Revista
ÁRVORE
ISSN 1806 – 9088

Scientific Article

LAND COVER EFFECTS ON REGENERANTS DENSITY AND RICHNESS IN RESTORATION TREATMENTS IN THE ATLANTIC RAINFOREST BIOME

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1 Received on 21.10.2023 accepted for publication on 08.05.2024.
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ABSTRACT

There is good evidence that the results of a restoration program depend largely on the landscape context. In restoration projects, it is crucial to consider the previous land uses and covers and landscape configuration as they have a significant impact on the entire process, especially seed dispersal and natural regeneration of sites. Thus, the objective of this work was to verify the effect of landscape (i.e., land use) on restoration success of total planting, seed sowing and natural regeneration sites in the Atlantic Forest biome, southeast Brazil. The methodology employed was based on demonstration units of restoration. The focus was on regenerant richness and abundance indicators, along with land use and land cover data (class area) from 2010, 2015, and 2020, obtained from the MapBiomas Project. Generalized linear models and correlation analysis were used for the study. We hypothesize that a landscape with more forest and natural regeneration cover (mosaic of agriculture and pasture) would positively affect regenerants in restored sites, which we only observed for natural regeneration treatment sites. In active restoration treatment sites, mosaic of agriculture and pasture was negatively and farming was positively associated to regenerants. We also found greater density and richness of regenerants in natural regeneration treatment sites than in seed sowing and seedling planting. The influence of the surrounding landscape, particularly mosaic, played a crucial role in this success. In addition, land use cover history, as we observed in classes in the last five and ten years, did explain regenerants in studied sites. Thus, results show that the characterization of landscape context and previous land-use history is essential to understand the limitations to succession and define cost-effective restoration strategies.

Keywords: Land use; Regeneration; Surrounding landscape

How to cite:
Luz, A. R. C., Massi, K. G., Pocius, O., Campos, M. M. S., & Santiami, E. L. (2024). Land cover effects on regenerants density and richness in restoration treatments in the Atlantic Rainforest biome. *Revista Árvore, 48*(1). https://doi.org/10.53661/1806-9088202448263729. Retrieved from https://www.revistaarvore.ufv.br/rarv/article/view/263729.

Revista ÁRVORE
ISSN 1806 – 9088

EFEITOS DA COBERTURA DO SOLO NA ABUNDÂNCIA E RIQUEZA DE REGENERANTES EM TRATAMENTOS DE RESTAURAÇÃO NO BIOMA MATA ATLÂNTICA

RESUMO – Há suficientes evidências de que os resultados de um programa de restauração dependem em grande parte do contexto da paisagem. Os usos e coberturas prévios da terra e a paisagem devem ser considerados nos projetos de restauração, pois influenciam todo o processo, especialmente na dispersão de sementes e na regeneração natural das áreas. Neste trabalho verificou-se o efeito da paisagem (uso do solo) no sucesso da restauração em áreas de plantio total, semeadura direta e de regeneração natural no bioma Mata Atlântica, sudeste do Brasil. A metodologia baseou-se em unidades demonstrativas de restauração, com foco nos indicadores de riqueza e abundância de regenerantes, juntamente com dados de uso e cobertura da terra das áreas entre os anos de 2010, 2015 e 2020, obtidos das Coleções MapBiomas. Aplicou-se modelos lineares generalizados e análise de correlação entre os dados. Nossa hipótese era que uma paisagem com mais cobertura florestal e de regeneração natural (mosaico de agricultura e pastagem) afetariam positivamente os regenerantes em locais restaurados, o que observamos apenas em áreas de tratamento de regeneração natural. Nos locais de restauração ativa, o mosaico de agricultura e pastagem foi negativamente associado e o uso agricultura foi positivamente associado aos regenerantes. Encontramos maior abundância e riqueza de regenerantes em locais de regeneração natural do que semeadura direta e plantio de mudas. A influência da paisagem, nomeadamente do mosaico, desempenhou um papel crucial neste sucesso. Além disso, o uso da terra, conforme observamos nos últimos cinco e dez anos, explicou os regenerantes nos locais estudados. Assim, os resultados mostram que o contexto paisagístico e o histórico anterior de uso do solo são essenciais para compreender as limitações à sucessão e definir estratégias de restauração custo-efetivas.

Palavras-Chave: Uso do solo; Regeneração; Paisagem do entorno.

1. INTRODUCTION

The Atlantic Forest biome, which originally covered from northeast to southeast Brazil, is a biodiversity hotspot (Myers et al., 2000). The main phytophysiognomies of Atlantic Forest are seasonal and tropical rainforests (IBGE, 2012). Due to intense deforestation and human disturbance that mostly occurred in the first half of the 19th century (Dean, 1996), only about 13% of Atlantic Forest biome native vegetation cover remains in Brazil (SOS Mata Atlântica and INPE, 2021). Nature reserves protect only 9% of the remaining forest (Ribeiro et al., 2009). Nonetheless, a net gain in native forest cover has occurred in recent decades (Rosa et al., 2021). Combined with market, demographic, and policy forces, recent forest restoration initiatives have promoted an Atlantic Forest biome landscape with many small islands of primary forest and secondary regenerating forest (Tabarelli et al., 2004; Rezende et al., 2015).

Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SER, 2004). Restoration efforts in some parts of Brazil have grown rapidly since about 2010, i.e., revisions to the national Native Vegetation Protection Law (Lei 12.651/Brasil, 2012) increased legal requirements (using a rural environmental registration policy) for forest recovery and conservation in areas with forest deficits like the Atlantic Forest biome (Soares-Filho et al., 2014). The National Policy for the Recovery of Native Vegetation of 2017 (Decreto 8.972/Brasil, 2017) promotes actions for the recovery of forests and other forms of native vegetation across Brazil. 2021-2030 is the United Nations Decade on Ecosystem Restoration (UN, 2023) and intense efforts by nongovernmental organizations to recover native Brazilian ecosystems also are occurring, as The Nature Conservancy, which has projects aiming to restore millions of hectares of Atlantic Forest restoration in Brazil (The Nature Conservancy: tnc.org.br, Programa Conservador da Mantiqueira).

Active (planting) and passive (natural regeneration) restoration are two important strategies to aid the recovery of large areas of deforested and degraded tropical lands (Morrison and Lindell, 2010). Among active restoration methods, planting of seedlings in total area has been mostly used in Atlantic Forest restoration (Brancalion et al., 2019b), while direct sowing is usually being implemented in Cerrado areas (Sampaio et al., 2019). In general, the presence of nearby old-growth forest remnants and high levels of seed dispersal make recovery (passive restoration) possible; however, under high disturbance conditions and with an absence of forest remnants a site may never return to a state similar to the original, and active restoration is needed (Brancalion et al., 2015). In both cases, a landscape with more native vegetation cover and choosing species properly may represent greater restoration success.

Landscape configuration, the distribution, size and abundances of forest patches, related to habitat fragmentation, isolation and distance to native vegetation sites, influences seed dispersal and vegetation regeneration processes (Jordano et al., 2006). These forest remnants might function as seed sources (through seed rain) to forest succession (Holl, 1999; Nuñez et al., 2021). It is well-known that native forest remnants positively influenced tropical forest regeneration in abandoned pasture areas (Aide et al., 2000; Charles et al., 2019) through seed rain (Lorenzon and Massi, 2023). However, if presence of tropical forest remnants or other land use and land cover may affect the effectiveness of active restoration is still to be investigated, but landscape configuration is expected to be related to biodiversity and ecological processes and consequently to recovery results. Thus, the interconnection between landscape metrics, biodiversity, ecological processes and restoration outcomes are scientific gaps and, in this study we aim to fill one of them, the effects of land use and cover, i.e., agriculture, forests and mosaics on restoration success.

Species selection might also affect planting and sowing endpoints and monitoring studies have been verifying that (Fiore et al., 2019; Pagoto et al., 2023, respectively). Furthermore, biotic interactions and the environment (such as soil, climate, and disturbances) would filter these species to site-specific conditions (Boukili and Chazdon, 2017). Assessment and monitoring of ecosystems under restoration are essential to track the effectiveness of trajectories towards the recovery of sites (Brancalion et al., 2015). In this context, we verified the effect of landscape (i.e. land use and land cover) on restoration success of total planting, seed sowing and natural regeneration sites in the Atlantic Forest biome, southeast Brazil. Thus, this study aims to analyze land use and land cover around restoration sites and to evaluate the role of this cover on density and richness of regenerants in restored sites. Our hypothesis is that a landscape with more forest and natural regeneration cover (mosaic of agriculture and pasture) would positively affect regenerants in restored sites.

2. MATERIAL AND METHODS

2.1 Study sites and restoration project

Study sites were restoration areas of the program Conservador da Mantiqueira by the NGO The Nature Conservancy (TNC). They are mostly hilly areas, in the Atlantic Forest biome in Minas Gerais and São Paulo state, southeast Brazil. Soil is mainly Latosols and the landscape is dominated by agriculture, as exemplified in the Machado demonstration unit (Figure 1 and Table 1). The Conservador da Mantiqueira program is an initiative that brings together several actors from 284 municipalities in southeast Brazil, to build a forest restoration network. The program is based on experiences from demonstration units of restoration sites implemented by TNC and local partners [https://www.tnc.org.br/o-que-fazemos/nossas-iniciativas/mantiqueira/].

After selecting DUs (Demonstration Units), in which TNC considered previous land use, planting was carried out (in 2020), using complete randomized blocks, using three treatments, namely: seed sowing (muvucas), total planting of seedlings and natural regeneration (only fencing), which were selected by the NGO. With regards to seed sowing and the total planting of seedlings, they were planted in 1 meter x 1 meter in pits, using native species (seed sowing also used green manure species). After one year of planting, monitoring was carried out based on the large plot method (25 m x 4 m transect), referring to individuals greater than 50 cm in height. Individuals of all life forms were sampled. Monitoring indicators were richness of regenerants and density of regenerants (regenerants were individuals higher than 50 cm in height and smaller than 15 cm in circumference at breast height), according to Resolution SMA 32/2014 (São Paulo, 2014), and were the response variables.

Revista ÁRVORE
ISSN 1806 – 9088

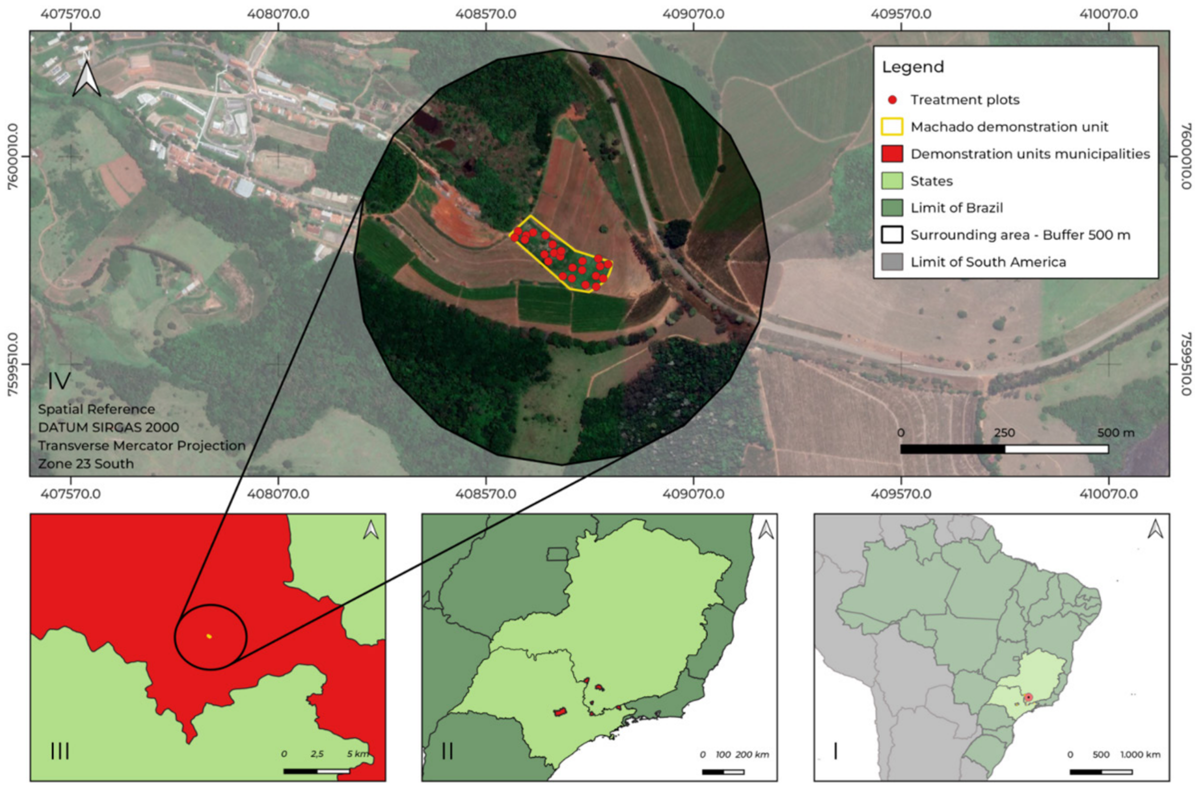

Figure 1. Treatment plots located in the Machado demonstration unit and in other municipalities in the states of Minas Gerais and São Paulo, Conservador da Mantiqueira restoration program, southeastern Brazil. I - Study area and its location in relation to the Brazilian border II - States and municipalities in which the areas studied are located, III - Detail and closer look at the municipality of Machado and IV - Detail of one of the restoration project areas (DU) showing the limit of the area and the surrounding area.

Figura 1. Parcelas de tratamento localizadas na unidade demonstrativa de Machado e em outros municípios dos estados de Minas Gerais e São Paulo do programa de restauração Conservador da Mantiqueira, sudeste do Brasil. I - Área de estudo e sua localização em relação à fronteira brasileira, II - Estados e municípios em que estão localizadas as áreas estudadas, III - Detalhe e visão mais próxima do município de Machado e IV - Detalhe de uma das áreas do projeto de restauração (UD) mostrando o limite da área e a área de entorno.

Table 1. Demonstration units (DUs), your average central coordinate and its hydrographic basin, climate, biome, soil, land use and relief in studied sites of Conservador da Mantiqueira restoration program, southeast Brazil.

Tabela 1. Unidades demonstrativas (UDs), suas respectivas coordenadas centrais médias e suas bacias hidrográficas, clima, bioma, solo, uso da terra e relevo nos locais estudados do programa de restauração Conservador da Mantiqueira, sudeste do Brasil.

DUs	Hydrographic basin	Climate	Biome	Soil	Land use	Relief
Cruzeiro (22°39'00''S, 44°57'12'' W)	Rio Paraíba do Sul	Cfa	Atlantic rainforest	Red-yellow Latosols	Agriculture (pasture), urban areas, native vegeta-tion	Hilly to mountains (15 a 24 degrees)

Cont...

Cont...

DUs	Hydrographic basin	Climate	Biome	Soil	Land use	Relief
Inconfidentes (22°18'23"S, 46°19'47"W)	Rio Grande	Cwb	Atlantic rainforest	Latosols, Gleysols, Cambisols	Agriculture (pasture and coffee), urban areas, native vegetation	Hilly to mountains
Machado (21°42'11"S, 45°52'55"W)	Rio Grande	Cwb	Atlantic rainforest	Red-yellow Latosols and Dystrophic red Latosols	Agriculture (pasture and coffee), urban areas, native vegetation	Hilly to mountains (8 to 45%)
Muzambinho (21°20'55"S, 46°32'05"W)	Rio Grande	Cwb	Atlantic rainforest	Dystrophic red Latosols	Agriculture (pasture and coffee), urban areas, native vegetation	Hilly to mountains (8 to 45%)
Piracicaba (22°48'13"S, 47°48'31"O)	Rio Piracicaba	Aw	Atlantic rainforest	Red-yellow Argisols and Neosols	Agriculture (sugar cane), urban areas	Flat

2.2. Landscape effects

In each Demonstration Unit, an average central coordinate was taken of all the plots within the restoration polygons in Cruzeiro, Inconfidentes, Machado, Muzambinho and Piracicaba, and a buffer around the central point (500 m), which is an appropriate distance for analyzing the effects of the landscape on restoration. This distance is based on studies that have evaluated the influence of the surrounding landscape on restoration areas (Souza et al., 2020; Gallé et al., 2022). In these studies, the buffer size ranged from 500 m to 1000 m. Thus, as our analyses were local and in smaller areas, the 500 m reference was applied. We used land use and land cover from MapBiomas Project (MapBiomas, 2021), with spatial resolution of 30 m, for the years 2010, 2015 and 2020 - Collection 6, available on the platform ([https://mapbiomas.org/]; Souza et al., 2020, from Série Anual of Soil Use and Cover in Brazil). Images have as spatial reference SIRGAS 2000 UTM Zone 23S. According to the land use and land cover classes available in Collection 6, we defined four classes: Forestry Formation; Farming, which encompassed the classes of planted forest, degraded pasture, sugarcane, soybean (agriculture), and other temporary crops; Mosaic of Agriculture and Pasture class, which can correspond to natural regeneration, and Non-Vegetation Area class, formed by urban infrastructure classes and other non-vegetated areas (in Figure 2 there is an example of buffer and classes) for the five demonstration units, Cruzeiro (CRZ), Inconfidentes (INC), Machado (MAC), Muzambinho (MUZ) and Piracicaba (PIR). The MapBiomas Collection was processed using The Google Earth Engine platform [https://earthengine.google.com] and QGIS 3.32, ArcMap 10.8 version (ESRI, 2020).

A 10-year historical series of land use and land cover was built (2010 - 2015 - 2020), in 500 m buffers, for five seedling planting plots, five direct muvuca plots and five natural regeneration sites in Cruzeiro (totaling 45 classified buffers of 500 m) and four plots of each treatment (totaling 36 classified buffers of 500 m in each DU), thus, in total there were 189 classified buffers of 500 m. Then, we used 2020 year classified buffers as references and subtracted differences from 2015 (five years of changes) and from 2010 (ten years of land use and cover change) for forest, farming and mosaic.

2.3. Statistical analysis

To access the effect of forest, mosaic and pasture cover (both current and past) on the density and richness of regenerants, generalized linear models (GLMs) were

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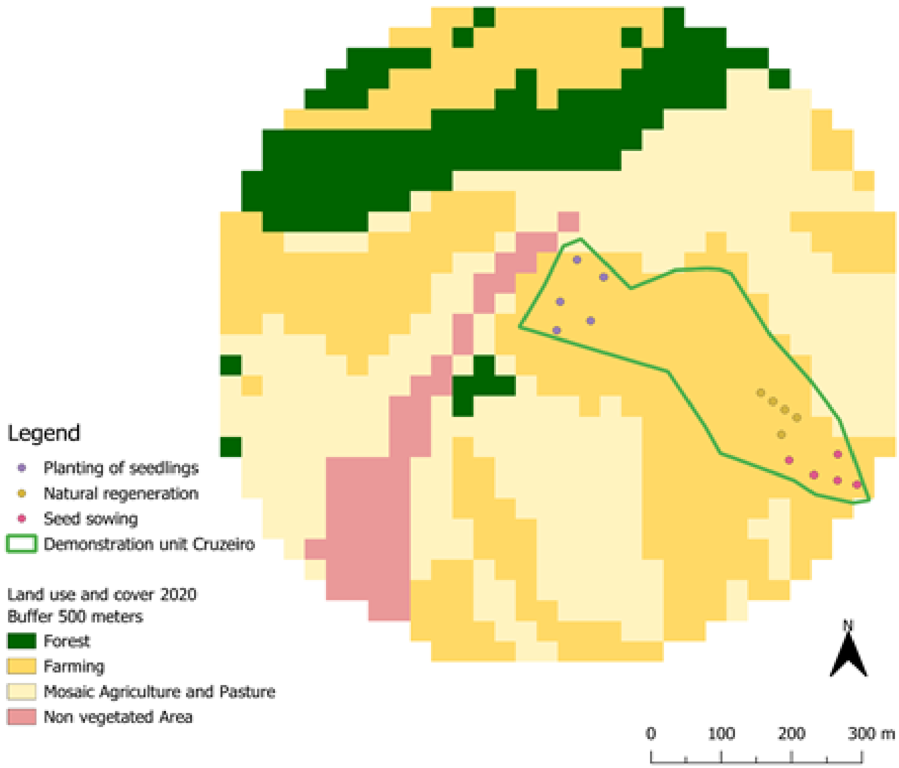

Figure 2. Example of a 500 m buffer around plots and land use and land cover classes in a demonstration unit, Conservador da Mantiqueira restoration program, southeast Brazil.

Figura 2. Exemplo de um buffer de 500 m ao redor das parcelas e classes de uso e cobertura da terra em uma das unidades demostrativas do programa de restauração Conservador da Mantiqueira, sudeste do Brasil.

adjusted, using a Poisson distribution for richness and a negative binomial distribution for density (McCullagh and Nelder 1989, Hilbe 2014). We chose the negative binomial distribution for modeling density of regenerants because overdispersion of residues (residual overdispersion) was detected in the modeling using Poisson distribution (the same did not happen for richness), where the input data were land use and cover classes in the three years analyzed for each DU in each of restoration plots. Models were adjusted separately for the three different restoration methods studied (seedling planting, seed sowing and natural regeneration). Because there was strong multicollinearity between land use and land cover variables, we decided to carry out three sets of regressions, one for each type of cover, being the current value (2020) and changes in five and ten years the explanatory variables for each model. These correlation coefficients between restoration methods and land use and land cover variables were the output data of analysis for both the abundance and richness of regenerating plants. Significant predictors were identified through a model selection procedure that considered all possible combinations of variables and ranked them according to the Akaike Information Criterion corrected for small sample sizes - AICc, Burnham and Anderson 2002). Analyzes were performed using R version 4.1.2 (R Core Team 2021) and packages “stats” (R Core Team 2021) for GLMs with Poisson distribution, “MASS” (Venables and Ripley 2002) for GLMs with negative binomial distribution and “performance” (Lüdecke et al. 2021) for calculating the AICcs.

3. RESULTS

In 2020, agriculture and pastures dominated in buffers around seed sowing and natural regeneration treatments, while mosaic dominated around seedling planting treatments (Table 2). Throughout treatments native forest and mosaic covers were lost, while farming cover increased in the last ten years; in the last five years (Table 2) forest increased slightly, mosaic increased more and farming decreased (Table 2). Regenerants density and richness were higher in natural regeneration sites, followed by seed sowing and seedling planting (Table 2).

In general, most models were explained by the three variables together (a land use and land cover in 2020, in the last five and ten years: Table 3). In addition, we observed that forest (+) and mosaic (-) covers in the last ten years, mosaic (+) and farming (-) covers in the last five years and mosaic (-) and farming covers (+) in 2020 strongly affected response variables (Table 3).

In regeneration sites, regenerants density and richness were largely explained by forest cover (+) in the last ten (Figure 3A) and by the mosaic (+) and farming (-) in the last five years, while the current land use and cover was not associated with regenerants (Table 3A and D, reduced model results). In both cases, effects had the same relations but they were more than double for regenerants density than for richness, i.e. (-0.88 for density and -0.31 for richness under farming: Table 3A and D, reduced model results). Cover of farming had the greatest negative effect on density and of mosaic, the greatest positive, on richness, for natural regeneration (Table 3A and D).

In seedling planting sites, regenerants density and richness were largely explained by mosaic (-) and farming (+) cover in the current year and by the mosaic (-) in the last ten years (Table 3B and E). Also, effects had the same relations but they were more than double for density than for richness, i.e. (1.47 for density and 0.65 for richness under farming: Table 3B and E, reduced model results). Cover of farming had the greatest negative effect on density and of mosaic, the greatest positive, on richness, for seedling (Table 3B and E and Figure 3B).

Regarding seed sowing, regenerating density was positively linked to farming (Figure 3C) in the current year and negatively in the last five years and to mosaic in the last ten (Table 3C and F). Richness of regenerants in seed sowing treatments was only affected positively by mosaic in the last five years (Table 3C and F). Effects did not have the same relations, but were higher for density than for richness, especially a strong negative effect of

Table 2. Average percentage cover of forest, mosaic and farming in 2020, in the last five and ten years in natural regeneration, seedling planting and seed sowing treatments in Conservador da Mantiqueira restoration program, southeast Brazil.

Table 2. Cobertura percentual média de floresta, mosaico e agricultura em 2020, nos últimos cinco e dez anos nos tratamentos de regeneração natural, plantio de mudas e semeadura direta no programa de restauração Conservador da Mantiqueira, sudeste do Brasil.

	Natural regeneration	Seedling planting	Seed sowing
Forest 2020	10.03	12.45	8.97
Forest in the last 5 years	0.07	0.14	-0.51
Forest in the last 10 years	-0.26	-0.02	-1.33
Mosaic 2020	29.80	31.23	29.82
Mosaic in the last 5 years	2.61	3.60	3.56
Mosaic in the last 10 years	-1.50	-0.67	-0.64
Farming 2020	33.71	28.86	35.28
Farming in the last 5 years	-2.83	-3.82	-3.11
Farming in the last 10 years	1.01	0.28	1.23
Regenerants density	18.38	9.28	11.20
Regenerants richness	3.20	1.85	2.60

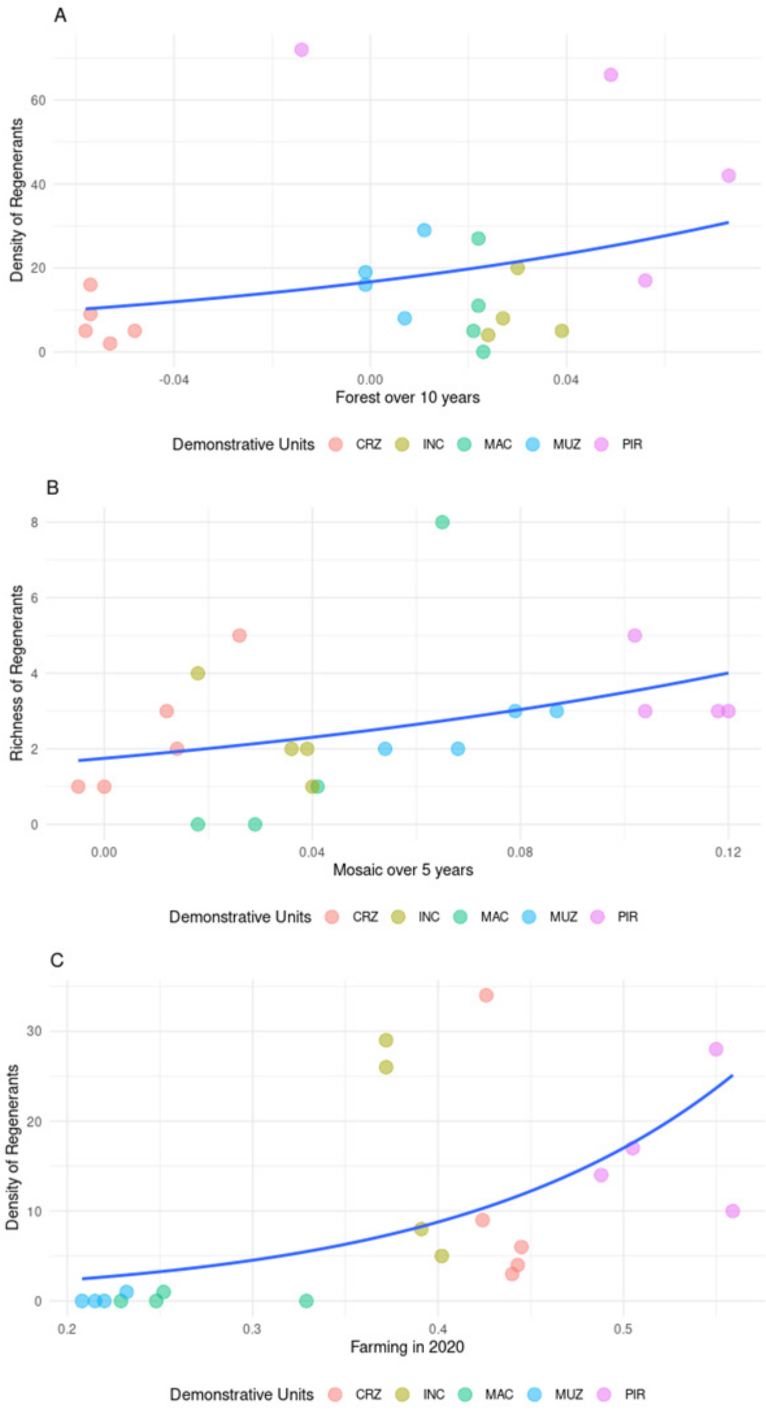

Figure 3. Relationship between variables: (A) forest in the last ten years and regenerants abundance in natural regeneration sites. (B) mosaic in the last five years and regenerants richness in seed sowing sites, and (C) and farming in 2020 and regenerants abundance in seedling planting sites, Conservador da Mantiqueira restoration program, in the demonstration units: Cruzeiro (CRZ), Incofidentes (INC), Machado (MAC), Muzambinho (MUZ) e Piracicaba (PIR), southeast Brazil.

Figure 3. Relação entre as variáveis: (A) floresta nos últimos dez anos e abundância de regenerantes em locais de regeneração natural. (B) mosaico nos últimos cinco anos e riqueza de regenerantes em locais de semeadura direta, e (C) agricultura em 2020 e abundância de regenerantes em locais de plantio de mudas do programa de restauração Conservador da Mantiqueira, nas unidades demonstrativas: Cruzeiro (CRZ), Incofidentes (INC), Machado (MAC), Muzambinho (MUZ) e Piracicaba (PIR), sudeste do Brasil.

Table 3. Regenerant density (A, B and C) and richness (D, E and F) of the natural regeneration treatment (A and D), seedling planting (B and E) and seed sowing (C and F). Full and Reduced models. P-values <0.05 represent significant variables.

Table 3. Densidade de regenerantes (A, B e C) e riqueza (D, E e F) do tratamento de regeneração natural (A e D), plantio de mudas (B e E) e semeadura direta (C e F). Modelos cheios e reduzidos. P-valores <0.05 representam variáveis significativas.

	Forest				Mosaic				Farming			
	Full		Reduced		Full		Reduced		Full		Reduced	
Predictors	Estimates (SE)	p	Estimates (SE)	p	Estimates (SE)	p	Estimates (SE)	p	Estimates (SE)	p	Estimates (SE)	p
A												
(Intercept)	2.71 (0.21)	<.001	2.72 (0.20)	<.001	2.63 (0.17)	<.001	2.65 (0.17)	<.001	2.65 (0.20)	<.001	2.65 (0.18)	<.001
2020 (current)	-0.30 (0.37)	0.413			0.20 (0.30)	0.499			0.52 (0.81)	0.523	0.45 (0.24)	0.056
5 years	-0.42 (0.53)	0.436	-0.64 (0.38)	0.089	0.46 (0.33)	0.171	0.70 (0.19)	<.001	-0.91 (0.47)	0.051	-0.88 (0.21)	<.001
10 years	0.72 (0.22)	<.001	0.71 (0.23)	0.002	-0.33 (0.24)	0.17			-0.06 (0.52)	0.914		
Observa-tions	21		21		21		21		21		21	
Nagelke-rke's R2	0.60		0.56		0.82		0.76		0.76		0.76	
p-value	0.011		0.006		< .001		< .001		0.001		< .001	
B												
(Intercept)	2.29 (0.26)	<.001	2.23 (0.28)	<.001	1.51 (0.37)	<.001	1.50 (0.36)	<.001	1.62 (0.33)	<.001	1.73 (0.36)	<.001
2020 (current)	-0.61 (0.34)	0.070			-1.35 (0.47)	0.004	-1.24 (0.40)	0.002	3.01 (0.85)	<.001	1.47 (0.21)	<.001
5 years	0.70 (0.53)	0.184			0.16 (0.53)	0.765			-0.04 (0.26)	0.882		
10 years	-0.43 (0.40)	0.284	-0.06 (0.29)	0.843	-0.79 (0.40)	0.048	-0.92 (0.26)	<.001	-1.51 (0.83)	0.068		
Observa-tions	21		21		21		21		21		21	
Nagelke-rke's R2	0.09		0.004		0.72		0.72		0.70		0.62	
p-value	0.710		0.854		0.002		< .001		0.002		< .001	
C												
(Intercept)	2.37 (0.23)	<.001	2.41 (0.20)	<.001	2.31 (0.21)	<.001	2.34 (0.20)	<.001	2.29 (0.23)	<.001	2.31 (0.21)	<.001
2020 (current)	-0.62 (0.34)	0.070			-0.44 (0.67)	0.511			1.24 (0.66)	0.060	0.55 (0.18)	0.002
5 years	0.73 (0.62)	0.238			0.45 (0.58)	0.438			-0.93 (0.39)	0.017	-0.55 (0.16)	<.001
10 years	-0.22 (0.43)	0.606	0.08 (0.22)	0.717	-0.07 (0.39)	0.849	-0.43 (0.12)	<.001	-0.60 (0.52)	0.247		
Observa-tions	21		21		21		21		21		21	

Cont...

Cont...

Predictors	Forest				Mosaic				Farming			
	Full		Reduced		Full		Reduced		Full		Reduced	
	Estimates (SE)	p	Estimates (SE)	p	Estimates (SE)	p	Estimates (SE)	p	Estimates (SE)	p	Estimates (SE)	p
C												
Nagelkerke's R2	0.14		0.012		0.34		0.27		0.43		0.38	
p-value	0.556		0.681		0.134		0.037		0.061		0.042	
D												
(Intercept)	1.11 (0.15)	<.001	1.11 (0.14)	<.001	1.11 (0.14)	<.001	1.11 (0.13)	<.001	1.09 (0.13)	<.001	1.12 (0.13)	<.001
2020 (current)	-0.45 (0.28)	0.110	-0.33 (0.19)	0.079	-0.10 (0.25)	0.694			0.80 (0.59)	0.170		
5 years	0.16 (0.27)	0.570			0.43 (0.24)	0.072	0.33 (0.12)	0.006	-0.71 (0.40)	0.073	-0.31 (0.12)	0.010
10 years	0.29 (0.16)	0.070	0.32 (0.12)	0.007	0.10 (0.22)	0.654			-0.53 (0.37)	0.153		
Observations	21		21		21		21		21		21	
Nagelkerke's R2	0.41		0.39		0.39		0.38		0.51		0.31	
p-value	0.067		0.034		0.077		0.010		0.024		0.022	
E												
(Intercept)	0.58 (0.24)	0.014	0.62 (0.21)	0.004	0.28 (0.26)	0.271	0.28 (0.24)	0.247	0.39 (0.24)	0.109	0.43 (0.22)	0.056
2020 (current)	-0.19 (0.37)	0.614			-0.71 (0.40)	0.073	-0.71 (0.30)	0.016	1.16 (0.68)	0.087	0.65 (0.20)	<.001
5 years	0.50 (0.59)	0.400			-0.003 (0.35)	0.994			0.07 (0.16)	0.651		
10 years	-0.39 (0.39)	0.309	-0.09 (0.19)	0.629	-0.54 (0.30)	0.067	-0.54 (0.17)	0.002	-0.47 (0.71)	0.506		
Observations	21		21		21		21		21		21	
Nagelkerke's R2	0.15		0.02		0.67		0.67		0.64		0.59	
p-value	0.432		0.578		< .001		< .001		0.002		< .001	
F												
(Intercept)	0.92 (0.19)	<.001	0.94 (0.17)	<.001	0.89 (0.17)	<.001	0.91 (0.17)	<.001	0.92 (0.20)	<.001	0.92 (0.17)	<.001
2020 (current)	0.09 (0.47)	0.842			-0.45 (0.42)	0.285			0.41 (0.75)	0.583		
5 years	-0.57 (0.55)	0.295	-0.08 (0.16)	0.606	0.70 (0.46)	0.124	0.27 (0.12)	0.024	-0.41 (0.35)	0.246	-0.21 (0.16)	0.201
10 years	0.46 (0.29)	0.111			0.34 (0.40)	0.391			-0.24 (0.48)	0.617		
Observations	21		21		21		21		21		21	
Nagelkerke's R2	0.18		0.02		0.32		0.23		0.19		0.13	
p-value	0.394		0.553		0.127		0.050		0.357		0.149	

farming (Table 3C and F). Seed sowing was the treatment with smaller fitness of models (Table 3).

4. DISCUSSION

In this study, we verified the effect of land use and land cover on restoration success of total planting, seed sowing and natural regeneration sites in the Atlantic Forest biome, southeast Brazil. Our hypothesis was that a landscape with more forest and mosaic cover would positively affect regenerants in restored sites, which we only observed for natural regeneration treatment sites. In active restoration treatment sites, mosaic was negatively and farming was positively associated to regenerants.

Farming dominated in buffers, but through the last five years this cover has been decreasing; on the other hand, forest and mosaic (considered sites of abandoned pastures that are regenerating) together, represented land covers that have been generally increasing in the last five years. In the Atlantic rainforest, the study site, a net gain in native forest cover has occurred in recent decades (Rosa et al., 2021). Some studied regions were hilly, native vegetation covers mountains and agriculture is mostly family farming (as Inconfidentes and Muzambinho), while another was large scale commodities agricultural sites, with very low native vegetation cover and natural regeneration (as Piracicaba).

We verified greater density and richness of regenerants in natural regeneration treatment sites than seed sowing and seedling planting. A meta-analysis showed that natural regeneration surpasses active restoration in achieving tropical forest restoration success for plant biodiversity (34 to 56% higher in natural regeneration than in active restoration systems) and for structure (cover, density, litter, biomass, and height, from 19 to 56%: Crouzeilles et al., 2017). Furthermore, natural regeneration and assisted regeneration approaches are cheaper, but performed in the minority of restoration projects in Amazon, Cerrado, and Atlantic Forest (Brancalion et al., 2019a). Especially in the studied regions, with great native vegetation cover and forest fragments, this passive technique may be beneficial, as the study showed. In addition, management treatments in the initial phase of total planting, or other management practices, may have suppressed part of natural regeneration in active restoration sites. Lastly, there might have been a significant mortality of seedlings and seeds in the field, reflecting on regenerants. In the second place of regenerants, seed sowing may facilitate forest regeneration as it presents higher plant density in the early stages, which could benefit forest structure formation. That high density of plants might also attract fauna, that brings exogenous seeds.

We found that native forest and mosaic cover on buffers had a positive influence on regenerants. The landscape of Atlantic Forest biome consists of many islands (mostly less than 50 ha) of old growth forests and secondary forest and abandoned pastures undergoing regeneration (Ribeiro et al., 2009). Presence of forest patches (large and small) has important roles in providing seeds to regenerating sites (Lorenzon and Massi, 2023). Accordingly, pasture landscapes, especially hilly areas that are not prone to agricultural activities, if abandoned, have higher forest regrowth potential (Schweizer et al., 2022) than large scale and commodities agriculture landscapes (as sugarcane found in Piracicaba Demonstrative Unit). Regenerated forests have greater probability of occurrence and persistence in steeper slopes, close to rivers and existing forests (Piffer et al., 2022). The studied region, around Mantiqueira mountain chains and Paraíba do Sul river basin is under increasing native vegetation and natural regrowth (Silva et al., 2017; Sapucci et al., 2022), which may be reflecting on greater density and richness of regenerants in all this landscape.

On the other side, regenerants on seedling planting and seed sowing treatment sites were positively linked to farming and negatively related to mosaic. That is probably explained by the fact that sites that are under active restoration are not placed in regions that are able to naturally be restored, and then, there is an intrinsic correlation between farming and active restoration sites. Despite, around Mantiqueira mountain chains and Paraíba do Sul river basin natural regenerated sites have been increasing, active restoration has a high priority due to extensive farming land use and land cover and to deforested permanent protected areas. However, seedling planting, seed sowing and regenerants in previous farming areas suffer from several abiotic restrictions, such as soil compacting and

Revista ÁRVORE
ISSN 1806 – 9088

low water availability (Jipp and Markham, 1998) and management strategies, such as fertilization and invasive Brachiaria species suppression.

Lastly, it is noteworthy that land use and land cover history, as we observed in classes in the last five and ten years, did explain regenerants in studied sites. Successional pathways depend on intensity, spatial extent, frequency, duration and management practices of land uses and the characterization of landscape context and previous land use history is essential to understand the limitations to succession and therefore to define cost effective restoration strategies (Jakovac et al., 2021). Limitations of this study rely on the different analysis scales (smaller in restored plots and greater in the landscape), age of restoration sites (young), only one landscape metric used (land use and cover) and different reference ecosystems (seasonal and tropical forests). Availability of better resolution images could help to perform more fine landscape analysis. We filled one scientific gap by understanding the effects of land use and cover, i.e., agriculture, forests and mosaics on restoration success.

5. CONCLUSION

The analysis of land cover and land use areas and the use of statistical models validated our hypothesis, indicating that buffers with greater forest cover and landscape mosaic are positively associated with regenerants in the areas studied. In addition, natural regeneration was more successful than active restoration, showing a notable increase in the abundance and richness of regenerants, which was strongly explained in the model. The influence of the surrounding landscape, particularly abandoned areas in natural regeneration (mosaic), played a crucial role in this success.

The use of statistical models to analyze land use history in restoration areas provides a more comprehensive understanding of the complex relationships between regenerant density and richness, treatment types and landscape dynamics in different locations. This contributes to the formulation of economically viable and sustainable restoration strategies, while also improving knowledge about the factors that affect restoration success.

This study focused specifically on the influence of landscape factors (land use and class area) on the density and richness of regenerants in different restoration treatments. Correlation analysis was used to examine the relationship between these variables. In future studies, the exploration of other landscape metrics, such as connectivity, fragment size and edge effect, and relate them to the same response variables of regenerant density and richness, could provide an even more comprehensive understanding and provide new perspectives for improving ecological restoration strategies in Atlantic Forest ecosystems.

6. ACKNOWLEDGEMENTS

We thank to The Nature Conservancy for data availability. Klécia Massi is PQ2-CNPQ granted 309541/2022-0

AUTHOR CONTRIBUTIONS

Massi, K.: Conceptualization, Writing - Original Draft, Data Curation. Simões, O.: Data Analysis, Statistical Analysis, Writing - Review & Editing. Luz, A.: Data Collection, Data Analysis, Statistical Analysis, Writing - Original Draft. Campos, M.: Data Collection, Writing - Review & Editing. Santiami, E.: Data Collection, Writing - Review & Editing.

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