosystem services for sustainable cacao production (Rice and Greenberg 2000; Clough et al. 2009; Somarriba et al. 2013).

Conclusions

This study contributes to describing management strategies, focused on successional transition of shade trees used for cacao-AFS in southern Pará, which are similar to other cacao growing regions in Eastern Amazon. The findings reinforce the different classification for cacao production systems and suggest a successional management strategy, based on composition and phytosociological aspects of shade trees, according to cacao-AFS age. In the beginning (IS), the majority of shade tree individuals belongs to few species, which will leave the system in the next phase (SS).

Cacao-AFS is able to hold high diversity of shade trees, presenting an increase of richness and diversity, besides a clear transition in its species composition, from IS to SS. Despite this transition, some management practices are still needed to guarantee the shade tree succession and maintenance of cacao crop. Early successional species are predominant in IS, but also have an expressive presence in SS, while late successional species become more common in SS. The potential of shade trees to provide products and services could be improved by management practices for economic diversification. It is strongly recommend technical capacity building programmes and extension services for shade tree management and long-term successional planning of cacao-AFS.

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