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Ecological restoration indicators in agroforestry systems in the Atlantic forest

Indicadores de restauração ecológica em sistemas agroflorestais na mata atlântica

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Abstract

The Agroforestry Systems (SAF) is forms of land use and land occupation in which woody plants are managed in association with herbaceous and agricultural ones with the potential to recover degraded areas. Thus, the monitoring and assessment of areas recovered with Agroforestry Systems are extremely important to evaluate if their environmental functions can be equivalent to the areas recovered only with native species. Thereby, the objective of this study was to evaluate, through forest restoration indicators, the recovery of ecosystem functions in a SAF implanted in Ribeirão Grande, São Paulo State. The sample design was completely randomized by 3 plots (15 x 15 m each) allocated in a SAF area and other 3 plots in a reforestation area with native species only (RN), both with five years old and in the same watershed. The indicators were crown diameter, forest litter stock, height and diameter above the base of the individual trees, soil temperature and moisture. The assumptions of normality and homogeneity of variance were verified through the Waste Analysis, with subsequent analysis using nonparametric Wilcoxon-Mann-Whitney test. Statistical analyzes were performed using the R software (R Development Core Team, 2012) with a significance level of 5% (α = 0.05). It is concluded that the recovery area only with native species presents better development of vertical structure, with greater canopy closure. For soil indicators there were no differences. Agroforestry systems run by natural succession can be an alternative to the recovery of degraded areas, because they are more similar to the structure of native forests.

Keywords*: Recovery of degraded areas; natural succession; ecosystem functions.*

Resumo

Os Sistemas Agroflorestais (SAFE) são formas de uso da terra e ocupação do solo em que plantas lenhosas são manejadas em associação com herbáceas e os agrícolas, com potencial para recuperação de áreas degradadas. Assim, o acompanhamento e avaliação de áreas recuperadas com sistemas agroflorestais são extremamente importantes para avaliar se as funções ambientais podem ser equivalentes as de áreas recuperadas apenas com espécies nativas. Desse modo, o objetivo deste estudo foi avaliar, através de indicadores de restauração florestal, a recuperação das funções ecossistêmicas em um SAF implantado em Ribeirão Grande, Estado de São Paulo. O desenho amostral foi inteiramente casualizado com 3 parcelas (15 x 15 m cada) alocadas em uma área de SAF e outras 3 parcelas em uma área de reflorestamento somente com espécies nativas (RN), sendo que ambos os tratamentos com cinco anos de idade e localizados na mesma bacia hidrográfica. Os indicadores foram diâmetro de copa, estoque serapilheira, altura e diâmetro acima da base das árvores individuais, temperatura do solo e umidade. Os pressupostos de normalidade e homogeneidade de variância foram verificados através da Análise de Resíduos, com posterior análise usando o teste não paramétrico de Wilcoxon-Mann-Whitney. As análises estatísticas foram realizadas utilizando o software R (R Development Core Team, 2012) com um nível de significância de 5% (α = 0,05). Conclui-se que a área de recuperação apenas com espécies nativas apresenta melhor desenvolvimento da estrutura vertical, com maior fechamento do dossel. Para os indicadores de solo não houve diferenças. Sistemas agroflorestais dirigidos pela sucessão natural podem ser uma alternativa para a recuperação de áreas degradadas, devido à maior semelhança com a estrutura de florestas nativas.

Palavras chave: Recuperação de áreas degradadas, sucessão natural, funções ecossistêmicas.

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1 Introduction

Agroforestry systems are use and occupation of land arrangement in which woody perennials are managed in association with herbs, shrubs, trees, crops, fodder and/or integration with animals, in the same management unit, according to one spatial and temporal settlement, with high species diversity and interactions among these components (PASSOS and COUTO, 1997).

These systems are an alternative to minimize environmental degradation, since there is better use of available natural resources (nutrients, water and light), and the tree component generally contributes to the protection and improvement of soil conditions. It increases nutrient cycling and reduces erosion (RODRIGUES et al., 2008).

According to Peneireiro (1999), the SAF, driven by natural succession and similar in structure and function to tropical forests, proved to be a promising alternative for the recovery of degraded areas. It enables economic return, aligning production with conservation of natural resources, including biodiversity, without the use of external inputs.

Resck et al. (1996) in a study conducted in the savannah concluded that agroforestry systems provided improved soil fertility, mainly due to higher biomass production.

Thus, SAF based on ecological restoration and commercial production emerge as a promising alternative in the Atlantic Forest region, given the fact its recognized potential for the rehabilitation of degraded areas and natural resource management, income generation and food security (VIEIRA et al., 2009).

The use of SAF for recovery of degraded areas and legal reserve is provided for in the Forest Code and it was regulated in São Paulo State through the publication of the State Department of Environment Resolution nº. 44/08, and it can be applied on small farms, up to 30 hectares, including the use of 50% of exotic species.

In Brazil, the SAF are typically introduced and managed according to two paradigms. The first one is forestry, facing the ecological rehabilitation of degraded areas. The second is agronomic, with primarily commercial purposes (MILLER, 2009).

Forestry SAF usually combine agricultural and forestry production through the knowledge of the ecological potential of harvested species, the pattern of development and natural regeneration of the species (functional group: pioneer and late), the density limit (carrying capacity) of viable species by area, among others (MILLER, 2009).

In this regard, a major problem for the recovery of degraded areas is the lack of scientific consensus on the most appropriate indicators for efficiency analysis of the forest restoration process and rehabilitation of ecological functions (SIQUEIRA and MESQUITA, 2007).

In general, however, the restoration of indicators should allow reviews that combine both structural as functional aspects of the local ecosystem, so that the dynamics of forest reconstruction is verified visually by the landscape and through the recovery of vital ecological processes for the conservation of biodiversity over time (RODRIGUES e GANDOLFI, 2004; BELLOTTO et al., 2009).

The monitoring and assessment of recovery areas are extremely important, considering the different situations in which the SAF are introduced. According to Ribeiro (2003) to assess the sustainability levels, it requires the use of appropriate indicators that can address social, economic and environmental dimensions.

From this, the objective of this study is to evaluate, through forest restoration indicators, the recovery of ecosystem functions in agroforestry system implanted in Ribeirão Grande, São Paulo State. The intention is to verify that the agroforestry methods introduced in the region are paying off for the ecological restoration of the area. In addition, it intends to select the most representative indicators for quality improvement of environmental compliance project and minimize monitoring costs.

2 Materials and methods

The research was conducted in SAF located in a rural area of Ribeirão Grande (24° 05' 56" S 48° 21' 54" O, 690 m), in Paranapanema upper basin county, southwest region of São Paulo State. Comprising 0.5 hectares of area total, the random sampling design was carried out by three land plots (15 x 15 m each) randomly allocated in a SAF area; and other 3 land plots (15 x 15 m each) in a reforestation with native species only (RN), both five years old, in the same watershed.

Restoration indicators used to assess ecological conditions of forest structure and functioning were: canopy diameter, forest litter stock, height and diameter above the base of the individual trees, temperature and soil moisture. The choice of this set is due to the easiness to apply, simple understanding, fast check and low cost, which can facilitate the frequent monitoring along the small farmers, besides the acquisition of specific and affordable results (WODA, 2009).

The diameter of the trees was inferred from measurements of the circumference of the base height, while the height information was obtained with the help of Vertex device. The forest litter material stored on the soil surface was collected randomly from each plot by means of three 1.0 x 1.0 m size PVC templates.

The litter stock sample in the intake site is due to two factors: 1) convenience, since the collection of senescent material from the contributed trees in the soil should be performed biweekly or monthly for obtaining viable estimates, and 2) as the litter is a decomposition initial extract and it will make nutrients available to the soil again, the template is the most direct sampling alternative of senescent material stock from trees. The supply of litter was weighed in a laboratory after oven drying for 72 h at 60° C.

In the same litter collection sites, it was also measured, through a thermohygrometer (0.5°C and 0.1% accuracy), the average variation in soil temperature and humidity.

The species occurring in the plots were identified by calculating the phytosociological parameters of relative frequency, relative density, relative dominance; percentage of coverage, value index of importance and classification of successional group. The species identification was made on the spot and classification adopted the APG III system (2009).

Data analysis

The assumptions of normality and homogeneity of variance were verified through the Waste Analysis. Later, according to the adhesion or not to the premises, the differences between treatments (SAF and RN) were determined using Analysis of Variance (ANOVA) of the structural variables (DAB, height and canopy diameter) and by non-parametric test of Wilcoxon-Mann-Whitney for the other variables (ZAR, 2004).

Similar to the unpaired t test, for the comparison of means among different treatments, the non-parametric test was used for variables that did not meet mainly the premise of homogeneity of variances, litter, temperature and humidity. Statistical analyzes were all performed using the R software (R Delopment Core Team, 2012) with a significance level of 5% (α = 0.05) (BOLKER, 2008; VERNABLES, SMITH, 2015).

3 Results and discussion

According to the results, it was evident the difference in development of ecological and forest conditions among treatments, especially for the variables corresponding to the tree structure and canopy closure. In this case, the height and diameter restore indicators were significantly different among treatments (Table 1).

This distinction, observed in the development of forestry structure and the size of trees, denotes a number of aspects that were expected, given the more adaptive character of restored areas only with native species. While in agroforestry systems, either forestry or conventional agronomic type, the goal of reforestation is coupled to the timber/non-timber production and fruit growing; in ecological restoration projects, the order becomes a priority for the recovery of natural conditions. Regardless of the ideal spacing planning and the restoration conduct, according to the environmental group of species (pioneer and late), the simple planting of native trees evidenced more adaptive due to greater phenotypic plasticity of local vegetation type species. In other words, the greatest potential of individuals to change their physiology and/or morphology because of environmental change, gives them greater strength and resilience (SCHLICHTING, 1986; BERKES, TURNER, 2006; SUDING, 2011).

In a study on the phenotypic potential of red Savannah Cherry (*Eugenia calycina*), Cardoso and Lomônaco (2003) identified the role of phenotypic plasticity to generate phenotypic variability and its relevance to the adaptive processes involved in the very formation of vegetation type paths of savannah biome.

In addition to the plasticity, the most adaptive potential of native species also is due to the increased possibility - in probabilistic terms - that they are allocated according to the most representative ecological groups of the successional stage of area development. These functional groups usually made by pioneer and late species, and/or secondary typical ones, have well-defined characteristics, which leads to general standards of reference for most tropical forests, regardless of their floristic composition (KAGEYAMA, GANDARA, 1998).

Table 1 - Mean (μ), standard deviation (± SD) and sample size (N) of the indicators in treatments agroforestry (SAF) and restoration with native (RN)

Indicators	SAF		RN	
	μ ± S.D.	N	μ ± S.D.	N
*Height**	2.23±0.70 a	38	3.63±1.59 b	43
*DAB**	7.88±5.69 a	38	12.14±7.53 b	43
Litter	0.66±0.25 a	9	1.86±1.22 b	9
Canopy diameter	1.4 ± 0.69 a	14	2.36 ± 1.07 b	18
Humidity	28.38±1.57 a	9	29.04±14.54 a	9
Temperature	19.44±0.52 a	9	19±2.91 a	9

Different letters in line represent difference statistics.
* Statistical significance a $\alpha \leq 1$ %

Table 2 -Phytosociological characterization of area of RN in Ribeirão Grande in 04/2013

Botanical family	Species	GS	F R (%)	D R (%)	Dom R (%)	P C (%)
Bignoniaceae	*Spathodea campanulata*	EX	4,2	1,6	0,2	1,7
Lythraceae	*Lafoensia pacari*	NP	8,3	3,1	0,1	3,3
Meliaceae	*Cedrella fissilis*	NP	8,3	6,3	2,1	8,4
Anacardiaceae	*Schinus molle*	P	8,3	9,4	2,7	12,0
	Schinus terebinthifolius	P	12,5	17,2	9,6	26,8
Myrtaceae	*Psidium guajava*	NP	12,5	7,8	1,4	9,2
Faboideae	*Erythrina speciosa*	P	12,5	15,6	31,1	46,7
Caesalpinaceae	*Schizolobium parahyba*	P	4,2	1,6	0,7	2,2
Caesalpinioideae	*Caesalpinia tinctoria*	NP	8,3	4,7	0,8	5,5
Mimosoideae	*Anadenanthera colubrina*	NP	8,3	26,6	51,0	77,6
Fabaceae	*Senna bicapsularis*	P	4,2	1,6	0,4	2,0
Rosaceae	*Eriobotrya japonica*	EX	4,2	1,6	0,0	1,6
Araucariaceae	*Araucaria angustifolia*	NP	4,2	3,1	0,0	3,1
	Total		100	100	100	200

GS: successional group; FR: relative frequency; DR: relative density; Dom R: relative dominance; PC: percent coverage; P: pioneer species; NP: late species; EX: exotic species.

Table 3 - Phytosociological characterization of areas of SAF in Ribeirão Grande in 04/2013

Botanical family	Species	GS	F R (%)	D R (%)	Dom R (%)	P C (%)
Fabaceae	*Myroxylon peruiferum*	NP	7,7	3,8	1,0	4,9
	Machaerium stipitatum	NP	7,7	3,8	1,4	5,3
	Not identified		7,7	3,8	2,2	6,0
Myrtaceae	*Eugenia involucrata*	NP	7,7	3,8	0,9	4,8
	Eugenia uniflora	NP	7,7	7,7	0,7	8,4
	Psidium guajava	NP	7,7	7,7	1,2	8,9
Malvaceae	*Luehea candicans*	NP	7,7	3,8	0,3	4,2
Faboideae	*Erytrina speciosa*	P	7,7	11,5	25,9	37,4
Anacardiaceae	*Schinus terebinthifolius*	P	7,7	7,7	8,7	16,4
Rutaceae	*Citrus* sp.	EX	7,7	23,1	46,2	69,3
Rosaceae	*Eriobotrya japonica*	EX	7,7	7,7	3,9	11,6
	Prunus persica	EX	7,7	3,8	3,1	6,9
Arecaceae	*Archontophoenix cunninghamiana*	EX	7,7	11,5	4,4	15,9
	Total		100	100	100	200

GS: successional group; FR: relative frequency; DR: relative density; Dom R: relative dominance; PC: percent coverage; P: pioneer species; NP: late species; EX: exotic species

In the case, considering that both areas have five years of age is to be expected that the reforestation with native has greater number and diversity of early or pioneer species that the SAF area. The later one presents more exotic species (Table 2 and Table 3), especially low height ones, contributing to lower canopy closure and it may influence other ecological characteristics of the area, especially over time. The difference in species composition can be observed by Sorensen similarity index, equal to 0.29.

It is observed in the area with RN that the distribution of successional groups are arranged according to the SMA Resolution 08/2008, which provides up to 60% of an ecological group, but the species *Anadenanthera colubrina* presents relative density above the permitted by this Resolution. The maximum allowable occurrence of a species is 20%. In addition, this species has dominance over 50%, compromising the environmental functions of the area.

The SAF, introduced for commercial purposes, has 46% of exotic species. This percentage is in line with the SMA Resolution 44/2008, which allows the use of these species for recovery of degraded areas. However, in the analyzed case, the small number of pioneer species ultimately reduces the canopy closure and the development of structure forest.

With the results, it is inferred that the SAF with agronomic bias, with greater occurrence of exotic low height species, geared for commercial purposes, does not give the same rehabilitation of degraded areas, compared to only native species recovery. In this case, if the purpose of SAF is the ecological rehabilitation of the area, natural agroforestry system is an option, which is similar in structure and function of tropical forests, presenting a promising alternative for the recovery of degraded areas, with the possibility of economic return, and conservation of natural resources, including biodiversity (PENEIREIRO, 1999).

According to Brancalion et al. (2012), a conservation action of the Atlantic Forest would be the implementation of agroforestry systems and/or silvicultural commercial plantations on the edge of the side forest fragments, in order to reduce the edge effect. These elements allow the biological flows in the landscape between forests in different stages of succession, increasing climax species. It also establishes ecological corridors, increasing functional connectivity between forest fragments.

As suggested by Vieira et al. (2009), the agrosucessional restoration, that incorporate a range of agroecological techniques and agroforestry systems as a transitional phase at the beginning of forest restoration, can also contribute to ecological restoration, increasing the area management period, bringing economic returns and food security to smallholders.

According to Rodrigues et al. (2008), agroforestry systems proved to be an important tool in the recovery of Legal Reserve areas in Paranapanema county - São Paulo State, among family farmers. They recommended its use in the restoration of ecosystems, as these can play an innovative role, reconciling restoration, conservation and production.

SAF usually combine agricultural and forestry production through knowledge of the ecological potential of harvested species, the pattern of development and natural regeneration of the species (functional group: pioneer and late species), the limit density (carrying capacity) of viable species by area, etc. (MILLER, 2009).

From the evaluated indicators, it is possible to identify better ecological recovery standard of the restored area with native species than with SAF. All indicators were lower in SAF than in RN, and only for climate variables - temperature and humidity - there were no significant difference.

Campanha et al. (2007), in a study on litter accumulation in agroforestry systems with coffee aged 14, found that SAF contributed with 6.1 mg ha^{-1} yr^{-1} of dry litter, while the monoculture contributed with 4.5 mg ha^{-1} yr^{-1}, and the agroforestry system presented higher moisture content of 20-40 cm. In our case, these variables showed no significant differences, which may be due to the age of the area, with only five years of implementation.

It appears that the crown diameter in SAF was significantly lower than in RN. This result can be explained by the need for high productivity in SAF, which favors the choice of deciduous species - with leaves falling in autumn and winter - or smallest canopy diameter to enable greater sunlight or smaller sized species, especially fruit trees, thus compromising the canopy closure.

In agroforestry coffee plantations, for example, producers usually prefer deciduous or semi-deciduous species such as *Luehea grandiflora*, *Senna macranthera*, *Erythrina verna*, among others, to encourage the entry of light in the system and thus decrease labor with constant pruning (DUARTE, 2007).

These results show, in a way, the strategic side of agroforestry plantation. While the smallest canopy diameter of SAF allows more sunlight in the system lines, increasing productivity; higher crown density increases, at least, the thermal comfort for rural workers.

In this sense, studying the shading and thermal comfort provided by arboreal species typical of urban environment, Labaki et al. (2011) found that the false Brazilwood (*Caesalpinia peltophoroides*), despite the considerably small leaves, was responsible for the highest solar radiation attenuation among all surveyed species. Despite the extremely tiny leaves, the geometry of false Brazilwood crown presents an efficient pattern of leaf overlap, responsible for great absorption of solar radiation (LABAKI et al., 2011).

However, despite the significant differences between treatments, the ability of SAF cannot be disregarded for the recovery of degraded areas, since for climatic variables (temperature and humidity); there was no significant difference from the reforestation with native species, as noted in Table 1.

With respect to forest litter in the area with RN, due to higher density, dominance and frequency of native species, with characteristics of semi-deciduousness, provided high accumulation compared to the SAF area, with a predominance of non-deciduous species, according to the data shown in Tables 2 and 3.

As stated by Silva (2002), regarding the degraded areas with agroforestry, the results indicated that it did not affect the biological properties of the soil, nor the growth of native trees. Although, it is worth noting that the opposite must also be evaluated in moderation, given the fact that other results indicate a structural development, litter and canopy cover delay, when compared to reforestation with native.

In this regard, Fearnside (2009) points out that the efficiency of SAF regarding the recovery of degraded areas is often exaggerated, being used as a justification to release unsustainable infrastructure projects. Newly deforested areas and less degraded soils will always be more profitable for the deployment of SAF, which makes the expansion of agroforestry systems dependent on subsidies for smallholders.

Daronco et al. (2012) found that the use of agricultural species in consortium with native ones to recovery riparian vegetation did not cause differences in the development of the seedlings as to the height, diameter and crown cover, besides mortality. In addition, it promoted economic returns using agricultural.

According to Brancalion et al. (2010), agroforestry and reforestation systems with exotic species are valuable for the restoration of environmental services, but these strategies should not be treated within the ecological restoration of megadiverse jungles, such as the Atlantic Forest, where the maintenance of forest services, including native biodiversity, should be the guiding central goal of the actions.

Finally, agroforestry systems geared to the recovery of degraded areas should prioritize management practices that meet the principles of the agrossucessional restoration, which Vieira et al. (2009) defines as the fusion of elements of the agro-ecology and agroforestry techniques to avoid the socioeconomic and ecological restoration obstacles along to small farmers. The strengthening of local initiatives and the involvement of farmers are, therefore, of vital importance to the success of this new type of restoration.

4 Conclusion

Although some of the used indicators demand greater sampling effort, most of them proved feasible and extremely applicable to the diagnosis of structural development and rehabilitation of ecological conditions of the areas. Thus, without ignoring the natural rehabilitation capacity and ecological sustainability of the SAF in relation to other forms of resources use, few studies using indicators for environmental services demonstrated the real potential for ecological restoration of agroforestry systems. Not that it is impossible to combine both restoration objectives and commercial production, but it is noted that the demands should be well established at all stages of the process, from planning, implementation, monitoring the development to the subsequent management by small producers. The steps needed for the restoration, besides the integration of local actors in decision-making, should make it clear what is the main objective to be achieved. Restoration with native species invariably present best environmental performance, however, regardless of the deployment strategy of projects - agronomic and forestry - costs must be passed on or minimally better redistributed among producers and other beneficiaries of the recovered area. Biodiverse successional SAF may present the best option to restore degraded areas, since they are closer to the structure and functions of natural forests.

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