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Original Article

Conservation of Nature

Restoring Ecological Functions Using Agroforestry Systems in Riparian Forests

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ABSTRACT

Agroforestry systems and restoration models were compared with native forests by examining the restoration of ecological processes that generate stability, resilience and reliability. The stability assessment was obtained using indicators of diversity, structure and functionality. Indicators of soil protection and nutrient cycling were also used to estimate the resilience. The reliability was assessed by management and protection indicators, anthropic impact and canopy (percentage of light). Agroforestry systems did not promote the restoration of ecological functions due mainly to structural factors than management. The production of biomass and carbon storage were higher in the agroforestry system considering the association of trees with short cycle crops (3.2 t ha^{-1} yr^{-1}; 39.81 t C ha^{-1}) than trees with green manure system (2.4 ha^{-1} yr^{-1}; 34.09 t C ha^{-1}). After 36 months, the restoration methods and agroforestry systems did not provide resilience and stability for the riparian forests protection.

Keywords: ecological indicators, adaptive management, carbon sequestration.

1. INTRODUCTION AND OBJECTIVES

Agroforestry systems have been one of the alternatives for ecological restoration because reconcile environmental recovery and the diversified production (Oliveira et al., 2016). These systems gained prominence in Brazil with the publication of the National Plan for the Recovery of Native Vegetation, Decree no. 8.972 (Brasil, 2017) which imposes the recomposition of 12 million hectares in 20 years, being part of those with agroforestry systems (AFS) established in legally protected areas. The planting of AFS in legally protected riparian areas (APPs) is regulated by legal requirements (Brasil, 2011) that allowed its adoption in small properties until the fifth-year post-planting. In São Paulo, the Resolution SMA no. 44 of June 30, 2008 (São Paulo, 2008b) defined the criteria for using AFS in APP of small properties. Also, the Resolution SMA no. 32 of April 3, 2014 (Art. 11, subsection IV, §4 and Art. 12) allowed the use of this system for the restoration of up to 50% of the riparian area (São Paulo, 2014). Although AFSs can promote environmental sustainability (Seoane et al., 2014), it is still necessary to assess and monitor their ability to restore the ecological functions previously performed by forest cover. In general, these ecological functions are associated with the structure and the forest´s composition (Srivastava & Vellend, 2005), and they contribute to the system's diversity, stability and resilience (Astier et al., 2011). However, other functions related to ecological processes such as productivity, biomass and carbon accumulation (Sharrow & Ismail, 2004); biological nitrogen fixation (Piotto, 2008); nutrient cycling and presence of functional groups species (Lomov et al., 2006) can also be considered as indicators of the restoration effectiveness (Tongway & Hindley, 2004). The monitoring of ecological functions such as its fixation potential and the CO_2 reducing effectiveness levels can work as an indicator to evaluate the restoration (Melo & Durigan, 2006) being capable of analyzing the ecosystems functioning, which allows the comparison of different systems and their fragility degree (Deponti et al., 2002). However, for the AFSs differences, among the models used, their unique composition, management forms, density and arrangement of plants make it difficult to extrapolate and compare one system to another (Nair, 2012).

Among the monitoring environmental methods for sustainability, the Mesmis (Indicator-based Framework for Evaluation of Natural Resource Management Systems) (López-Ridaura et al., 2002) stands out for its flexibility to compare different systems over time (Theodoro et al., 2011). It is based on stability indicators (system's ability to maintain steady), resilience (ability to return to the equilibrium state or maintain its productive potential, even after disturbance) and reliability of systems (ability to keep productivity at the levels close to its long-term equilibrium) (López-Ridaura et al., 2002). However, its effectiveness depends on the application on several scenarios in order to generate reference data (Astier et al., 2011). In this context, the objective of this work was to evaluate the ecological restoration processes in different agroforestry models systems in riparian areas.

2. MATERIALS AND METHODS

The studies were carried out in five areas located at the Sorocaba and middle Tietê river, São Paulo. The local climate is defined as Cwa (high-altitude tropical), with averages of temperature 22 ºC and, annual rainfall 1.206 mm (Fundespa, 2009; Itesp, 2007). Based on the Mesmis method (López-Ridaura et al., 2002), the following areas were used as reference: (a) fragment of a conserved dry forest area (AR1), and (b) a restoration area (AR2). They were compared with another restoration area (R) and two agroforestry systems (F and H) (Table 1), located in a riparian area of the same rural settlement of 17 ha. In AR1 and AR2, floristic studies were carried out in 15 random plots of 100 m^2, with subplots of 10 m × 10 m. In the other areas (R, F and H), five permanent plots of 20 m × 20 m were divided into 10 m × 10 m subplots where the indicators were applied. Monitoring was accomplished in August 2012, in the fourth (H and F) and fifth (R) post-planting year with 23 indicators based on expected scenarios and theoretical references (Table 2). The indicators were transformed into parameters and used to elaborate radar charts, which allowed to compare the areas within the same evaluation unit as proposed by Ricarte et al. (2006).

For the species diversity and composition analysis, the richness, diversity and equitability indices were determined according to Magurran (2004). Total height and diameter at breast height (DBH) data were obtained for plants with DBH ≥ 5 cm and over 1.30 m height, observing the bifurcations presence and position and the epiphytes occurrence. The percentages of soil covering with herbaceous species, invasive grasses, mulch and litter were estimated at three random points in each subplot

using a 0.5 m × 0.5 m frame subdivided into quadrants of 0.25 m × 0,25 m. At each point, the litter height was measured and samples (n = 5) were collected. In the laboratory, the litter samples were separated into the fractions of leaves, branches, reproductive material and remains, and then dried in an oven at 65 ºC for 24 h to get the biomass quantification (kg ha^{-1}). The canopy closure was estimated by: (a) incident light (%), obtained with the use of a flat reflector subdivided into 40 squares of 4 cm^2; it was kept at 50 cm from the observer, at the height of the ground and 1 m from it in the center of each subplot sample, obtaining the average number of squares with more than 50% covered by the crown projections in each direction (N, S, E and W). (b) Canopy cover, obtained in each permanent plot by tracing a 25 m diagonal line, collecting the data from the crown projections, according to Melo et al. (2007). The difference between the areas concerning the descriptors of diversity and species composition was evaluated by the non-parametric Kruskal-Wallis test and, for height and DBH, by the chi-square test. The similarity between the areas was determined by the cluster analysis using the Euclidean distance method calculated by the original data arranged in the 5 × 23 matrix (areas × indicators) using the free program Past. 3.14 (Hammer et al., 2001). Estimation of carbon fixation was obtained for all trees with DBH ≥ 5 cm. The biomass (Y) above the soil was calculated with the allometric equation developed for tropical forests (Brown, 1997) (Equation 1) and the CO_2 stock estimates were based on the factor 0.5 (MacDicken, 1997).

$$Y = \exp [-1.996 + 2.32 \times \ln (DBH)] \quad (1)$$

Y: above ground biomass; exp: exponential; ln: Napierian logarithm; DBH: diameter at breast height.

Table 1. Characterization of the reference area located in Sorocaba (AR1), the restoration models located in Itu, SP (AR2), Porto Feliz, SP (R) and agroforestry systems (F and H) located in legally protected riparian areas (APP) in Porto Feliz, SP.

Code	Function/ Restoration model	Characterization	Dominant forest species
AR1	Conservation reference area	Set of fragments (F) at 16.6 h. Being: F1 – 4.5 ha, F2 – 1.68 ha, F3 – 4.75 ha, F4 – 4.16 ha and F5 – 1.54 ha, with pastures predominance in its surroundings, located in Sorocaba-SP (23º34"41.00" S e 47º31'04.89" O).	*Lithraea molleoides* (Vell.) Engel, *Copaifera langsdorffii* Desf, *Casearia sylvestris* Sw, *Cryptocarya moschata* Ness; C., *Protium heptaphyllum* (Aubl.) M., *Pera glabrata* (Schott) Poepp., *Gochnatia polymorpha* (Less.) Cambess *Persea pyrifolia* Ness, *Tapirira guianensis* Aubl
AR2	Forest Restoration reference area	Restoration area (127.98 ha) in 2008 with different reforestation models, applying regular silvicultural practices according to SMA no. 08/2008 (São Paulo, 2008a). It was used a 6-ha study unit with 3 m × 2 m spacing, by the diversity and filling model (Rodrigues et al., 2009), at the planting of 800 seedlings ha-1 and enrichment with 200 seedlings ha-1. Location: Itu, SP (23°20' S and 47°20' W). Age: 48 months.	*Aloysia virgata* (Ruiz;Pav.) Juss, *Aspidosperma polyneuron* Muell. Arg., *Bauhinia longifólia* D. Dietr, *Casearia sylvestris* Sw., *Schinus terebinthifolius* Raddi, *Cytharexyllum myrianthum* Cham, *Guazuma ulmifolia* Lam., *Luehea divaricata* Mart., *Machaerium nyctitans* (Vell.) Benth., *Cedrella fissilis*Vell., *Copaifera langsdorffii* Desf., *Eugenia uniflora* L., *Inga edulis* Mart.
R	Forest Restoration model in APP	APP Reforested pasture area (8.0 ha) using the filling and diversity model (Rodrigues et al., 2009) with spacing 3 m × 2 m, planted in 2007. In this area, silvicultural practices were applied irregularly, not following SMA Resolution 08/2008. Location: Porto Feliz, SP (23º13'02' S, 47º31'35" O). Age: 60 months.	*Anadenanthera colubrina* (Vell.) Brenan, *Campomanesia lineatifolia* Ruiz; Pav., *Chorisia speciosa* A.St.-Hil., *Citharexylum myrianthum* Cham., *Croton floribundus* Spreng., *Croton urucurana* Baillon., *Enterolobium contortisiliquum* (Vell.) Morong., *Guazuma ulmifolia* Lam., *Inga vera* Willd., *Jacaranda decurrens* Cham., *Myrcia bella* Cambess., Blake
F	Restoration model with agroforestry system (AFS). Association of native forest species and green manure	APP Reforested pasture area (3.7 ha) by the filling and diversity model (Rodrigues et al., 2009), planted in 2008. Native forest species and short cycle crop species association unit, with soil restoration function. In this area, the effective management of biomass incorporation in the soil (pigeon pea – Cajanus cajan (L.) Millsp) was not carried out. Location: Porto Feliz, SP (23º13'02' S, 47º31'35" O). Age: 48 months.	*Anadenanthera colubrina* (Vell.) Brenan, *Caesalpinia férrea* Mart. ex Tul., *Citharexylum myrianthum* Cham., *Croton urucurana* Baillon,*Enterolobium contortisiliquum* (Vell.) Morong. *Erytrhrina dominguezii* Hassl., *Handroanthus* heptaphyllus (Vell.) Mattos, *Inga laurina* (Sw.) Willd., *Jacaranda micrantha* Cham., *Luehea divaricata* Mart., *Luehea grandiflora* Mart. *Muntigia calabura* L., *Peltophorium dubium* (Spreng) Taub., *Senegalia polyphylla* (DC) Britton; Rose
H	Restoration model with agroforestry system (AFS). Association of native forest species and short cycle crops	Sequential AFS unit in the Taungya model containing native forest species and short cycle crop species (*Zea mays* L., *Phaseolus vulgaris* L., *Manihot esculenta* Crantz, *Cucurbita moschata* (Duch.) Duch. Ex Poir., *Ananas comosus* L. Merril, *Musa* spp.) and green manure (*Cajanus cajan* (L.) Millsp., Crotalaria *juncea L.*, *Helianthus annuus* L., *Canavalia ensiformis* (L.) DC.). The management was carried out until the 3rd year post-planting, being abandoned later. Location: Porto Feliz, SP (23º13'02' S, 47º31'35" O). Age: 48 months.	*Albizia niopoides* (Bentham) Burkart, *Caesalpinia ferrea* Mart. ex Tul., *Chorisia speciosa* A.St.-Hil. *Croton floribundus* Spreng., *Croton urucurana* Baillon,*Enterolobium contortisiliquum* (Vell.) Morong., *Erithrina crista galli* L., *Eugenia monosperma* Vell., *Inga vera* Willd., *Jacaranda micrantha* Cham., *Lafoensia pacari* A.St.-Hil., *Peltophorium dubium* (Spreng.) Taub., *Senna macranthera* (DC. ex Collad.) H.S. Irwin; Barneby, *Triplaris americana* L.

Table 2. Set of ecological sustainability attributes with their descriptors and ecological indicators used for the functionality comparison of the study areas. Based on the Mesmis method (López-Ridaura et al., 2002).

Descriptor	Indicator	Description	Scenario	Parameters
Stability and resilience				
Community structure				
Diversity and species composition (Magurran, 2004)	Diversity	Shannon Index (H')	Similar to the AR1 reference area	H' > 2.0 = 3 (high)
			H' = 1.671 nat.ind^{-1}	1.0 < H' < 1.9 = 2 (mean)
				H' < 0.9 = 1 (low)
	Equitability	Pielou Index (J')	Similar to the AR1 reference area	J' ≥ 1 = 3
			J' = 1.09	0.5 < J' < 0.9 = 2
				J' < 0.5 = 1
	Species richness	Number of tree species (SR)	Presence of 50 % of the species number in the reference area (AR1)	SR > 30 = 3
			S = 75	10 < SR <30 = 2
				SR < 10 = 1
Structure of the area	Height (m)	Average height increments (IMA)	Average increase in the species height with confidence interval between 0.04 m to 0.17 m month^{-1} to 15 months of age	IMA > 0,17 m month^{-1} = 3
				0.04m/month < IAM < 0.17 m month^{-1} = 2
				IMA < 0.04 m month^{-1}= 1
	DBH (cm)	Average diameter increment (ADI)	Mean increase in diameter (IMD) with a confidence interval of 0.20 cm to 0.27 cm per month^{-1} to 15 months in restoration plantations	ADI> 0.27 cm-1 = 3
				0.20 cm month-1 <IMD <0.27 cm month -1 = 2
				ADI <0.20 cm month -1 = 1
	Bifurcation (no.)	Reflect excessive light, delay in establishing competition or inadequate silvicultural practice	Values compatible with those found in the reference area (AR1)	No. bifurcations < AR = 3
			Number of bifurcated individuals = 2.3 ± 0.35	No. bifurcations = AR = 2
				No. bifurcations > AR = 1
	Bifurcation position		Similar to that obtained in AR1	UT < 24.3 % = 3
			In the upper thirds (UT) from zero to 24.3% of the individuals sampled	UT > 24.3 % = 1
	No. of strata	Forest stratification	Presence in the three vegetation strata formed by the upper canopy (height greater than 12 m), medium stratum (from 5 m to 12 m) and lower (< 5 m) (Brasil, 1994)	Three strata = 3
				Two strata = 2
				A stratum = 1
	Functional diversity			
	Presence of epiphytes	Forest structure restoration	Sources of resources and shelter for fauna, water cycling and nutrients	Present = 3
				Absent = 0
Succession process	% of species per ecological group	Number of species by ecological groups used in restorations	Minimum percentage of species per ecological group of 40 % (SMA 08/2008). NP = non-pioneer; P = pioneer	NP > 60% = 3
				40% < NP < 60 % = 2
				NP < 40 % = 1
	Ecological functions of species	Ecological functions of the species employed	Presence of species with ecological functions (f_{eco}) of nitrogen fixation by microorganisms, biomass contribution (deciduous species), fauna attraction (zoocoric species) and shading (broad crowns)	$f_{eco} \geq 4 = 3$
				$1 > f_{eco} < 4 = 2$
				$f_{eco} \leq 1 = 1$
				None = 0
Organic matter contribution	Height of litter	Height of leaf deposition stratum	Similar to that obtained in AR1, at the same time	> AR1 = 3
			(AR1 = 5.46 ± 0.2 cm)	FALSE
				< AR1 = 1
	% of area covered by litter	Soil covering with organic matter.	Values similar to the reference area (AR1)	> 75 % = 3
				50 % – 75 % = 2
				25 % – 50 % = 1
				1 – 25% = 0

Table 2. Continued...

Descriptor	Indicator	Description	Scenario	Parameters
Stability and resilience				
Community structure				
Management and conservation				
Sanity	Presence of termites and ants	Ants and termites nests	Absence of ants and termites is expected, indicating the implementation of appropriate cultural practices and control	Absent = 3 Present = 1
	Presence of lianas and vines	Non-arboreal species that dominate the crown of trees, especially the upper and middle thirds	In degraded areas, the presence of vines and lianas is more frequent indicating the occurrence of clearings in the area	Absent = 3 Present = 1
Degree of intervention and impacts in the area	Level of disturbance in the area	Occurrence of fire, domestic animals grazing, garbage, artifacts of woody individuals	The absence of disturbances that restrict the development and establishment of natural regeneration and vegetation in general	Absent = 3 Present = 1
	Human presence (negative aspects)	Tracks and paths	Disturbed areas frequently used by people tend to become vulnerable and may interfere with vegetation	Absent = 3 Present = 1
	% of soil cover with grasses	Soil surface covered by invasive grasses	Dominant invasive species in degraded areas indicate lack of management control and cultural practices	0 % = 3 0 % – 25 % = 2 25 % – 50 % = 1 > 50 % = 0
Degree of intervention and impacts in the area	Presence of exotic species	Agricultural or forest species exotic to the region and invasive (except for grasses)	Absent in conservation areas or used for environmental restoration purposes	Absent = 3
	% area with mulch	Ground covered due to silvicultural practice on grasses control.	The presence of mulch originated from the control of grasses protects the soil against erosion and favors the penetration of water in the soil	> 50 % = 3 (high) 30 % – 50 % = 2 (mean) 0 % – 30 % = 1 (low)
Canopy closure	% light on the ground	Amount of light that crosses the canopy and reaches the surface of the soil	The rapid vegetation development promotes shading in restoration projects, reduces the incident lightness on the soil, an important factor on the weed-competition reduction	0 % – 30 % = 3 (low) 30 % – 50 % = 2 (mean)
	% light at 1 m from the ground	Amount of light reaching 1 m from the ground		> 50 % = 1 (high)
	Crown cover	Canopy closure, light reduction and direct incident rain on the ground	The crown cover controls the quantity, quality and temporal and spatial distribution of light, to determine differentiated levels of air humidity, temperature and soil moisture conditions (Halpern & Lutz, 2013)	> 50 % = 3 25 % – 50 % = 2 0 % – 25 % = 1 0 % = 0

3. RESULTS AND DISCUSSION

The highest similarity on species composition occurred for R, with 10 species in common with the others, while AR1 showed only one in common with AR2 (Table 3). Despite this, AR2 obtained the same AR1 values at 64.3% (n = 9) of the system stability and resilience indicators (Figure 1).

Although AR1 presented higher diversity (H' = 1.671 nat.ind^{-1}) than AR2 (H' = 1.368 nat.ind^{-1}), there was no significant difference between them related to plant density, and on diversity and species composition indicators (SR, J and H') ($c^2 = 0.09818$; $p > 0.01$).

However, both showed a lower diversity index than other seasonal forests areas in the state of São Paulo, which diversity ranges from 3.0 nat.ind^{-1} to 3.45 nat.ind^{-1} (Filho & Santin, 2002). Furthermore, at 48 months, AR2 still showed low species richness (SR = 39), absence of epiphytes and low herbaceous and regenerant cover and number of species lower than 80 sp.ha^{-1} (Table 3), as recommended by SMA no. 8 of January 31, 2008 (São Paulo, 2008a).

There was a high mortality level in AR2 (29%) with only 1.213 ind.ha^{-1}, and after 48 months, it was below the minimum limit of 1.667 ind.ha^{-1} recommended by the legislation (São Paulo, 2008a). However, the density of plants in AR2 at 48 months, resembled other areas with 36 months ranging from 1.240 ind.ha^{-1} to 2.200 ind.ha^{-1} (Melo et al., 2007).

Concerning height and diameter, AR1 and AR2 differed from each other ($c^2 = 26.48$; $p < 0.01$), which was expected due to their difference of age. However, according to Conama Resolution no. 1 of January 31, 1994 (Brasil, 1994), both can be considered as initial

Table 3. Species diversity and density data; values obtained for the stability and resilience system attributes; as well as management and conservation of the studied areas. Data collected in 2012.

Descriptor	Indicator	AR1	AR2	F	H	R
Diversity and species composition	Density (ind hA^{-1})	1.720	1.213	1.420	1.380	980
	H' (nat ind.$^{-1}$)	1.671	1.368	1.3456	1.5003	1.2683
	J'	0.8549	0.8599	0.3919	0.4067	0.4045
	SR	91	39	31	40	23
Area 1 structure	Height (m)	7.7 ± 3.05	2.7 ± 1.2	3.9 ± 0.5	3.8 ± 0.4	3.9 ± 0.7
	DBH (cm)	12.3 ± 6.5	4.0 ± 0.9	9.16 ± 2.5	9.90 ± 1.5	8.22 ± 2.8
Succession process	Epiphytes	Presence	Absence	Absence	Absence	Absence
	Soil cover (%) with herbaceous and regenerating	< 25	< 25	3.8	0	2.7
	Species by ecological group (%)	64.5	53.5	33.3	39.5	39.1
Nutrients contribution	Area covered by litter (%)	> 75	25-50	7.0	11.3	3.8
Sanity	Termites and ants	Absence	Presence	Presence	Presence	Presence
Intervention degree and impacts in the area	Level of disturbance in the area	Absence	Absence	Presence	Presence	Presence
	Human presence (negative aspects)	Presence	Absence	Presence	Presence	Absence
	Soil cover with grasses (%)	25	50	53.8	42.1	34.5
	Presence of exotic species	Presence	Presence	Absence	Presence	Absence
	Mulch (%)	< 30 %	> 50 %	< 30 %	< 30 %	> 50 %
Canopy closure	Light on ground (%)	> 50	> 50	20.9	30.8	32.4
	Light at 1 m from the ground (%)	> 50	> 50	23.7	34.3	32.4
	Crown cover (%)	> 50	> 50	126.4	93.4	70.0

AR1: conservation reference area in Sorocaba, SP; AR2: restoration reference area in Itu -SP; F: agroforestry system with forest species and pigeon pea, at 48 months (Porto Feliz, SP); H: agroforestry system with forest species and vegetable cultivation, at 48 months (Porto Feliz-SP); R: forest restoration at 60 months (Porto Feliz-SP); Ind.: individual; SR: number of tree species; J': Pielou index; H': Shannon index; DBH: Height and diameter deviation mean at breast height.

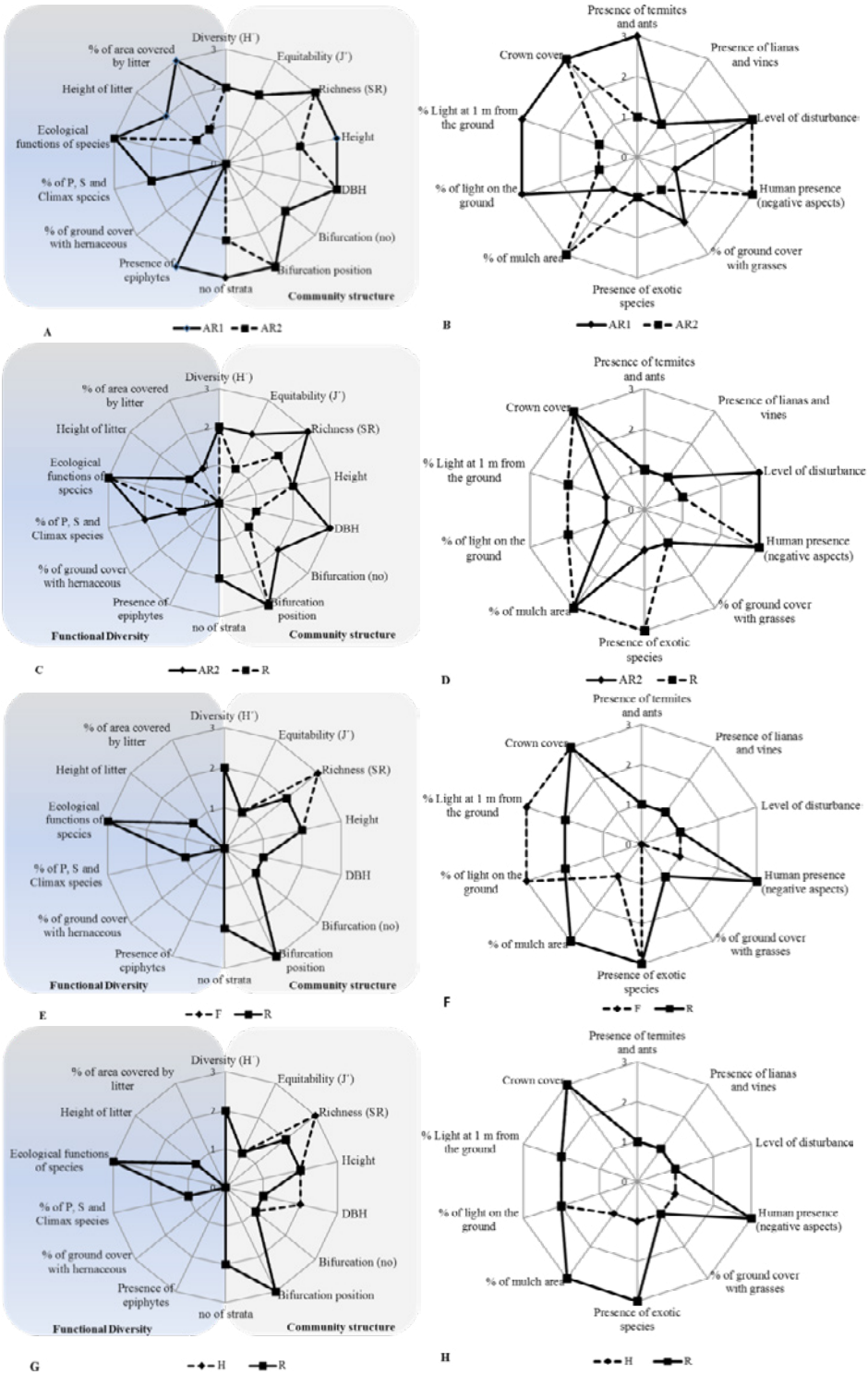

Figure 1. Values assigned to sustainability indicators for stability and resilience attributes (A, C, E, G) and management and conservation (B, D, F, H). AR1: conservation reference area; AR2: restoration reference area; R: forest restoration; F: agroforestry system with forest species and pigeon pea; H: agroforestry system with forest species and vegetables crops; P: pioneer species; S: secondary species; SR: number of tree species; H': Shannon index; J': Pielou index; DBH: height and diameter deviation mean at breast height.

secondary forest, although considering the management and conservation attribute, AR2 presented 60 % of the indicators (n = 10) similar or higher than AR1. The presence of grasses in both AR1 and AR2 reflects the fact that canopy closure has not yet occurred, confirming its initial successional stage condition (Table 3, Figure 1B).

Comparing the two restoration areas (Figure 1C), it was observed that R was lower than AR2 in most of the community structure indicators (Table 3, Figure 1C). Regarding the system functional diversity, 66.7 % of the indicators (n = 6) were the same and according to the management and conservation (Figure 1D), the R and AR2 areas were similar in 60 % of the indicators (n = 10).

Although AR2 is more recent than R, 48 and 60 months respectively, the AR2 best performance for stability and resilience may be a reflection of its community structure (Figure 1C). On the other hand, although AR2 received weeding four times a year and replanting in the 2nd year (Table 2), the R model with silvicultural management and practices at irregular intervals still showed higher soil covering indicators than AR2 (Figure 1D).

In the systems located in the same region, the F and R similarity for most (93 %) of stability and resilience indicators (n = 14) can be observed, except for species composition, in which F was higher than R (Figure 1E). Although the 31 species of F represented only one third of the 80 species required by the legislation at that time (São Paulo, 2008a), this value was close to the 30 species recommended by SMA no. 44/2008 (São Paulo, 2008b) for AFSs (Table 3). Moreover, F also complies with this legislation in terms of number of individuals, with density above 1.000 ind.ha^{-1}. However, it was expected that in F, the association with legumes species would provide greater organic matter input; however, there was no difference on soil litter height and covering between the two areas, with 50 % of similarity among management indicators for F and R (Figures 1E and 1F).

Considering the H and R areas analysis, there was equality in 72 % of the resilience stability indicators. This condition was lower than that observed for F and R, which may represent a better restoration condition in the F model adoption. Despite this, H was similar to restoration (R) in 75 % of the community structure indicators, being similar for functional diversity. In general, H was better than R only in the initial species composition and in DBH (Figure 1G), while they were similar in 60 % of management and conservation indicators (Figure 1H).

Concerning restoration ecology, one of the possible objectives is the area return to the closest possible conditions of the original situation (Hobbs et al., 2009). The indicators showed that AR2 was different from the fragment (AR1) (Figure 2). In general, AR2 differed from AR1 towards the structure and successional processes, which can be attributed to their difference of age (Figures 1A and 1B). However, the other restoration area (R) was distinct from these areas and from the agroforestry systems F and H (Figure 2).

Although the two restoration areas were installed in the same model, R presented superior management results, but with structure indicators lower than AR2, showing low species and functional diversity (Figures 1C and 1D). Even though these areas are only between 48 (AR2) and 60 months old (R), these data point out that the AR2 structure, rather than its management, may have influenced the differences between them.

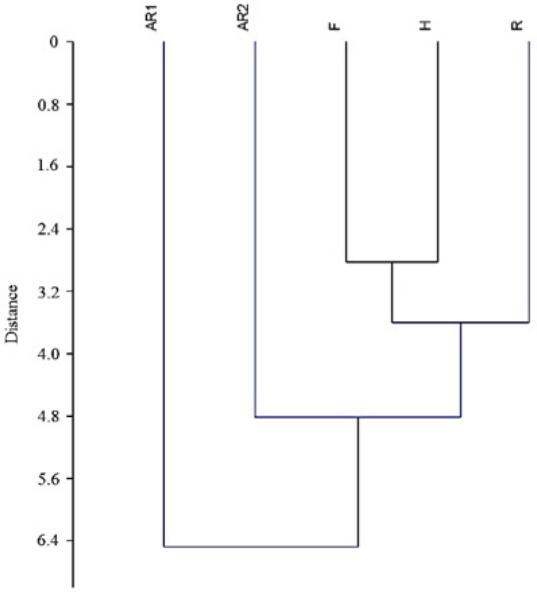

Figure 2. Grouping dendrogram areas based on indicators assessed. Sorocaba river basin and middle Tietê River, 2012. AR1: conservation reference area; AR2: restoration reference area; F: agroforestry system with forest species and pigeon pea; H: agroforestry system with forest species and cultivation of vegetables; R: forest restoration.

It can be suggested that, even with species richness increasing from 23, as observed in R, to 39 (AR2), or even 40 as in H (Table 3), this condition may not be sufficient to achieve the stability and the resilience observed in the fragments (AR1). The obtained data show that the low functional and the species diversity may have affected the restoration of the ecological functions and that, in this period, the number of species used was not enough to reach stability and resilience.

In terms of management, it is important to note that SMA Resolutions no. 08/2008 and SMA no. 44/2008 (São Paulo, 2008a, 2008b) recommended that AFSs could be managed only up to three years after planting. By the set of indicators, it can be affirmed that the two AFSs (F and H) did not provide, until 48 months, similar ecological conditions to the restoration plantings (R and AR2) and still less to the reference fragment (AR1). This reinforces the necessity to carry out adaptive management practices, specifically the enrichment with other species, even after 48 months. From 2014, this condition was incorporated into SMA Resolution no. 32/2014, which replaced SMA no. 08/2008 (São Paulo, 2008a, 2014).

The data obtained strengthen the need to review not only the legal guidelines on restoration, but also the methodology used. Observing the legal terms, SMA Resolution no. 32/2014 incorporated the need for monitoring based on ecological indicators. According to the indicators in this resolution, the studied area (R), even at 60 months, still falls into the category of "criticism" due to the low soil covering with native vegetation, the low number of native regenerating species and to the density of regenerants, requiring intervention.

At the same time, regarding the biomass contribution, litter production presented a higher value for AR1, which produced 6,898.32 kg ha^{-1} $year^{-1}$. Among the analyzed models, the highest contribution was obtained from H with production of 3,189.85 kg ha^{-1} $year^{-1}$. The model F presented 2,430.32 kg ha^{-1} $year^{-1}$ and R, 1,856.78 kg ha^{-1} $year^{-1}$. Despite the contribution promoted, only H presented similar values to those from dry forests in the same region with 3.3 t ha^{-1} $year^{-1}$ to 8.0 t ha^{-1} $year^{-1}$ (Scoriza & Piña-Rodrigues, 2014) and those from other models of AFSs in legally protected riparian areas in the Atlantic Forest (Souza et al., 2016).

Table 4. Density, estimated carbon stock values, annual average increment (AAI) of carbon stock in living aboveground biomass for restoration and agroforestry systems in Porto Feliz, SP, 2012.

Area	Density (trees ha^{-1})	Age (months)	Carbon (t ha^{-1})	Carbon AAI (t ha^{-1} $year^{-1}$)
R	980	60	17.91	3.58
F	1420	48	34.09	8.52
H	1380	48	39.81	9.95

R: forest restoration; F: agroforestry system with forest species and pigeon pea; H: agroforestry system with forest species and vegetables crops.

Regarding the fixation of atmospheric carbon, H and F (Table 4) were superior to the 1-to-6-year plantations from the Paranapanema Valley, whose values ranged from 1.07 t ha^{-1} to 19.7 t ha^{-1} (Melo & Durigan, 2006). Although the indicators have shown less efficiency in the restoration of ecological functions, AFSs models have accumulated carbon in a greater proportion than the restoration (R), showing their potential in providing environmental services, regarding this parameter.

4. CONCLUSIONS

Up to 48 months, the agroforestry systems models studied did not promote the ecological functions restoration when compared to restoration areas, but were superior in terms of carbon fixing, especially in the sequential association of forest and short-cycle agriculture. The species diversity and the functional diversity were more important than management for the ecological restoration functions; however, the 48 months management was insufficient to allow the reestablishment of the expected ecological functions.

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