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Articles

Testing different monitoring protocols for restoration sites in highlands of southeast Atlantic Forest biome

Testando diferentes protocolos de monitoramento para sítios de restauração em terras altas do sudeste do bioma Mata Atlântica

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ABSTRACT

Assessment and monitoring of restored forests are essential to correct and improve restoration techniques, especially in tropical ecosystems. Our objective was to monitor direct sowing restoration sites in highland Atlantic forest in southeast Brazil and compare different methods to assess recovery success. Monitoring protocols use different methodologies. The study sites were three rural areas located in the buffer zone of the Serra do Mar State Park, in the mountainous region of Cunha. We monitored direct seeding restoration sites using five different protocols (large plot, subplot, small plot, transect line and touch) after six months of planting and and until one year after that. We expected to observe a progressive restoration path in the one year observation, which we found, and that different sampling methods would produce different results and, on the contrary, we observed similarities in monitoring protocols in relation to the total richness and abundance of plant species. Despite this, we found that the large plot method was the best when compared to the others in terms of monitoring species abundance and that the touch method proved to be more efficient for monitoring species richness. Studies testing different monitoring methods are scarce and should be sought out, especially in the United Nations Decade for Ecosystem Restoration.

Keywords: Methods; Protocols; Direct seeding; Richness; Abundance

RESUMO

A avaliação e o monitoramento de florestas restauradas são essenciais para corrigir e melhorar as técnicas de restauração, especialmente em ecossistemas tropicais. Nosso objetivo foi monitorar sítios de restauração com semeadura de sementes na Mata Atlântica de altitude no sudeste do Brasil e comparar diferentes métodos para avaliar o sucesso da recuperação. Os protocolos de monitoramento utilizam metodologias diversas. Os locais de estudo foram três áreas rurais localizadas na zona de amortecimento do Parque Estadual da Serra do Mar, na região serrana de Cunha. Monitoramos os locais de restauração por semeadura direta utilizando cinco protocolos diferentes (parcela grande, subparcela, parcela pequena, linha de transecto e toque), após seis meses de plantio e até um ano depois. Esperávamos observar um caminho progressivo de restauração na observação de um ano, o que encontramos, e que diferentes métodos de amostragem produziriam resultados diferentes e, pelo contrário, observamos semelhanças nos protocolos de monitoramento em relação à riqueza total e abundância de espécies vegetais. Apesar disso, verificamos que o método das parcelas grandes foi melhor quando comparado com os restantes em termos de monitoramento da abundância de espécies e que o método do toque se revelou mais eficiente no monitoramento da riqueza de espécies. Os estudos que testam diferentes métodos de monitoramento são escassos e devem ser procurados, especialmente na Década das Nações Unidas para a Restauração dos Ecossistemas.

Palavras-chave: Métodos; Protocolos; Semeadura direta; Riqueza; Abundância

1 INTRODUCTION

The Atlantic Forest biome, which originally covered from northeast to southeast Brazil, is a biodiversity hotspot (MYERS, MITTERMEIER, MITTERMEIER, FONSECA & KENT, 2000). 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 (Fundação SOS Mata Atlântica, 2018). Nature reserves protect only 9% of the remaining forest (RIBEIRO, METZGER, MARTENSEN, PONZONI & HOROTA, 2009). Nonetheless, a net gain in native forest cover has occurred in recent decades (ROSA, BRANCALION, CROUZEILLES, TAMBOSI, PIFFER, LENTI, HORITA, SANTIAMI & METZGER, 2020). 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 (OBSERVATÓRIO DA RESTAURAÇÃO E REFLORESTAMENTO, [2021]). However, restoration of highland forests in this biome and ecosystem service provision is initial (SILVA, MILLINGTON, MORAN, BATISTELLA & LIU, 2020).

Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SER, 2004, p.3). Restoration efforts in some parts of Brazil have grown rapidly since about 2010, i.e., revisions to the national Forest Code (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, RAJÃO, MACEDO, CARNEIRO, COSTA, COE, RODRIGUES & ALENCAR, 2014). From 2021 to 2030 is the United Nations Decade on Ecosystem Restoration (DECADE ON RESTORATION [2023]), restoration of terrestrial ecosystems is among UN Sustainable Development Goals (UNITED NATIONS DEVELOPMENT PROGRAMME, 2022) and, thus, intense efforts by nongovernmental organizations to recover native Brazilian ecosystems are occurring.

Active (planting) and passive (natural regeneration) restoration are two important strategies to aid the recovery of large areas of deforested and degraded tropical lands (BRANCALION, GANDOLFI, RODRIGUES, 2015). Among active restoration methods, direct seeding is usually being implemented in Cerrado areas (SAMPAIO, VIEIRA, HOLL, PELIZZARO, ALVES, COUTINHO, CORDEIRO, RIBEIRO & SCHMIDT, 2019) and a few studies have been conducted about this technique in the Atlantic Forest biome (MELI, ISERNHAGEN, BRANCALION, ISERNHAGEN, NEHLING & RODRIGUES, 2017; PAGOTO, MASSI, COLLARD, 2022). Direct seeding has been gaining prominence in some areas of the country due to its effectiveness and because it is a relatively low-cost technique that allows the simultaneous introduction of native and exotic seeds of different growth forms and ecological groups (LEÃO, BRAGA, PEREIRA & SANTOS, 2022; PALMA & LAURANCE, 2015), eliminating the need to produce and transport seedlings. The technique allows mechanization and a greater density and richness of planted species and produces communities that are more adapted to the local environmental conditions (BRANCALION, GANDOLFI, RODRIGUES, 2015).

The assessment and monitoring of restored forests are essential for correcting and improving restoration techniques, especially in tropical ecosystems (BRANCALION, GANDOLFI, RODRIGUES, 2015). Monitoring is possibly the most important step in a restoration project, since it allows researchers to evaluate, through indicators, the responses of a degraded area to treatments. In this sense, monitoring becomes fundamental to redefine the successional trajectory of an area, as through it one can identify if an area declines or has low potential for future sustainability, thus avoiding waste of resources and time (BRANCALION, VIANI, RODRIGUES, GANDOLFI, 2013). Some studies performed in tropical environments highlight the importance of monitoring for restoration (MASSI, FIORE, FERREIRA, DZEDZEJ, 2019). However, the difficulty in carrying out these studies relates to the fact that monitoring is performed mostly to fulfill legal commitments. In addition, the lack of consensus in scientific literature on the most appropriate indicators for assessing the success of tropical forest restoration and, consequently, the associated environmental gains and high costs of implementation are important obstacles for monitoring neotropical rain forest restoration (CHAVES, DURIGAN, BRANCALION & ARONSON, 2015; BRANCALION, GANDOLFI, RODRIGUES, 2015). Even more scarce are monitoring studies evaluating efficiency of direct seeding in highland sites in the Atlantic Forest biome.

Monitoring protocols use diverse methodologies, indicators and sample sizes. Regarding how to collect data, plots can be transects of 25 x 4 m for example, in the legal protocol of São Paulo state (Resolution SMA 32/2014, Governo do Estado de São Paulo, 2014). In another legal requirement, a simplified protocol by walking on the restoration site and observing indicators is recommended (Resolution SAA/SIMA 01/2022, Governo do Estado de São Paulo, 2022). A study showed that different plant inventory methods, as plots and walking paths, can produce different results (WALTER & GUARINO, 2006).

Thus, this study aims to monitor restoration sites in highland Atlantic forest in southeast Brazil and to compare different methods to assess the recovery success. We expected to observe a progressive path of restoration in the one year observation and that different methods would produce different results. Despite the short duration of inventories and the early stage of the restoration project, this study is important to better understand effectiveness of monitoring methods and of direct seeding for restoration in Atlantic Forest.

2 METHODS

2.1 Study site and restoration project

The study sites were three rural areas located in the buffer zone of Serra do Mar State Park (PESM), nucleus Cunha, Paraíba do Sul river valley, southeast Brazil. Since 18th century, the Paraíba valley has experienced a suppression of its native vegetation (DEVIDE, CASTRO, RIBEIRO, ABBOUND, PEREIRA & RUMJANEK, 2014). The region is under the influence of the Cfb Köppen climate type, with an average annual temperature of 16.68°C and average annual precipitation of 1778.30 mm and a season with low precipitation between May and September (ALVARES, STAPE, SENTELHAS, DE MORAIS GONÇALVES & SPAROVEK, 2013). Soil is classified as Red-Yellow Latosol (Ministério da Agricultura, 1960) and the vegetation natural area that covers this relief is called Dense Ombrophilous Forest (IBGE, 2012).

PESM buffer zone is located in a 10 km buffer of park limits (Resolution CONAMA 13/1990, Brasil, 1990) and it has many rural lands on it without native vegetation. The PESM is located in a wide area of the Atlantic Forest biome, encompassing the Lowland Dense Ombrophilous Forest, Submontane Dense Ombrophilous Forest, Montane Grasslands, and Montane and Altomontane Dense Ombrophilous Forest, the latter being more common in the northern part of the park, especially in the Cunha core (SMA, 2006, p. 84). Because of its high levels of biological diversity (1265 species of vascular plants and 1523 amphibians, reptiles, birds and mammals SMA, 2006, p. 67), PESM plays a key role in biodiversity conservation in southeast Atlantic Forest (AYRES, FONSECA, RYLANDS, QUEIROZ, PINTO, MASTERSON & CAVALCANTI, 2005), in addition to providing significant ecosystem services (STARZYNSKI, SIMÕES, SOARES &

GONÇALVES, 2018). For this reason, restoration of these areas is very important. In Cunha, PESM covers 19,163 ha, includes 20 rural neighborhoods and corresponds to 13.62% of the municipal territory.

The restoration project, called Forest that creates water - Expansion of biodiversity corridors and water supply in the Atlantic Forest: strategic actions to strengthen the restoration chain in the municipality of Cunha and Paraíba valley Paulista region, aimed to restore 15 ha in the buffer zone using different techniques, it was funded by WWF (World Wildlife Foundation) and conducted by SerraCima, an NGO that encourages the participatory generation of environmentally sustainable and socially fair knowledge and practices, using agroecology concepts and tools (SERRACIMA, [2023]).

We only monitored direct seeding sites, these areas had hilly relief (in general, more than 45 degrees), were abandoned pastures (*Brachiaria* sp., *Pinus elliotti* and other invasive species) and had native vegetation remnants in the surroundings. Before planting, the following management practices were performed: manual crowning (1 m), planting pits of 40 cm x 40 cm with fertilization (mostly Ca and P) and hydrogel inside them, 30 kg/ha of green manure seeds (mostly beans: Fabaceae *Cajanus cajan* (L.) Huth, feijão guandu, Fabaceae *Canavalia ensiformis* (L.) DC., feijão de porco, and Fabaceae *Crotalaria* L. species) and 30 kg/ha of native species seeds (shrubs, pioneer and secondary species) planted 3 cm deep in pits, lastly sawdust was used to cover seeds. We do not know the diversity of seed mixtures (the muvucas) used in this project, but it was certainly higher than 42 species, this number representing green manure species, native tree species and additional regenerant species. Seeds were sown in the wet season between November and January 2021/2022.

2.1.1 Monitoring protocols

We adopted five monitoring protocols that are used by the NGO TNC (The Nature Conservancy Brazil) in its projects (Table 1): large plot method, small plot method, subplot method, linear transect method and touching method. Monitoring was carried out at intervals of 6 months (June 2022), 12 months (January 2023) and 18 months (June 2023) after seeding. All plots were georeferenced and each individual was counted following methods described below (Table 1) and all individuals were identified according to species name or genera and bands (each band was 5 m long) or positions in the line. The identification of individuals was carried out through photographic analysis and popular names provided by field technicians, after which a comparison was made with the Flora and Funga do Brazil (FLORA E FUNGA DO BRASIL, 2024). When identification was not possible we gave a code to unknown individuals.

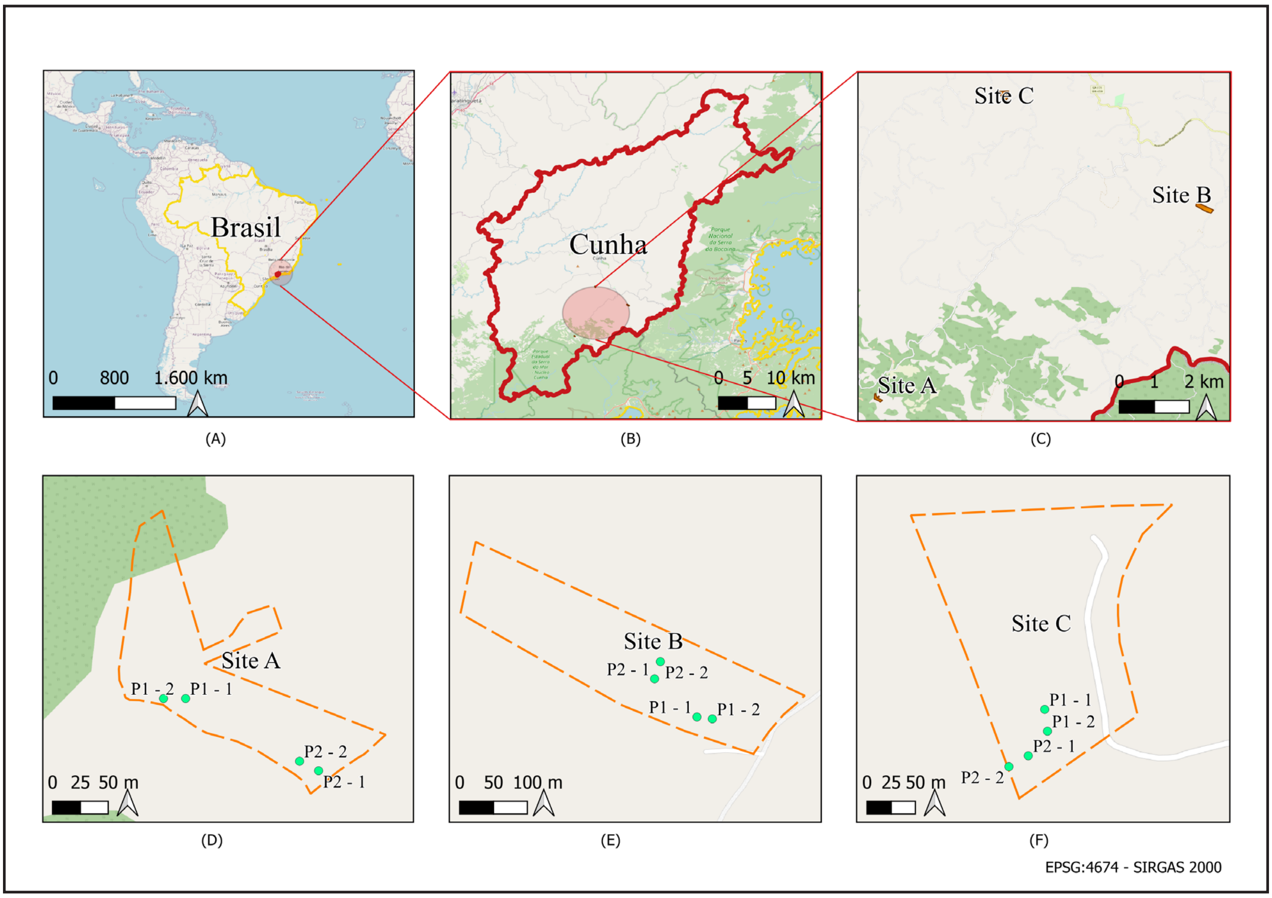
Table 1 - Description of the monitoring methods (large plot, small plot, subplot, linear transect and touching) used in the restoration sites, Cunha, southeast Brazil

	Large plot	**Small plot**	**Subplot**	**Linear transect**	**Touch**
plot size	25 m x 4 m	five plots of 1 m x 1 m	25 m x 1 m	25 m (0.5 m aboveground)	25 m
division	five bands of 5 m x 4 m (A, B, C, D and E)	one plot inside each band	five bands of 5 m x 4 m (A, B, C, D and E)	no (plant canopy has to fully or partially intercept the transect)	26 points (each 1 m starting from zero)
inclusion criteria	regenerants and sowed individuals greater than 0.5 m in height	exotic and native graminoids and herbs	regenerants and sowed individuals greater than 0.5 m in height	regenerants and sowed individuals greater than 0.5 m in height	regenerants and sowed individuals
life forms	all (trees, shrubs, herbs, grasses and palms)	graminoids and herbaceous	all	all	all
strata	medium: 0.5-2 m height high: > 2m	low: < 0.5 m height	low: < 0.5 m height	-	low: < 0.5 m height medium: 0.5-2 m height high: > 2m
circumference at breast height	I: < 15 cm II: > 15cm	-	I: < 15 cm II: > 15cm	-	-
dead plants	yes	-	yes	no	no

Source: Authors (2023)

Two plots were done in each three sites (A, B and C) located in different rural lands, totaling six plots (Figure 1). Each site had the same planting design of the restoration project and were in similar conditions. We calculated species richness and abundance per plot in each monitoring protocol above (except for the small plot that only surveys graminoids). A list of species richness found is presented in table 2. The small plot method aimed to quantify graminoids through percentage coverage and because of that we could not be compared to the other methods.

Figure 1 – Location of the study area inside Brazil (A), inside Cunha municipality (B) and the three land sites (A, B and C) monitored (C), with the location of each monitoring plot in site A (D), in site B (E) and site C (F)



Source: Authors (2023)

2.2 Data Analysis

We compared richness and abundance per plot among the three inventories and compared large plot with subplot method and transect line with touch method. Plots (in square meters) could not be compared with touch and transect line (in meters). We used the Wilcoxon signed-rank test for paired samples to observe variations between inventories and to compare different methods. Analyzes were performed in R version 3.6.3 (R-CORE-TEAM, 2018).

3 RESULTS

We observed 42 species, belonging to 21 families (30 species could not be identified, because plants had only a few or damaged leaves that made the identification difficult), in all plots inventoried. Only *Schinus terebinthifolius*, *Baccharis punctulata*, *Croton blanchetianus*, *Pteridium aquilinum*, *Cajanus cajan* and *Canavalia ensiformis* were found in all monitoring methods (except for small plots).

Table 2 – Species composition and families in four monitoring methods in restoration sites, Cunha, southeast Brazil

Family	Species	Large plot	Subplot	Transect	Touch
Anacardiaceae	*Lithraea molleoides (Vell.) Engl.*	x			x
	Schinus terebinthifolius Raddi	x	x	x	x
Arecaceae	*Syagrus oleracea (Mart.) Becc.*	x		x	
Asteraceae	*Eremanthus erythropappus (DC.) MacLeish*	x			x
	Moquiniastrum polymorphum (Less.) G. Sancho	x		x	x
	Solidago chilensis Meyen	x			
	Solidago L.	x			x
	Tagetes minuta L.	x			
	Vernonia polyanthes (Spreng.) Less.	x			x
Astereae	*Baccharis dracunculifolia DC.*	x			
	Baccharis punctulata DC.	x	x	x	x
	Baccharis trimera (Less.) DC.	x			
Berberidaceae	*Berberis laurina Billb.*	x			
Bignoniaceae	*Jacaranda copaia (Aubl.) D.Don*	x		x	x
Dennstaedtiaceae	*Pteridium aquilinum (L.) Kuhn*	x	x	x	x

To be continued ...

Table 2 – Continuation

Family	Species	Large plot	Subplot	Transect	Touch
Euphorbiaceae	*Croton blanchetianus Baill.*	x	x	x	x
	Croton bonplandianus Baill.	x			
	Ricinus communis L.	x		x	x
Fabaceae	*Anadenanthera macrocarpa* (Benth.) Brenan	x			x
	Cajanus cajan (L.) Huth	x	x	x	x
	Canavalia ensiformis (L.) DC.	x	x	x	x
	Crotalaria juncea L.	x		x	x
	Enterolobium contortisiliquum (Vell.) Morong				x
	Pterodon emarginatus Vogel	x			x
	Tephrosia noctiflora Bojer ex Baker	x		x	x
Lauraceae	*Nectandra membranacea (Sw.) Griseb.*	x	x	x	
Malvaceae	*Lagunaria patersonia (Andrews) G. Don*	x		x	
Melastomataceae	*Miconia albicans (Sw.) Steud.*	x			
	Miconia prasina (Sw.) DC.	x			x
	Miconia pusilliflora (DC.) Naudin	x			
Meliaceae	*Cedrela fissilis Vell.*	x			
Moraceae	*Ficus enormis Mart. ex Miq.*	x			x
Myrtaceae	*Myrceugenia miersiana var. lanceolata D.Legrand*	x			
	Psidium cattleyanum Sabine	x			
	Psidium guajava L.	x		x	x
	Psidium guineense Sw.	x			
Primulaceae	*Myrsine coriacea (Sw.) R. Br. ex Roem. & Schult*	x			
Rosaceae	*Prunus myrtifolia (L.) Urb.*	x			
Rutaceae	*Citrus sinensis (L.) Osbeck*	x			
	Zanthoxylum rhoifolium Lam.	x			x
Salicaceae	*Casearia sylvestris Sw.*	x			x
Sapindaceae	*Dodonaea viscosa Jacq.*	x			
Styracaceae	*Styrax leprosus Hook. & Arn.*	x	x		x
	sp. 1				x
	sp. 2	x	x		
	sp. 3	x			
	sp. 4	x	x		
	sp. 5	x			
	sp. 6	x			
	sp. 7				x
	sp. 8	x			
	sp. 9				x
	sp. 10				x
	sp. 11	x		x	x
	sp. 12	x		x	x
	sp. 13	x			x

To be continued ...

Table 2 – Conclusion

Family	Species	Large plot	Subplot	Transect	Touch
Styracaceae	*Styrax leprosus Hook. & Arn.*	x	x		x
	sp. 14				x
	sp. 15	x	x		
	sp. 16	x	x	x	x
	sp. 17				x
	sp. 18				x
	sp. 19			x	
	sp. 20	x			
	sp. 21	x			x
	sp. 22	x			
	sp. 23		x		
	sp. 24	x			
	sp. 25		x		
	sp. 26	x	x		
	sp. 27	x			x
	sp. 28	x			
	sp. 29	x			
	sp. 30				x

Source: Authors (2023)

We found that richness and abundance did not vary in the monitoring period for all methods used (Table 3). The only exception was abundance of the subplot method that significantly reduced from January to June 2023 (Table 3). Despite that, inventories in the large plot indicated a tendency of increased richness (Figure 2a) and decreased abundance (Figure 2b), especially of green manure species that have a short life cycle and might be leaving the restoration sites (Figure 2c), indicating that native species might be recruiting. Cover of graminoids in the small plots, which was always 100% in plots along monitoring dates, was still 100% in the last monitoring date (Figure 2d) and the main species were *Brachiaria* sp. and *Melinis minutiflora*.

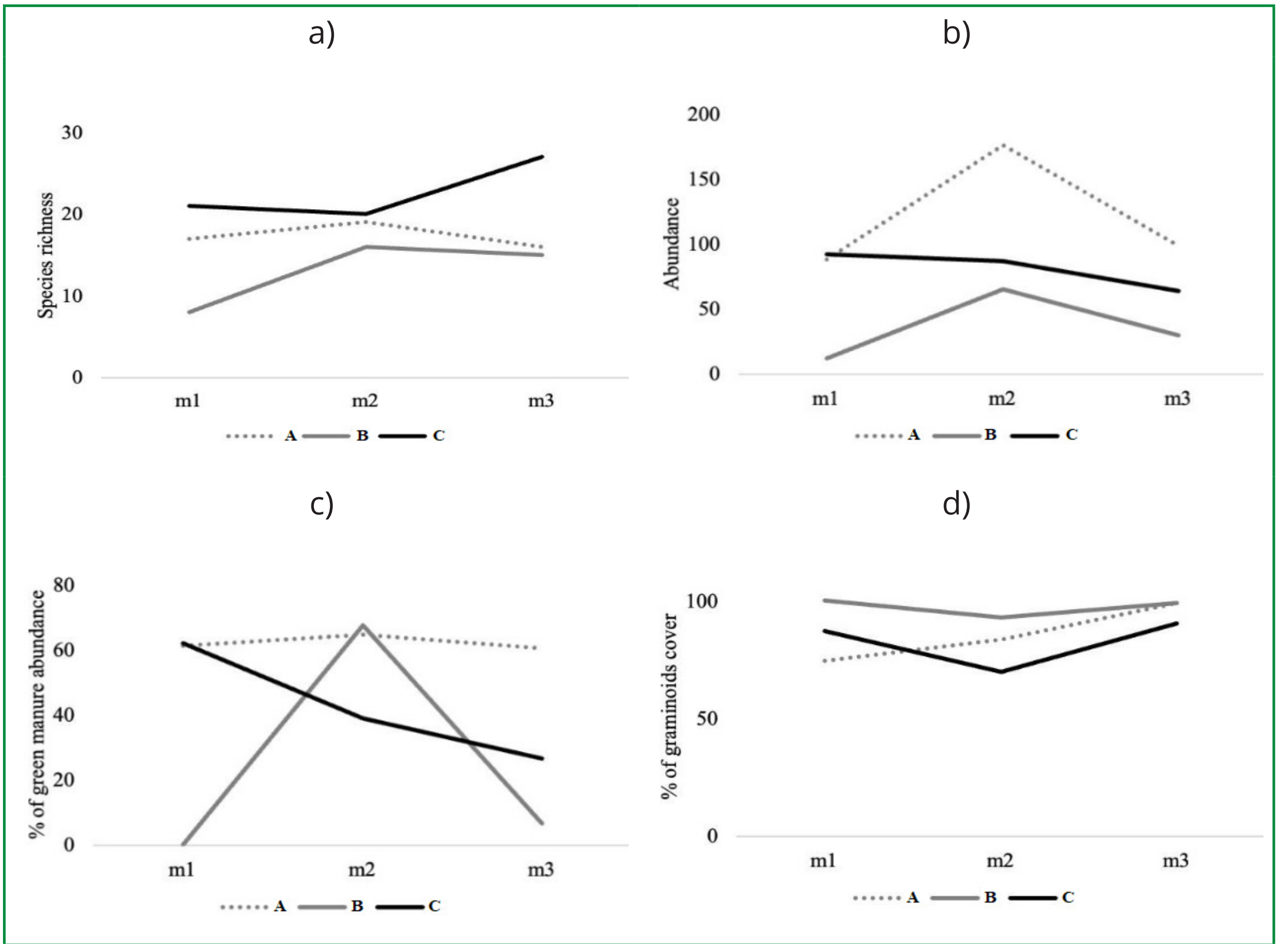
Table 3 – Richness (Rich) and Abundance (Abun) inventoried in different methods among monitoring dates in restoration sites, Cunha, southeast Brazil

	Rich m1	Rich m2	Rich m3	Statistics
Large plot	8	9	10	m1-m2: W=15.5, p=0.744 m2-m3: W=19.5, p=0.872 m1-m3: W=16, p=0.808
Subplot	1 (c: 5)	3 (c: 13)	1 (c: 5)	m1-m2: W=7.5, p=0.100 m2-m3: W=8, p=0.115 m1-m3: W=20, p=0.801
Statistics	W=25, p=0.295	W= 18, p=1	W=28, p=0.122	
Transect line	4	3	2	m1-m2: W-19.5, p=0.870 m2-m3: W=10.5, p=0.241 mi-m3: W=25, p=0.286
Touch	5	5	4	m1-m2: W=17.5, p=1 m2-m3: W=13, p=0.466 m1-m3: W=14, p=0.568
Statistics	W=24.5, p=0.329	W=28, p=0.119	W=30.5, **p=0.049***	
	Abun m1	**Abun m2**	**Abun m3**	**Statistics**
Large plot	32	55	32	m1-m2: W=12.5, p=0.423 m2-m3: W=7, p=0.093 m1-m3: W=18, p=1
Subplot	8 (c: 31)	13 (c: 53)	2 (c: 8)	m1-m2: W=10.5, p=0.261 m2-m3: W=0.5, **p=0.006*** m1-m3: W=11, p=0.294
Statistics	W=19, p=0.936	W= 18, p=1	W=33.5, **p=0.016***	
Transect line	7	6	5	m1-m2: W=17, p=0.935 m2-m3: W=14.5, p=0.627 m1-m3: W=14, p=0.571
Touch	15	16	12	m1-m2: W=16.5, p=0.872 m2-m3: W=16.5, p=0.872 mi-m3: W=13.5, p=0.520
Statistics	W=27, p=0.171	W=27.5, p=0.146	W=30.5, p=0.053	

Source: Authors (2023)

In where: m1 (June 2022); m2 (January 2023); m3 (June 2023); C is the corrected number for the similar area between subplot and large plot.

Figure 2 – Species Richness, Abundance, Percentage of green manure abundance, and Percentage of graminoids cover inventoried in the large plot method among monitoring dates in restoration sites (A, B and C), Cunha, southeast Brazil



Source: Authors (2023)

In where: m1 (June 2022); m2 (January 2023); m3 (June 2023).

Regarding comparison among methods, we verified that large plot and subplot methods were able to provide the same responses related to abundance and richness among the monitoring period (Table 3). In the third monitoring though, the plant abundance in large plot was higher than in the subplot (Table 3). In addition, transect line and touch methods performed equally, with plant richness in touch being higher than transect line (Table 3).

4 RESULTS AND DISCUSSIONS

We verified a total of 42 species in less than two years after seeding and between 21 and 27 species (maximum values) per site, from the first to the last monitoring. In other restoration sites in the same region and with similar ages, 35 species were found in a seedling planting site (FIORE, FERREIRA, DZEDZEJ, MASSI, 2019), while 16 species were present in a direct seeding site (PAGOTO, MASSI, COLLARD, 2022). Older restored sites (nine years) in Paraíba do Sul riverbasin presented 28 regenerant species richness (MASSI, FIORE, FERREIRA, DZEDZEJ, 2022). This result indicates that the restoration sites are having a progressive path, despite differences verified in the monitoring methods, and despite all the unfavorable conditions in restored sites that were verified along the 1-year study, as neighbor chickens eating planted seeds, exotic grasses (*Brachiaria* sp. and *Melinis minutiflora*) and *Pteridium* invasion, frost and freezing temperatures in winter and degraded and rocky soils of Cunha highlands. We do not know the diversity of seed mixtures (the muvucas) used in this project, but it was certainly higher than 42 species, this number representing green manure species, native tree species and additional regenerant species. According to a recent meta analysis, the establishment and growth of tree species by direct seeding are usually very low (SOUZA & ENGEL, 2023). Regarding individuals abundance, we noticed an increased number from the first to the second monitoring, together with an increase in green manure cover, and a strong decrease in the third monitoring, linked again to green manure. Green manure played an important role in shading the area, controlling *Brachiaria* and *Pteridium* invasions and helping native species to grow, as another study in the region found (PAGOTO, MASSI, COLLARD, 2022), and it is also likely to be related to the growth of invasive exotic species. Also, one of the implications of sowing legume-rich mixtures in the long term is the increased abundance of legumes at a young age rather than the increase in native species richness (HERNÁNDEZ-ESTEBAN, ROLO, LÓPEZ-DÍAZ, MORENO, 2019). Due to its short life cycle, it is expected that these shrub and tree species would leave the restoration system in two to three years, to make restoration more cost-effective (RAUPP, FERREIRA, ALVES, CAMPOS-FILHO, SATORELLI, CONSOLARO & VIEIRA, 2020), enabling native species survival and growth (PIERIK, RUIJVEN, BEZEMER, GEERTS & BERENDSE, 2011). Cover of exotic graminoids, that is a challenge in pasture landscapes as in Cunha, was always high during monitoring, it decreased a bit when green manure was higher, but it improved again in the third monitoring, when green manure cover decreased. It might be needed to keep monitoring and to perform management strategies to control these invasive grasses, especially non-chemical interventions (WEIDLICH, FLÓRIDO, SORRINI, BRANCALION, 2020).

In regards to monitoring protocols, we observed that large plot and subplot were about the same and transect line and touch had similarities in results, contrary to our expectations and to another study in Cerrado (WALTER & GUARINO, 2006). Thus, this result might help to obtain a better collection of sample data in the field, as well as providing a shorter execution time, as subplot and transect methods were easier to inventory. Monitoring restoration protocols are diverse and its applicability and results will depend on its aims and approach, for example, a legal protocol, as in São Paulo state (Resolution SMA 32/2014 and Resolution SAA/SIMA 01/2022) have to be easily and quickly performed, but at the same time provide credible ecological information on the successional paths of restored sites (MASSI, FIORE, FERREIRA, DZEDZEJ, 2019). Furthermore, we noted that the large plot method was the best when compared to the others in terms of monitoring species abundance and the touch method proved to be more efficient for monitoring species richness.

The UN Decade on Ecosystem restoration is making restoration more visible, mainstreamed and funded and, in the next few years, several restored sites will need to seek monitoring. Brazil is in the vanguard of monitoring, but more studies are needed as the few highland sites in Cunha, highlighting the importance of carefully choosing monitoring methods based on specific restoration objectives. Besides, a restoration program that is performed in the buffer zone of a protected area, as in PESM, has many other important features that must be considered and evaluated.

5 CONCLUSIONS

This study monitored direct seeding restoration sites in highland Atlantic forest in southeast Brazil and compared different methods to assess the recovery success. We did find a progressive path of restoration in the one year of observation, increasing plant species richness and individuals abundance. However, exotic grasses covered 100% of plots in all sites and represent a challenge for the success of restoration. For plant richness we verified the touch method to be cost-effective, and for abundance the subplot one. In addition, shallow and rocky soil conditions, lack of restoration management, climate (related to frosting temperatures) might impose additional challenges to restoration of highland forests. Lastly, species that are in seed mixtures have to be adapted to the regional conditions and we believe that seeds that come from other parts of the biome should be taken with care in the muvucas.

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REFERENCES

ALVARES, C. A., STAPE, J. L., SENTELHAS, P. C., DE MORAIS GONÇALVES, J. L. & SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift** vol. 22 No. 6, p. 711 - 728, dec., 2013. Available at: https://www.schweizerbart.de/papers/metz/detail/22/82078/Koppen_s_climate_classification_map_for_Brazil. Accessed in: 20 May 2024.

AYRES, J.M., FONSECA, G.A.B., RYLANDS, A.B., QUEIROZ, H.L., PINTO, L.P., MASTERSON, D. & CAVALCANTI, R.B**. Os corredores ecológicos das florestas tropicais do Brasil**. Belém PA: Sociedade Civil Mamirauá, 2005.

BRANCALION, P. H. S., GANDOLFI, S., RODRIGUES, R. R. **Restauração Florestal**. São Paulo: Oficina de textos, 2015. Available at: http://www.lcb.esalq.usp.br/sites/default/files/publicacao_arq/978-85-7975-019-9.pdf. Accessed in: 22 Oct. 2023.

BRANCALION, P. H. S., VIANI, R. A. G., RODRIGUES, R. R., GANDOLFI, S. **Restauração Ecológica de Ecossistemas Degradados**. 2013. 293p. Parte de monografia/livro. Viçosa: Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, 2013.

BRASIL. **Lei nº 12.651**, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa. Available at: https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/L12651compilado.htm. Accessed in: 27 May 2024.

BRASIL. O**bservatório da Restauração e Reflorestamento**, 2021. Available at: https://observatoriodarestauracao.org.br/dashboard. Accessed in: 22 Oct. 2023.

BRASIL. **Resolução CONAMA nº 13**, de 06 de dezembro de 1990. Available at: https://cetesb.sp.gov.br/licenciamento/documentos/1990_Res_CONAMA_13.pdf. Accessed in: 27 May 2024.

CHAVES, R. B., DURIGAN, G., BRANCALION, P. & ARONSON, J. On the need of legal frameworks for assessing restoration projects success: new perspectives from São Paulo state (Brazil). **Restoration Ecology**, volume 23, Issue 6, pages 754 - 759, November 2015. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/rec.12267. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.1111/rec.12267

DEAN, W. **A ferro e fogo**: a história e a devastação da Mata Atlântica brasileira. São Paulo: Companhia das Letras, 1996. p. 484-484.

DECADE ON RESTORATION - UNITED NATIONS DECADE ON ECOSYSTEM RESTORATION 2021-2030. **Preventing, halting and reversing loss of nature**: we need to restore our ecosystems now - for climate, nature and people. Available at: https://www.decadeonrestoration.org/. Accessed in: 22 Oct. 2023.

DEVIDE, A. C. P., CASTRO, C. M., RIBEIRO, R. L. D., ABBOUND, A. C. S., PEREIRA, M. G. & RUMJANEK, N. G. História Ambiental do Vale do Paraíba do Sul, Brasil. **Revista Biociências**, v. 20, n. 1, p. 12-29, 2014 (ISSN 1415-7411), july 2014. Available at: http://periodicos.unitau.br/ojs/index.php/biociencias/article/view/1867. Accessed in: 22 Oct. 2023.

FIORE, N. V. ,FERREIRA, C. C.,DZEDZEJ, M., MASSI, K. G. **Monitoring of a seedling planting restoration in a permanent preservation area of the southeast Atlantic Forest biome**, Brazil. Repositório Institucional Unesp, v. 10, n. 9, 2019. Available at: https://repositorio.unesp.br/items/fa0698b8-b464-4efd-a2d3-2508ebe32e2e. Accessed in: 22 Oct. 2023. DOI: http://hdl.handle.net/11449/197954

FLORA E FUNGA DO BRASIL. **Jardim Botânico do Rio de Janeiro**. Available at: http://floradobrasil.jbrj.gov.br/. Accessed in: 15 ago. 2024.

FUNDAÇÃO SOS MATA ATLÂNTICA. Instituto Nacional das Pesquisas Espaciais. **Atlas dos remanescentes florestais da Mata Atlântica período 2016–2017**. São Paulo, 2018. Available at: https://cms.sosma.org.br/wp-content/uploads/2019/06/Atlas-mata-atlanticaDIGITAL.pdf. Accessed in: 22 Oct. 2023.

GOVERNO DO ESTADO DE SÃO PAULO. **RESOLUÇÃO SMA Nº 32**, DE 03 DE ABRIL DE 2014. Estabelece as orientações, diretrizes e critérios sobre restauração ecológica no Estado de São Paulo, e dá providências correlatas. Available at: http://arquivos.ambiente.sp.gov.br/legislacao/2016/12/Resolu%C3%A7%C3%A3o-SMA-032-2014-a.pdf. Accessed in: 22 Oct. 2023.

GOVERNO DO ESTADO DE SÃO PAULO. **Resolução SAA/SIMA/SES - 1, de 25/10/2022**. Determina a composição e o funcionamento do Comitê Consultivo Paulista para Gestão Pública Integrada do Uso de Agrotóxicos instituído pela Lei nº 17.054, de 06 de maio de 2019 e dá outras providências. Available at: https://www.defesa.agricultura.sp.gov.br/legislacoes/resolucao-saa-sima-ses-1-de-25-10-2022,1677.html. Accessed in: 22 Oct. 2023.

GOVERNO DO ESTADO DE SÃO PAULO. **Resolução SMA n°57**, de 05 de junho de 2016. Publica a segunda revisão da lista oficial das espécies da flora ameaçadas de extinção no Estado de São Paulo. Available at: https://cetesb.sp.gov.br/licenciamentoambiental/wp-content/uploads/sites/32/2019/05/Resolu%C3%A7%C3%A3o-SMA-n%C2%BA-57-2016.pdf. Accessed in: 27 May 2024.

HERNÁNDEZ-ESTEBAN, A., ROLO, V., LÓPEZ-DÍAZ, M. L., MORENO, G. Long-term implications of sowing legume-rich mixtures for plant diversity of Mediterranean wood pastures. **Agriculture, Ecosystems & Environment,** Volume 286, 106686, dec. 2019. Available at: https://www.sciencedirect.com/science/article/pii/S0167880919303020#bib0320. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.1016/j.agee.2019.106686

INSTITUTO BRASILEIRO DE GEOGRAFIA - IBGE. **Manual Técnico de Vegetação**: sistema fitogeográfico; inventário das formações florestais e campestres; técnicas e manejo de coleções botânicas; procedimentos para mapeamentos, 2ª ed. Rio de Janeiro, 2012. Available at: https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=263011. Accessed in: 20 May 2024.

LEÃO, B. M., BRAGA, M. A., PEREIRA, I. M. & SANTOS, G. C. Restauração Ecológica em área de pastagem por semeadura direta. **Ciência Florestal**, v.32 n.4, 1928–1947, 2022. Available at: https://periodicos.ufsm.br/cienciaflorestal/article/view/63831. Accessed in: 05 Nov. 2023. DOI: https://doi.org/10.5902/1980509863831

MASSI, K.G., FIORE, N.V., FERREIRA, C.C., DZEDZEJ, M., Monitoring of a Seedling Planting Restoration in a Permanent Preservation Area of the Southeast Atlantic Forest Biome, Brazil. **Forests**, 10, 768, 2019. Available at: https://www.mdpi.com/1999-4907/10/9/768#B22-forests-10-00768. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.3390/f10090768

MELI, P., ISERNHAGEN, I., BRANCALION, P. H. S., ISERNHAGEN, E. C. C., NEHLING, M. & RODRIGUES, R. R. Optimizing seeding density of fast-growing native trees for restoring the Brazilian Atlantic Forest. **Restoration Ecology,** Volume26, Issue2, pages 212-219, oct. 2017. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/rec.12567. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.1111/rec.12567

MINISTÉRIO DA AGRICULTURA. Centro Nacional de Ensino e Pesquisas Agronômicas. Serviço Nacional de Pesquisas Agronômicas. Comissão de Solos. **Levantamento de reconhecimento dos solos do Estado de São Paulo**: contribuição à carta de solos do Brasil. Rio de Janeiro, 1960. 634 p. (Brasil. Ministério da Agricultura. SNPA. Boletim, 12).

MYERS, N., MITTERMEIER, R., MITTERMEIER, C., FONSECA G. A. B. & KENT J. Biodiversity hotspots for conservation priorities. **Nature**, 403, 853–858, 24 de fevereiro de 2000. Available at: https://www.nature.com/articles/35002501#citeas. Accessed in: 22 Oct. 2023. DOI https://doi.org/10.1038/35002501

PAGOTO, J. M., MASSi, K. G., COLLARD, F. H. Green manure cover effects on restoration success in Southeast Atlantic Forest biome. **Scientia Forestalis**, 50, e3844, May 2022. Available at: https://www.ipef.br/publicacoes/scientia/v50_2022/2318-1222-scifor-50-e3844.pdf. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.18671/scifor.v50.18

PALMA, A. C., LAURANCE, S. G. W. A review of the use of direct seeding and seedling plantings in restoration: what do we know and where should we go? **Applied Vegetation Science**, v. 18, Issue4. p. 561–568, June, 2015. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/avsc.12173. Accessed in: 22 out. 2023. DOI: https://doi.org/10.1111/avsc.12173

PIERIK, M., RUIJVEN, J. V., BEZEMER, T. M., GEERTS, R. H. E. M. & BERENDSE, F. Recovery of plant species richness during long-term fertilization of a species-rich grassland. **Ecological Society of America,** Volume 92, Issue7, july 2011. Available at: https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/10-0210.1. Accessed in: 22 out. 2023. DOI: https://doi.org/10.1890/10-0210.1.2006

R CORE TEAM, 2018. **R**: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/. Accessed in: 25 June 2024.

RAUPP, P. P., FERREIRA, M. C., ALVES, M., CAMPOS-FILHO, E. M., SATORELLI, P. A. R., CONSOLARO, H. & VIEIRA, D. L. M. Direct seeding reduces the costs of tree planting for forest and savana restoration. **Ecological Engineering**, 148, 105788, april 2020. Available at: https://www.researchgate.net/publication/340035027_Direct_seeding_reduces_the_costs_of_tree_planting_for_forest_and_savanna_restoration. Accessed in: 22 out. 2023. DOI: https://doi.org/10.1016/j.ecoleng.2020.105788

RIBEIRO, M. C., METZGER, J. P., MARTENSEN, A. C., PONZONI F. J. & HOROTA M. M. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. **Biological Conservation**, Volume 142, Issue 6, pages 1141-1153, mar. 2009. Available at: https://www.sciencedirect.com/science/article/pii/S0006320709000974. Accessed in: 22 Oct. 2023. DOI https://doi.org/10.1016/j.biocon.2009.02.021

ROSA, M. R., BRANCALION, P. H., CROUZEILLES, R., TAMBOSI, L. R., PIFFER, P. R., LENTI, F. E. B., HORITA, M., SANTIAMI, E. & METZGER, J. P. Hidden destruction of older forests threatens Brazil's Atlantic Forest and challenges restoration programs. **Science Advances**, Vol. 7, Issue4, jan. 2021. Available at: https://www.science.org/doi/10.1126/sciadv.abc4547. Accessed in: 22 Oct. 2023. DOI: 10.1126/sciadv.abc4547

SAMPAIO, A. B., VIEIRA, D. L. M., HOLL, K. D., PELIZZARO, K. F., ALVES, M., COUTINHO, A. G., CORDEIRO, A., RIBEIRO, J. F. & SCHMIDT, I. B. Lessons on direct seeding to restore Neotropical savanna. **Ecological Engineering**, Volume 138, ISSN 0925-8574, Pages 148-154. Available at: https://www.sciencedirect.com/science/article/pii/S0925857419302538. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.1016/j.ecoleng.2019.07.025

SECRETARIA DO MEIO AMBIENTE (SMA). **Plano de Manejo do Parque Estadual da Serra do Mar**: Secretaria do Meio Ambiente, Instituto Florestal, Divisão de Reservas e Parques Estaduais. São Paulo, 441 p., 2006. Available at: https://fflorestal.sp.gov.br/planos-de-manejo/planos-de-manejo-planos-concluidos/plano-de-manejo-pe-serra-do-mar/. Accessed in: 24 June 2024.

SERRACIMA. **Mata que cria água, 2023**. Available at: https://www.serracima.org.br/portfolio/2021-23-mata-que-cria-agua/. Accessed in: 25 June 2024.

SILVA, R.F. B., MILLINGTON, J. D. A., MORAN, E. F., BATISTELLA, M. & LIU J. Three decades of land-use and land-cover change in mountain regions of the Brazilian Atlantic Forest, Landscape and Urban Planning. **Landscape and Urban Planning**, Volume 204, ISSN 0169-2046, dec. 2020. Available at: https://www.sciencedirect.com/science/article/pii/S0169204620312743. Accessed in em: 22 Oct. 2023. DOI: https://doi.org/10.1016/j.landurbplan.2020.103948

SOARES-FILHO, B, RAJÃO, R., MACEDO, M., CARNEIRO, A., COSTA, W., COE, M., RODRIGUES, H. & ALENCAR, A. Cracking Brazil's forest code. **Science**, v. 344, n. 6182, p. 363-364, april 2014. Available at: http://lerf.eco.br/img/publicacoes/Soares_Filho_etal_2014_artigo_Science.pdf. Accessed in: 22 Oct. 2023. DOI: 10.1126/science.1246663.

SOCIETY FOR ECOLOGICAL RESTORATION (SER), Grupo de Trabalho sobre Ciência e Política. **Princípios da SER International sobre a restauração ecológica**, v. 2, out., 2004.

SOUZA, D. C., ENGEL, V. L. Advances, challenges, and directions for ecological restoration by direct seeding of trees: Lessons from Brazil. **Biological Conservation** Volume 284, 110172, August 2023. Available at: https://www.sciencedirect.com/science/article/pii/S0006320723002732. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.1016/j.biocon.2023.110172.

STARZYNSKI R., SIMÕES, S. J. C., SOARES, P. V., & GONÇALVES, T. S. Demographic pressure in Serra do Mar State Park and its buffer zone, southeastern Brazil. **Environ Monit Assess**, ed. 190, p. 511, August 2018. Available at: https://link.springer.com/article/10.1007/s10661-018-6889-7#citeas. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.1007/s10661-018-6889-7

UNITED NATIONS DEVELOPMENT PROGRAMME SUB-REGIONAL HUB FOR WEST AND CENTRAL AFRICA. **ANNUAL REPORT 2022**. Available at: https://www.undp.org/africa/sustainable-development-goals. Accessed in: 22 Oct. 2023.

WALTER, B. M. T., GUARINO E. D. S. G. Comparison of the plot method with "rapid survey" for sampling the arboreal vegetation of Cerrado stricto sensu. **Acta Botanica Brasilica,** 20: 285-297, jun. 2006. Available at: https://www.scielo.br/j/abb/a/X9gGpzXjxWGWSR5ysyf6Q8N/abstract/?lang=pt#. Accessed in: 22 Oct. 2023. DOI: https://doi.org/10.1590/S0102-33062006000200005

WEIDLICH, E. W. A., FLÓRIDO, F. G., SORRINI, T. B. , BRANCALION P. H. S. Controlling invasive plant species in ecological restoration: A global review. **Journal of Applied Ecology**, 57:1806–1817,abril 2020. Available at: https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2664.13656. Accessed in: 22 Oct. 2023. DOI: 10.1111/1365-2664.13656.

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