Revista Brasileira de Agroecologia

v. 17 n. 3 (2022)
ISSN 1980-9735
Publicado em 30 de setembro de 2022
https://doi.org/10.33240/rba.v17i3.23546

DIVERSITY AND BASAL AREA OF AGROFORESTRY SYSTEMS IN SOUTHEAST REGION OF THE ATLANTIC FOREST BIOME

Diversidade e área basal de sistemas agroflorestais no sudeste do bioma Mata Atlântica .

Fernanda Campos de Paulo[1], Klécia Gili Massi[2]

[1] Discente no Departamento de Engenharia Ambiental da Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia, São José dos Campos, Brazil. [2]Mestranda em *Agricultural Environmental Management Engineering* na *University of Debrecen* (Unideb), *faculty of Agricultural, Food Sciences and Environmental Management*, Debrecen, Hungria, Orcid 0000-0002-3401-9100 e email fercpaulo@gmail.com

[2] Docente no Departamento de Engenharia Ambiental da Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia, Doutora em Ecologia pela Universidade de Brasília, São José dos Campos, Brazil. Orcid 0000-0003-1823-7965 e email klecia.massi@unesp.br

ABSTRACT

Current state of tropical forest degradation brings the need of alternatives for ecological restoration. Agroforestry systems (AFS) can be applied for the restoration of degraded areas and as an alternative to traditional agricultural practices, especially in biodiversity hotspots as the Atlantic Forest biome. Thus, we aimed to evaluate composition and basal area of twelve agroforestry sites in the southeast region of Atlantic Forest biome. We quantified species richness, Shannon diversity index, density and basal area of all AFS. We found 102 species, 2,164 individuals and 32 families in all AFS. Age of AFS did not influence richness, diversity, density, and basal area. In the AFS of this study, the designs led to differences in basal area, attributed to different densities and species diversity that composed them.

KEYWORDS: AFS, composition, structure, restoration.

RESUMO

O estado atual de degradação da floresta tropical traz a necessidade de alternativas para a restauração ecológica. Os sistemas agroflorestais (SAF) podem ser aplicados para a restauração de áreas degradadas e como alternativa às práticas agrícolas tradicionais, principalmente em *hotspots* de biodiversidade como o bioma Mata Atlântica. Dessa forma, objetivou-se avaliar a composição e área basal de doze sítios agroflorestais da região sudeste do bioma Mata Atlântica. Quantificamos a riqueza de espécies, o índice de diversidade de Shannon, a densidade e a área basal de todos os SAF. Encontramos 102 espécies, 2.164 indivíduos e 32 famílias em todos os SAF. A idade do SAF não influenciou a riqueza, diversidade, densidade e área basal. Nos SAF deste estudo, os desenhos de plantio levaram a diferenças na área basal, atribuídas às diferentes densidades e diversidade de espécies que os compunham.

Palavras Chaves: SAF, composição, estrutura, restauração.

COMO CITAR; PAULO, Fernanda C., MASSI, Klécia G. DIVERSITY AND BASAL AREA OF AGROFORESTRY SYSTEMS IN SOUTHEAST REGION OF THE ATLANTIC FOREST BIOME . **Revista Brasileira de Agroecologia**, v. 17, n. 3, p. 122 – 137, 2022. ISSN: 1980-9735. DOI: https://doi.org/10.33240/rba.v17i3.23546.

INTRODUCTION

The Atlantic Forest biome is a *hotspot* for biodiversity conservation (MYERS et al., 2000) with only 13 percent of its vegetation cover left in Brazil (SOS MATA ATLÂNTICA/INPE, 2018). Most of the deforestation in this biome happened in the first half of 19th century (DEAN, 1996). More recently, some portions of the Atlantic Forest landscape are increasing forest cover, mostly over former areas of degraded pastures, indicating that land abandonment and consequent forest natural regeneration is a phenomenon observed in this region (SILVA et al., 2017). The forest transition tends to occur in areas less suitable for agriculture, but socioeconomic drivers (social development, farmer credit, policies, and laws) play important roles in forest recovery (SILVA, BATISTELLA e MORAN 2016). In sites that are more suitable for agriculture, restoration techniques that could contribute to settling people in rural areas and at the same time promote vegetation recomposition are much needed.

Ecological restoration is “the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed” (SER, 2004). Active and passive restoration are two important strategies to aid the recovery of large areas of deforested and degraded tropical lands (MORRISON e LINDELL, 2010). Agroforestry systems (AFS) can be considered an active restoration technique, based on linking crop production and tree planting (PALUDO e COSTABEBER, 2012) applied to degraded land recovery and also as an alternative for conventional agriculture (ABDO, VALERI e MARTINS, 2008). Agroforestry systems encompass a wide variety of production systems using, at least, one woody component: (i) some are very simple in structure, with only two or three components and by that, demanding higher technological levels and more inputs to maintenance of productivity levels; (ii) others are very complex systems, like the multi-strata successional systems, which mimic natural succession and resembles to a forest structure (e. g. //www.embrapa.br/codigo-florestal/sistemas-agroflorestais-safs).

Agroforestry systems have the potential to provide fragment connections, enhance biodiversity, and contribute to biological conservation (BHAGWAT et al., 2008; JOSE, 2012; KUPSCH et al., 2019; SANTOS et al., 2019). Agroforestry systems may also improve degraded areas through the system’s diversity of native trees and include species with potential for providing environmental services (MARTINELLI et al., 2019), such as carbon storage and biodiversity preservation. Carbon sequestration is one of the ecosystem services related to AFS (FELICIANO et al., 2018, MA et al., 2020). Moreover, agroforests enhance food security, especially for local farmers, contribute for climate change mitigation, having a positive impact on environmental and social scales, thus being an important subject to be addressed by global agendas (MBOW et al., 2014), and can also be economically viable (VIEIRA et al., 2009; CORDEIRO et al., 2018).

According to a recent study with small-scale farms in the Atlantic Forest biome, one of the three most common reasons for conventional agriculture farmers to not shift to agroforestry practices was the lack of models and knowledge in the region (SAGASTUY e KRAUSE, 2019). In tropical ecosystems, using native species in restoration projects might facilitate the return of biodiversity (RODRIGUES, BRANCALION e ISERNHAGEN, 2009). Despite some initiatives recommending regional lists of common species to be planted in restoration projects in Brazil and, especially, in São Paulo state (TNC, 2015; BARBOSA, 2017), it is advisable to follow, if possible, local flora as a reference to restore ecosystems. Some studies address important species to be used in tropical agroforestry systems such as *Cajanus cajan* (L.) Milps (BELTRAME e RODRIGUES, 2007).

Thus, in the perspective of a national regulation where recomposition is mandatory (Lei 12.561, BRASIL, 2012) and agroforests are a viable restoration technique for environmental debt areas (Legal Reserves, for example), of the UN Restoration Decade where revegetation efforts may increase (https://www.decadeonrestoration.org) and of Payment of Ecosystem Services projects targeting carbon sequestration (https://www.fao.org/3/ar584e/ar584e.pdf), among other benefits, this study addresses important questions regarding 12 agroforestry systems in the Paraiba do Sul River Valley, in the Brazilian Atlantic Forest Biome. We hypothesized that agroforestry systems in the region would have different compositions and basal areas and that would be related to AFS age and we aimed to evaluate (i) composition and basal area and (ii) whether age had an effect on richness, diversity, density, and basal area of AFS.

METHODS

The study was carried out in twelve AFS (AFS 1 to 4: São José dos Campos municipality: 23°04’57.01”S, 45°49’22.21”W; AFS 5 to 8: Roseira municipality: 22°55'03.1"S, 45°15'39.2"W; AFS 9 to 12: Pindamonhangaba municipality: 22°54’17.73”S; 45°23’14.56”W), São Paulo state, in the southeast region of Atlantic Forest biome (Figure 1). Climate is classified as dry-winter humid subtropical (Cwa), according to Köppen (PEEL, FINLAYSON e MCMAHON 2007), the average mean temperature is 22°C and the average annual precipitation is 1233.6 mm (from 1992 to 2014; data collected at Taubaté Station: (http://www.ciiagro.sp.gov.br/ciiagroonline/Listagens/MonClim/LMClimLocal.asp). The region has a hilly relief, located in between two mountain chains the Serra da Mantiqueira and the Serra do Mar. The predominant soil types are Oxisols and Ultisols (SSS, 1999).

The AFS 1 to 4 started as livelihood models, but changed with time and it is now a productive property, while AFS 5 to 12 are, from the beginning, productive properties that sell fruits, vegetables and other products in regional and local markets. Due to intense management, natural regeneration was not noticed in all sites.

Design of each AFS was presented in Figure 2. Agroforestry systems with different ages, structure, and composition were surveyed (Table 2). Generally, all AFS had less than 2 x 2 m spacing. Planting methods included tree seedlings and seeding of green manure species.

Between August and September 2018, we randomly established one 9 x 18 m transect in each AFS (162 m^2), according to the monitoring protocol of the Atlantic Forest Restoration Pact (RODRIGUES, BRANCALION e ISERNHAGEN, 2009). In the Paraíba do Sul River Valley, rural properties with agroforestry systems are small, generally each AFS not exceeded 50 x 50 m, most times 20 x 20 m, which impeded more transects to be randomness installed by AFS. All individuals (bigger than 3 cm of circumference) planted inside transects were identified and measured.

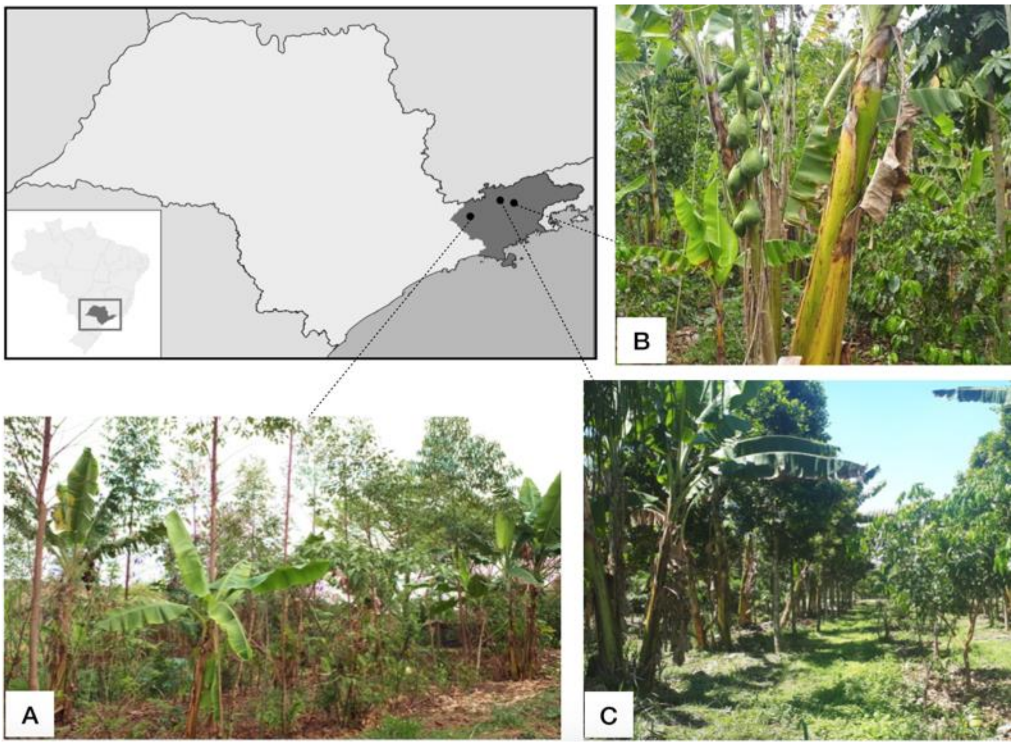

Figure 1. Location of the agroforestry systems (AFS) in southeast Brazil: AFS 1 to 4 in São José dos Campos (A), with a picture of AFS 4 (Eucalyptus sp and Musa sp.), AFS 5 to 8 in Roseira (B), with a picture of AFS 6 showing a papaya plant in the center, banana, and a coffee tree in the right and of AFS 9 to 12 in Pindamonhangaba (C), with a picture of AFS 12 with Calophyllum brasiliense Cambess (timber) and banana.

Source: Authors, 2021.

We surveyed species richness and abundance of individuals. We also measured circumference at soil height (CSH, in meters) of all plants, because some trees, shrubs, and subshrubs were not 1.3 high (for circumference at breast height). For plant family classification, we used the Angiosperm Phylogeny Group IV (APG IV, 2016) and Flora do Brazil List (each name was checked at http://floradobrasil.jbrj.gov.br/reflora/listaBrasil/ConsultaPublicaUC/ConsultaPublicaUC.do). We also classified species according to their main agricultural functions in AFS: fruit (F), native species (NS), green manure (GM), annual crop (AC), perennial crop (PC), exotic wood (W).

We calculated Shannon Diversity Index per AFS: $H = -\sum(n_i N^{-1}) ln(n_i N^{-1})$, ni= number of individuals of the species i, N = number of individuals of all species in a certain site. Basal area per species in each AFS (Supplementary Material) and per AFS was calculated as $BA = \sum CSH^2 4\pi^{-1}$. We grouped AFS sites by year, i.e., two sites were one year old, four sites were four years, three, were five years, two, were eight years, and one of then it was eleven years old. One-way analysis of variance (ANOVA) was used to find out whether the ages (divided in five classes of years: 1, 4, 5, 8, and 11 years old) of AFS had an effect on richness, diversity, density, and basal area. Statistical analyses were performed in R software version 3.5.0 (R Core Team, 2018).

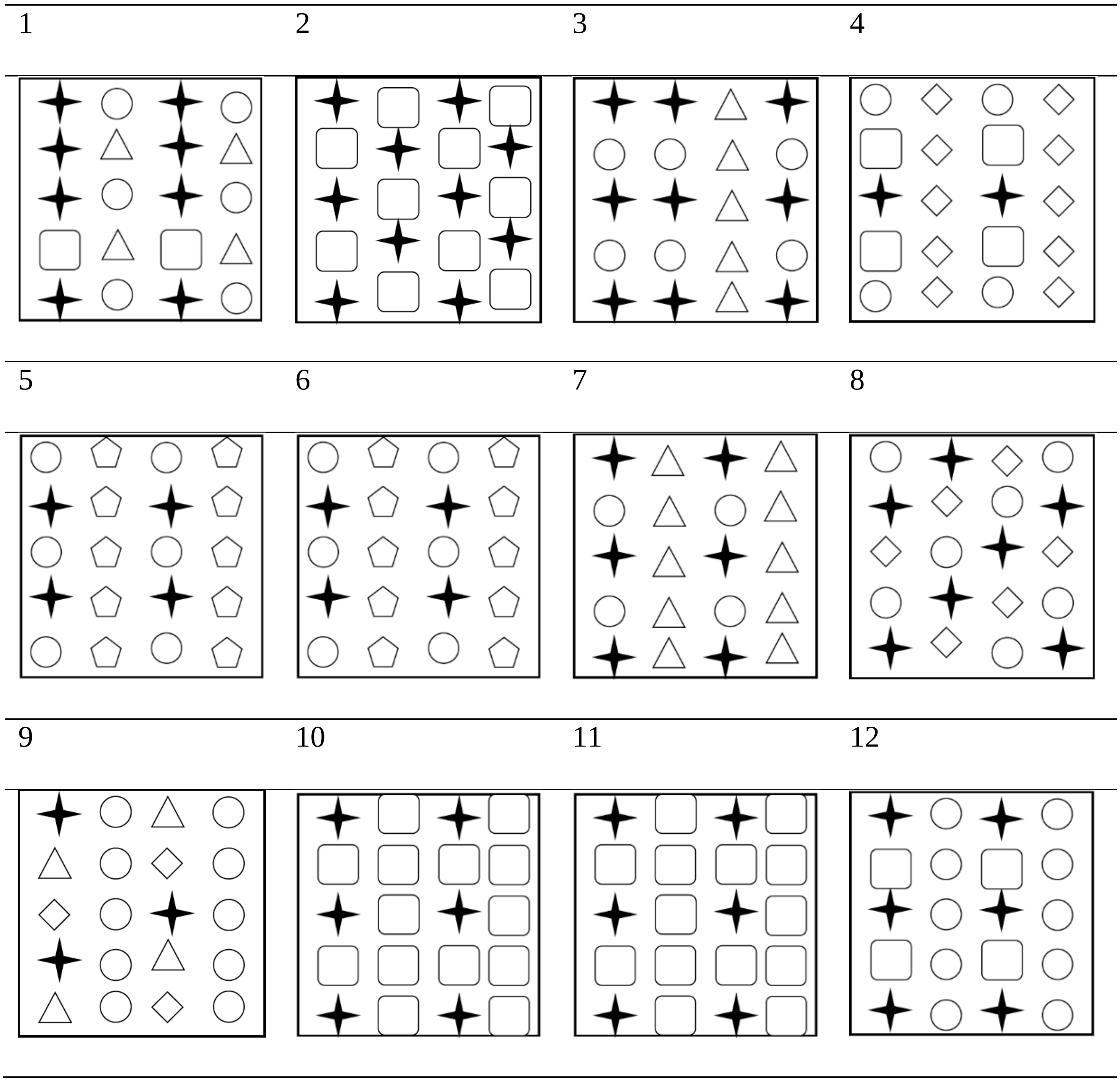

Figure 2. Planting design of Agroforestry systems (AFS 1 to 12). Star = fruit tree (F), square = native species (NS), circle = green manure shrub (GM), triangle = annual crop (AC), pentagon = perennial crop (PC), rhomb = exotic wood (W).

Source: Authors, 2021.

RESULTS AND DISCUSSION

We registered 2,164 individuals distributed in 102 species and 32 families in the twelve agroforestry systems (Table 1). The most abundant families were Fabaceae and Myrtaceae (each with 14 and 12 species, respectively), followed by Rutaceae, Arecaceae, and Euphorbiaceae (with five, four, and four species, respectively: Table 1). Most species were native of the Brazilian Flora (48) (FLORA DO BRASIL, 2018). *Cajanus cajan* (L.) Huth (673), *Musa* sp. (230), and *Flemingia* sp. (210) were the most abundant species (and genera). Fruits (especially *Musa* sp.) were present in all AFS, green manure and native species were found in almost every AFS (Table 1 and Figure 2).

Richness varied between seven (AFS 10) and 32 species (AFS 5); diversity, between 0.7 (AFS 9) and 2.8 (AFS 5); density, between 3,642 (AFS 2) and 46,728 individuals.ha^{-1} (AFS 9); basal area, between 4.01 (AFS 9) and 103.87 m^{2}ha^{-1} (AFS 11; Table 2).

Age of AFS did not influence richness (F=0.565, p=0.697), density (F=0.522, p=0.053), and basal area (F=1.859, p=0.222). On the other side, diversity was affected by the age of agroforestry systems (F=6.356, p=0.022, as presented in the Figure 3).

In agroforestry systems in the Paraiba do Sul River Valley, in the Brazilian Atlantic Forest Biome, there were a total of 102 species (and seven to 32 species per AFS). Our results showed that, opposed to expectations, age did not influence richness, density, and basal area of twelve agroforestry systems with different planting designs, but it did influence diversity. This indicates that both new and old agroforests might be interesting restoration models to increase species richness and biomass; it additionally indicates that higher biodiversity might be achieved later on time in these systems. In addition, studied AFS are productive systems under intense management that can be maintained in early stages, even with old ages.

The most abundant families, Fabaceae and Myrtaceae, have been registered as two of the most important woody families in the tropical forests (SARTORI et al., 2015), and in southeastern Brazil (LIMA et al., 2012), hence their use in forest restoration projects. It is also well known that Fabaceae plants grow faster than other families, produce great amounts of aboveground organic material, promoting soil chemical, physical, and biological recuperation, particularly if used as green manure crops when the whole plant is plowed down into the soil (SULTANI et al., 2007). Besides, some legumes are capable of biological N_2 fixation (SIDDIQUE et al., 2008). Additionally, fleshy fruits of Myrtaceae plants feed fauna, promoting ecological interactions and seed dispersal in the restored area (HOWE e SMALLWOOD, 1982; SILVA et al., 2015) and may foment economical use of native fruits, ornamentation, and medicinal species by local farmers in restoration projects (ABDO, VALERI e MARTINS, 2008).

Table 1. Species list, families, total number of individuals per species, according to agroforestry system (AFS) identification (1-12) and species group of agroforestry uses: fruit (F), native species (NS), green manure (GM), annual crop (AC), perennial crop (PC), exotic wood (W), and unknown (-).

Family	Species	Total	AFS	Species group
Anacardiaceae	*Astronium urundeuva (M. Allemão) Engl.*	1	8	NS
	Mangifera indica L.	3	3,8	F
	Schinus terebinthifolia Raddi	9	2,3,4,5,6,11,12	NS
Annonaceae	*Annona muricata* L.	5	1,3	F
	Annona squamosa L.	3	1,8	F
Arecaceae	*Archontophoenix cunninghamiana* (H.Wendl.) H.Wendl. & Drude	67	9,10	F
	Bactris gasipaes Kunth	7	5,8	NS
	Euterpe edulis Mart.	48	1,4,6,7,11,12	NS
	Euterpe oleracea Mart.	1	5	NS
Asteraceae	*Baccharis dracunculifolia* DC.	1	2	NS
	Tithonia diversifolia (Hemsl.) A.Gray	47	3,5,6,8	GM
	Vernonanthura polyanthes (Sprengel) Vega & Dematteis	9	1,3,4	NS
Bignoniaceae	*Handroanthus heptaphyllus* (Vell.) Mattos	5	7,11,12	NS
	Tabebuia roseoalba (Ridl.) Sandwith	1	8	NS
Bixaceae	*Bixa orellana* L.	58	4,11,12	NS
Bromeliaceae	*Ananas comosus* (L.) Merril	16	3,5	F
Calophyllaceae	*Calophyllum brasiliense* Cambess.	69	3,4,10,11,12	NS
Caricaceae	*Carica papaya* L.	31	6,7	F
Clusiaceae	*Garcinia gardneriana* (Planch. & Triana) Zappi	5	2,6,9	NS
	Garcinia mangostana L.	2	9	F
Cucurbitaceae	*Cucurbita* sp.	39	9	AC
Ebenaceae	*Diospyros kaki* L.f.	3	3	F
Euphorbiaceae	*Codiaeum variegatum* (L.) Rumph. ex A.Juss.	4	5	-
	Croton urucurana Baill.	1	11	NS

	Manihot esculenta Crantz	53	1,5,6,7	AC
	Ricinus communis L.	14	1,3,4	GM
Fabaceae	*Anadenanthera colubrina* (Vell.) Brenan	4	2,11,12	NS
	Bauhinia forficata Link	1	6	NS
	Cajanus cajan (L.) Huth	673	1,2,3,4,9	GM
	Centrolobium tomentosum Guillem. ex Benth.	10	6,8	NS
	Clitoria fairchildiana R.A.Howard	3	5	NS
	Erythrina sp.	6	4,11,12	NS
	Flemingia sp.	210	12	GM
	Gliricidia sepium (Jacq.) Kunth ex Walp.	31	4,5,7	GM
	Hymenaea courbaril L.	2	2	NS
	Inga laurina (Sw.) Willd.	1	5	NS
	Inga sp.	32	2,5,7,8,10,11,12	NS
	Piptadenia gonoacantha (Mart.) J.F.Macbr.	2	2,5	NS
	Schizolobium parahyba (Vell.) Blake	1	7	NS
	Tephrosia vogelii Hook.f.	57	1,3,5,6,7	GM
Lauraceae	*Cinnamomum cassia* (L.) J.Presl	2	2	-
	Persea americana Mill.	3	3,6,8	F
Lecythidaceae	*Cariniana estrellensis* (Raddi) Kuntze	3	8	NS
	Lecythis pisonis Cambess.	2	1	NS
Lythraceae	*Punica granatum* L.	1	6	F
Magnoliaceae	*Magnolia ovata* (A.St.-Hil.) Spreng.	1	12	NS
Malpighiaceae	*Byrsonima crassifolia* (L.) Kunth	1	5	NS
	Malpighia sp.	3	3	F
Malvaceae	*Ceiba speciosa* (A.St.-Hil.) Ravenna	2	2	NS
	Pachira aquatica Aubl.	2	6	NS
	Pseudobombax grandiflorum (Cav.) A.Robyns	9	4,11,12	NS
Meliaceae	*Khaya ivorensis* A.Chev.	42	2,8,9	W
	Melia azedarach L.	6	4	GM
Moraceae	*Morus nigra* L.	30	5,6,7	F
Musaceae	*Musa* sp.	230	1,2,3,4,5,6,7,8,10,11,12	F
Myrtaceae	*Campomanesia phaea* (O.Berg) Landrum	11	3,5,9	NS
	Eucalyptus sp.	21	4	W
	Eugenia brasiliensis Lam.	5	2	NS
	Eugenia involucrata DC.	2	8	NS
	Eugenia pyriformis Cambess.	1	1	NS
	Eugenia stipitata McVaugh	18	9,10,11	NS
	Eugenia uniflora L.	4	2	NS
	Myrciaria glazioviana (Kiaersk.) G.M.Barroso ex Sobral	1	8	NS

	Myrtaceae sp.	1	5	-
	Plinia edulis (Vell.) Sobral	6	10	NS
	Plinia peruviana (Poir.) Govaerts	2	4	NS
	Psidium guajava L.	17	3,4,5	NS
Poaceae	*Saccharum* sp.	3	2,3	AC
	Zea mays L.	13	3	AC
Polygonaceae	*Triplaris americana* L.	1	2	NS
Rubiaceae	*Coffea* sp.	74	5,6	PC
	Genipa americana L.	2	2	NS
Rutaceae	*Citrus* sp.	2	5	F
	Citrus limon (L.) Osbeck	1	4	F
	Citrus reticulata Blanco	3	4	F
	Pilocarpus microphyllus Stapf ex Wardlew.	1	3	NS
	Zanthoxylum rhoifolium Lam.	1	11	NS
Sapindaceae	*Sapindus saponaria* L.	44	2,4	GM
Solanaceae	*Iochroma arborescens* (L.) J.M.H. Shaw	1	11	NS
	Solanum paniculatum L.	1	4	NS
Urticaceae	*Cecropia* sp.	5	5,6	NS
Verbenaceae	*Citharexylum myrianthum* Cham.	2	12	NS
	Lantana sp.	3	1,3	-
-	Unknown 1	1	1	-
-	Unknown 2	2	1	-
-	Unknown 3	3	1,2	-
-	Unknown 4	1	1	-
-	Unknown 5	3	2	-
-	Unknown 6	1	3	-
-	Unknown 7	6	5	-
-	Unknown 8	1	5	-
-	Unknown 9	5	5,6	-
-	Unknown 10	2	6	-
-	Unknown 11	1	5	-
-	Unknown 12	1	8	-
-	Unknown 13	5	6	-
-	Unknown 14	1	8	-
-	Unknown 15	1	5	-
-	Unknown 16	9	5,6	-
-	Unknown 17	1	5	-
-	Unknown 18	1	8	-
-	Unknown 19	1	12	-

Source: Authors, 2021. Unknown represents small trees or shrubs, in low density, that were planted in planting collective efforts in studied sites and land owners did not know species, genus or family, or even popular names.

Table 2. Agroforestry system (AFS), age (years), richness, Shannon-diversity index (H), density, basal area (BA) and main species found in each AFS.

AFS	Age (years)	Richness	H	Density (ind.ha^{-1})	BA (m^{2}ha^{-1})	Main Species (represents more than 80% of total BA)
1	4	18	2.4	3765	27.54	*Musa* sp.
2	4	22	2.5	3642	29.54	*Musa* sp., *Inga* sp.
3	4	21	2.7	4136	26.78	*Musa* sp., *Saccharum* sp.
4	4	17	2.1	12099	47.63	*Musa* sp., *Eucalyptus* sp.
5	8	32	2.8	12469	87.43	*Musa* sp., *Pseudobombax grandiflorum*
6	5	19	2.2	8086	70.05	*Musa* sp.
7	5	13	2.0	9136	55.44	*Musa* sp., *Carica papaya* L.
8	5	18	2.2	5432	49.99	*Musa* sp.
9	1	8	0.7	46728	4.01	*Cajanus cajan* (L.) Huth
10	8	7	1.7	4568	48.27	*Musa* sp., *Calophyllum brasiliense*, *Archontophoenix cunninghamiana*
11	11	14	1.8	5062	103.87	*Musa* sp., *Calophyllum brasiliense*
12	1	14	1.2	18457	85.42	*Musa* sp., *Calophyllum brasiliense*

Fonte: Autores, 2021.

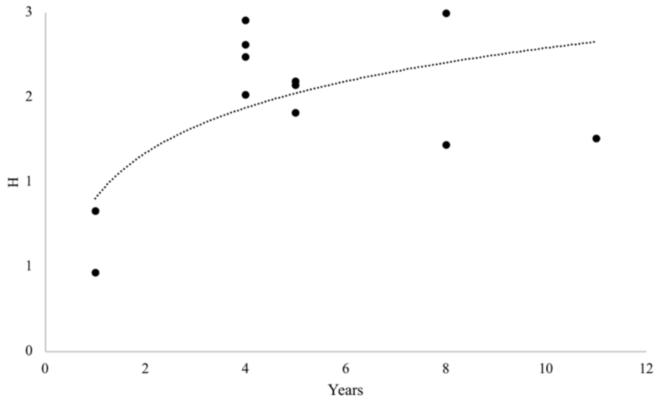

Figure 3. Relationship between diversity (H: Shannon diversity index) and age (in years) of agroforestry systems in southeast region of the Atlantic Forest Biome.

Source: Authors, 2021.

Generally, agroforestry tree richness corresponds to an average of 64% (range of eight to 213%: BAGWHAT et al., 2008) of the richness found in the neighboring forest reserves in the tropics. Thus, our results of 102 total species indicate low richness when compared to: (i) tropical native forests: 443 tree species per hectare in the southeastern region of Brazilian Atlantic Forest (THOMAZ e MONTEIRO, 1997); (ii) agroforests: about 284 species (according to estimates proposed by BAGWHAT et al., 2008) and (iii) to other Brazilian agroforests studies presenting 85 species (SOUZA et al., 2010), 105 species (ROLIM e CHIARELLO, 2004) and 216 species (SAMBUICHI et al., 2012).

Despite that, agroforestry systems are simpler in richness and diversity. For example, Sagastuy e Krauser (2019) found 75 small-scale agroforestry farmers in the Atlantic Forest planting one to 14 species per site. In ten AFS in the Northeast of Brazil (Bahia), 37 tree species were analyzed (FERNANDES, MATSUMOTO e FERNANDES, 2018). In Central Africa, 39 to 46 species were found per system (H' of 3.30 to 3.68: NOUMI et al., 2018). Massi et al. (2021), in a systematic review of 53 AFS studies in São Paulo state, pointed an average of 29.3 species planted per site. Our results (7 to 32 per AFS) are in accordance with these numbers and are explained by productive models followed by land owners in the studied site and in São Paulo state, in general. The predominant species, which were fruits, green manure and some native species for food production, determined the design, management and influenced on the studied parameters.

In agroforestry systems, species richness generally decreases with the increasing prevalence of crops, more intensive management, and shortening of cultivation cycles (SCALES e MARSDEN, 2008). In the studied AFS sites the choice of intensive planting of *Calophyllum brasiliense* (a commercial wood tree according to Lorenzi, 1992) and high plant abundance of *Cajanus cajan* (L.) Huth and *Flemingia* sp., used as green manure, were responsible for a decreased richness and increased density.

Basal area varied more than 25 times (4.01 to 103.87 m^2ha^{-1}) in a density changing from (46728 and 5062 $ind.ha^{-1}$, respectively). For a density of 1,667 cocoa $trees.ha^{-1}$ (LACHENAUD e MONTAGNON 2002), the total basal area ranged from 11.5 to 52.9 m^2ha^{-1}. Our results confirmed that the twelve study sites differed greatly in terms of richness, diversity, density, and basal area. These differences in structure appeared to be the result of both planting designs and management practices over time.

Despite our expectations of age having an effect on the studied parameters, we did not find differences in richness, density, and basal area in relation to the age of AFS. In fact, we argue that in the AFS of this study, the designs, the productive models and management led to differences in basal area, attributed to different densities and species richness which compose them. Similar data were found by Fernandes, Matsumoto e Fernandes (2018). In that case, cacao and rubber-tree were the dominant species in all the designs, which also contained fruit trees, and native and exotic shade trees, which made basal area differs among systems. In this case, banana (*Musa* sp.) and some native species (as *Pseudobombax grandiflorum* and *Calophyllum brasiliense*) were responsible for changes in basal area. Diversity, on the contrary was positively affected by age, which is a common result for restoration sites in tropical forests and might be related to the improvement of environmental conditions in sites (VIEIRA et al., 2009; SILVA et al., 2015). Studied sites were productive AFS models, and despite having restoration purposes, would have a limit in the provision of biodiversity and ecosystem services, when compared to native forests. A common knowledge points that older agroforestry systems may be simpler because having a few high productivity species, which we did not find in this study.

CONCLUSIONS

Our results showed that, opposed to expectations, age did not influence richness, density, and basal area of twelve agroforestry systems with different planting designs, but it did influence diversity. This indicates that both new and old agroforests might be interesting restoration models to increase carbon sequestration, vegetation cover, and species richness; it additionally indicates that higher biodiversity might be achieved later on time in these systems. Productive AFS determines planting design, management and, consequently, they may influence on composition, structure and functioning of these agroecosystems.

ACKNOWLEDGMENTS

We would like to thank owners of the studied sites (A. Salles, M. Marsicano, P. Assumpção, V. Santos) for permitting to conduct research in their properties, for all the help and for all the good exchanges. Without them this work would not be possible.

REFERÊNCIAS

ABDO, Maria Teresa V. N.; VALERI, Sergio V.; MARTINS, A. L. M. Sistemas agroflorestais e agricultura familiar: uma parceria interessante. **Tecnologia & Inovação Agropecuária**, p. 50-59, 2008.

APG IV (Angiosperm Phylogeny Group IV). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. **Botanical Journal of the Linnean Society**, v. 181, p. 1-20, 2016.

BARBOSA, Luís Mauro. **Lista de espécies indicadas para restauração ecológica para diversas regiões do estado de São Paulo**. São Paulo, SP: Instituto de Botânica, 2017.

BELTRAME, Tiago P.; RODRIGUES, Efraim. Feijão guandu (Cajanus cajan (L.) Millsp.) na restauração de florestas tropicais. **Semina: Ciências Agrárias**, vol. 28, p. 19-28, 2007.

BHAGWAT, Shonil. A.; WILLIS, Katherine J.; BIRKS, H. John B., WHITTAKER, Robert J. Agroforestry: a refuge for tropical biodiversity? **Trends in Ecology and Evolution**, v. 23, p. 261-267, 2008. http://dx.doi.org/10.1016/j.tree.2008.01.005

BRASIL. LEI Nº 12.651, DE 25 DE MAIO DE 2012. Dispõe sobre a proteção da vegetação nativa; altera as Leis nºs 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis nºs 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória nº 2.166-67, de 24 de agosto de 2001; e dá outras providências.

Ciiagro. Mensal temperature data range 09/12/1992-14/04/2014. Taubaté-SP. [cited 2018 nov. 5] Available from: http://www.ciiagro.sp.gov.br/ciiagroonline/Listagens/MonClim/LMClimLocal.asp.

CORDEIRO, Sidney A.; SILVA, Marcio L.; NETO, Silvio N. O.; OLIVEIRA, Tiago M. Simulação da variação do espaçamento na viabilidade econômica de um sistema agroflorestal. **Floresta e Ambiente**, v. 25, e00034613, 2018. http://dx.doi.org/10.1590/2179-8087.034613

DEAN, Warren. **A ferro e fogo: a história e a devastação da Mata Atlântica brasileira**. São Paulo, SP: Companhia das Letras, 1996.

FELICIANO, Diana; LEDO, Alicia; HILLIER, Jon; NAYAK, Dali R. Which agroforestry options give the greatest soil and above ground carbon benefits in different world regions? **Agriculture, Ecosystems & Environment**, v. 254, p. 117-129, 2018. https://doi.org/10.1016/j.agee.2017.11.032

FERNANDES, Cinira A. F.; MATSUMOTO, Sylvana N.; FERNANDES, Volney S. Carbon stock in the development of different designs of biodiverse agroforestry systems. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 22, p. 720-725, 2018. http://dx.doi.org/10.1590/1807-1929/agriambi.v22n10p720-725

FLORA DO BRASIL 2020 - Algas, Fungos e Plantas. JBRJ. Avaliable from: < http://floradobrasil.jbrj.gov.br >. Access on: 29 sept 2018.

FUNDAÇÃO SOS MATA ATLÂNTICA E INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. **Atlas dos Remanescentes Florestais da Mata Atlântica período 2016-2017**. São Paulo: Fundação SOS Mata Atlântica e INPE, 2018.

HOWE, Henry F., SMALLWOOD, Judith. Ecology of Seed Dispersal. **Annual Review of Ecology and Systematics**, v. 13, p. 201-228, 1982.

JOSE, Shibu. Agroforestry for conserving and enhancing biodiversity. **Agroforestry Systems**, v. 85, p. 1–8, 2012. https://doi.org/10.1007/s10457-012-9517-5

KUPSCH, Denis; VENDRAS, Elleni; OCAMPO-ARIZA, Carolina; BATÁRY, Péter; MOTOMBI, Francis N.; BOBO; Kadiri S.; WALTERT, Matthias. High critical forest habitat thresholds of native bird communities in Afrotropical agroforestry landscapes. **Biological Conservation**, v. 230, p. 20-28, 2019. https://doi.org/10.1016/j.biocon.2018.12.001

LACHENAUD, Philippe; MONTAGNON, Christophe. Competition effects in cocoa (Theobroma cacao L.) hybrid trials. **Euphytica**, v. 128, p. 97–104, 2002. https://doi.org/10.1023/A:1020669526647.

LIMA, Renato A. F.; SOUZA, Vinicius C.; DITTRICH, Vinícius A. O.; SALINO, Alexandre. Composição, diversidade e distribuição geográfica de plantas vasculares de uma Floresta Ombrófila Densa Atlântica do Sudeste do Brasil. **Biota Neotropica**, v. 12, p. 241-249, 2012.

LORENZI, Harri. **Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil**. Nova Odessa: Plantarum, 1992.

MA, Zilong; CHEN, Han Y. H.; BORK, Edward W.; CARLYLE, Cameron N.; CHANG, Scott X. Carbon accumulation in agroforestry systems is affected by tree species diversity, age and regional climate: A global meta-analysis. **Global Ecology and Biogeography**, v. 29, p. 1817–1828, 2020. https://doi.org/10.1111/geb.13145

MARTINELLI, Gabrielli C.; SCHLINDWEIN, Madalena M.; PADOVAN, Milton P.; GIMENES, Régio M. T. Decreasing uncertainties and reversing paradigms on the economic T performance of agroforestry systems in Brazil. **Land Use Policy**, v. 80, p. 274-286, 2019. https://doi.org/10.1016/j.landusepol.2018.09.019

MASSI, Klécia G.; BIGNOTTO, Rafael B.; GALLO JR, H.; DEVIDE, Antônio C. P. Estado da Arte dos trabalhos sobre sistemas agroflorestais no estado de São Paulo. **XII Congresso Brasileiro de Sistemas Agroflorestais**, 2021.

MBOW, Cheikh; SMITH, Pete; SKOLE, David; DUGUMA, Lalisa; BUSTAMANTE, Mercedes. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. **Current Opinion in Environmental Sustainability**, v. 6, p. 8-14, 2012. http://dx.doi.org/10.1016/j.cosust.2013.09.002

MORRISON, Emily B.; LINDELL, Catherine A. Active or Passive Forest Restoration? Assessing Restoration Alternatives with Avian Foraging Behavior. **Restoration Ecology**, v. 19, p. 170-177, 2010. https://doi.org/10.1111/j.1526-100X.2010.00725.x

MYERS, Norman; MITTERMEIER, Russel A.; MITTERMEIER, Cristina G.; FONSECA, Gustavo A. B.; KENT, Jennifer. Biodiversity hotspots for conservation priorities. **Nature**, v. 403, p. 853-858, 2000.

NOUMI, Valery. N.; DJONGMO, Victor A.; NYECK, Boris; MBOBDA, Roger B. T.; ZAPFACK, Louis. Vegetation structure, carbon sequestration potential and species conservation in four agroforestry systems in Cameroon (Tropical Africa). **Acta Botanica Brasilica**, v. 32, p. 212-221, 2018. https://doi.org/10.1590/0102-33062017abb0279

PALUDO, Rafael; COSTABEBER, José A. Sistemas agroflorestais como estratégia de desenvolvimento rural em diferentes biomas brasileiros. **Revista Brasileira de Agroecologia**, v. 7, p. 63-76, 2012.

PEEL, M. C., FINLAYSON, B. L.; MCMAHON, T. A. Updated world map of the Köppen-Geiger climate classification. **Hydrology and Earth System Sciences**, v. 11, p. 1633–1644, 2007. https://doi.org/10.5194/hess-11-1633-2007

RODRIGUES, Ricardo R., BRANCALION, Pedro H. S., ISERNHAGEN, Ingo. **Pacto pela restauração ecológica da Mata Atlântica: referencial dos conceitos e ações de restauração florestal**. São Paulo: Instituto BioAtlântica, 2009.

ROLIM, Samir G., CHIARELLO, Adriano G. Slow death of Atlantic forest trees in cocoa agroforestry in southeastern Brazil. **Biodiversity and Conservation**, v. 13, p. 2679-2694, 2004. https://doi.org/10.1007/s10531-004-2142-5

R CORE TEAM. **R: A language and environment for statistical computing**. v.3.5.3. Vienna: R Foundation for Statistical Computing, 2018.

SOIL SURVEY STAFF. **Soil Taxonomy: a basic system of soil classification for making and interpreting soil surveys**. Natural Resources Conservation Service. Washington, DC: U.S. Department of Agriculture, 1999.

SAGASTUY, Mauricio, KRAUSE, Torsten. Agroforestry as a Biodiversity Conservation Tool in the Atlantic Forest? Motivations and Limitations for Small-Scale Farmers to Implement Agroforestry Systems in North-Eastern Brazil. **Sustainability**, v. 11, p. 6932-6955, 2019. https://doi.org/10.3390/su11246932

SAMBUICHI, Regina H. R.; VIDAL, Daniela B.; PIASENTIN, Flora B.; JARDIM, Jomar G.; VIANA, Thiago G.; MENEZES, Agna A.; MELLO, Durval L. N.; AHNERT, Dario; BALIGAR, Virupax C. Cabruca agroforests in southern Bahia, Brazil: tree component, management practices and tree species conservation. **Biodiversity and Conservation**, v. 21, p. 1055-1077, 2012. https://doi.org/10.1007/s10531-012-0240-3

SANTOS, Pedro Z. F.; CROUZEILLES, Renato; SANSEVERO, Jerônimo B. B. Can agroforestry systems enhance biodiversity and ecosystem service T provision in agricultural landscapes? A meta-analysis for the Brazilian Atlantic Forest. **Forest Ecology and Management**, v. 433, p. 140-145, 2019. https://doi.org/10.1016/j.foreco.2018.10.064

SARTORI, Richieri A.; CARVALHO, Douglas A.; BERG, E. van den; MARQUES, João J. G. S. M.; SANTOS, Rubens M. Variações florísticas e estruturais do componente arbóreo de uma floresta estacional semidecidual montana em Socorro, SP. **Rodriguésia**, v. 66, p. 33-49, 2015. https://doi.org/10.1590/2175-7860201566103

SCALES, Ben R., MARSDEN, Stuart J. Biodiversity in small-scale tropical agroforests: a review of species richness and abundance shifts and the factors influencing them. **Environmental Conservation**, v. 35, p. 160-172, 2008. https://doi.org/10.1017/S0376892908004840

SER (Society for Ecological Restoration International Science & Policy Working Group). [cited 2018 jun. 20] Available from: https://cdn.ymaws.com/www.ser.org/resource/resmgr/custompages/publications/SER_Primer/ser_primer.pdf.

SIDDIQUE, I.; ENGEL, Vera L.; PARROTTA, John A.; LAMB, David; NARDOTO, Gabriela B.; OMETTO, Jean P. H. B.; MARTINELLI, Luiz A.; SCHMIDT, Susanne. Dominance of legume trees alters nutrient relations in mixed species forest restoration plantings within seven years. **Biogeochemistry**, v 88, p. 89-101, 2008. https://doi.org/10.1007/s10533-008-9196-5

SILVA, Fernanda R.; MONTOYA, Daniel; FURTADO, Rafael; MEMMOTT, Jane; PIZO, Marco A.; RODRIGUES, Ricardo R. The restoration of tropical seed dispersal networks. **Restoration Ecology**, v. 23, p. 852-860, 2015. https://doi.org/10.1111/rec.12244

SILVA, Ramon F. B.; BATISTELLA, Mateus; MORAN, Emilio F. Drivers of Land Change: Human-Environment Interactions and the Atlantic Forest Transition in the Paraíba Valley, Brazil. **Land Use Policy**, v. 58, p. 133-144, 2016. https://doi.org/10.1016/j.landusepol.2016.07.021

SILVA, Ramon F. B.; BATISTELLA, Mateus; MORAN, Emilio F.; LU, Dengsheng. Land changes fostering atlantic forest transition in Brazil: evidences from the paraíba valley. **The Professional Geographer**, v. 69, p. 80-93, 2017. https://doi.org/10.1080/00330124.2016.1178151

SOUZA, Helton N.; CARDOSO, Irene M.; FERNANDES, José M.; GARCIA, Flávia C. P.; BONFIM, Verônica R.; SANTOS, Alvori C.; CARVALHO, Anôr F.; MENDONÇA, Eduardo S. Selection of native trees for intercropping with coffee in the Atlantic Rainforest biome. **Agroforestry Systems**, v. 80, p. 1–16, 2010. https://doi.org/10.1007/s10457-010-9340-9

SULTANI, M. I., GILL, M. A., ANWAR, M. M.; ATHAR, M. Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions. **International Journal of Environmental Science and Technology**, v. 4, p. 109-118, 2007. https://doi.org/10.1007/BF03325968

THOMAZ, Luciana D., MONTEIRO, Reinaldo. Composição florística da Mata Atlântica de encosta da Estação Biológica de Santa Lúcia município de Santa Teresa-ES. **Boletim do Museu de Biologia Mello-Leitão Nova Série**, v. 7, p. 3-48, 1997.

TNC (The Nature Conservancy). Cartilha de Restauração Florestal de Áreas de Preservação Permanente. Alto Teles Pires: TNC, 2015.

VIEIRA, Daniel L. M.; HOLL, Karen D.; PENEIREIRO, Fabiana M. Agro-Successional restoration as a strategy to facilitate tropical forest recovery. **Restoration Ecology**, v. 17, p. 451-459, 2009. https://doi.org/10.1111/j.1526-100X.2009.00570.x