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Articles

Floristics and phytosociology of models ecological restoration intercropped with Eucalyptus in the Brazilian Atlantic Forest

Florística e fitossociologia de modelos de restauração ecológica consorciadas com Eucalipto na Mata Atlântica Brasileira

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ABSTRACT

This work aimed to evaluate the effectiveness of forest restoration combined or not with eucalyptus in the floristic and in the phytosociological recovery and in the species diversity. Three of them were managed with the following forest restorations: natural regeneration after clear cutting of eucalyptus plantations (RPA), planting of native species after clear cutting of eucalyptus plantations (RMA) and planting of native species after cutting 50% of eucalyptus plantations. eucalyptus (RAR), and a fourth stand consisting of a secondary forest (REF). The floristic and phytosociological data were collected in ten plots of 25 × 25 m in each stand. The active restoration with native forest species (RAM) was better than the restorations with eucalyptus (RAR and RPA), when analyzed using diversity, evenness and floristic composition indices, but they were not similar to the Secondary Forest area (REF). In areas undergoing forest restoration, even after ten years of implementation, the structural attributes similar to those in the Secondary Forest area were not verified. The use of restorations with native forest species in consortium with eucalyptus were not able to promote a recovery of the species diversity and structure. Restoration with the planting of native species without the presence of eucalyptus can recover species diversity and establish ecological succession in the Atlantic Forest. However, it was unable to restore the structure similar to a secondary forest.

Keywords: Recovery of degraded areas; Species diversity; Ecological succession

RESUMO

Este trabalho teve como objetivo avaliar a eficácia da restauração florestal consorciada ou não com eucalipto no restabelecimento da florística e estrutura de espécies florestais. Três sítios foram manejados com as seguintes restaurações florestais: regeneração natural após corte raso de plantio de eucalipto (RPA), plantio de espécies nativas após corte raso de plantio de eucalipto (RAM) e plantio de espécies nativas após corte de 50% do eucalipto plantado (RAR), e uma quarta área de floresta secundária (REF). Dados florísticos e da estrutura foram coletados em dez parcelas de 25 × 25 m em cada sítio. A RAM foi melhor que RAR e RPA quando analisada com o emprego dos índices de diversidade, equabilidade e composição florística, porém não foi similar à REF. Nas áreas de restaurações florestais, mesmo após dez anos de implantação, não foram verificados atributos da estrutura semelhantes aos da área de REF. O uso de restaurações com espécies florestais nativas consorciadas com eucaliptos não foi capaz de promover uma recuperação da diversidade de espécies e estrutura. A restauração com plantio de espécies nativas sem a presença de eucalipto pode recuperar a diversidade de espécies e estabelecer a sucessão ecológica na Mata Atlântica, porém não foi capaz de restaurar a estrutura similar a uma floresta secundária.

Palavras-chave: Recuperação de áreas degradadas; Diversidade de espécies; Sucessão ecológica

1 INTRODUCTION

In forest restoration, passive or active models can be used. Although the methods predict the closest possible return to the conditions observed in the original ecosystem, the restoration projects being carried out in the Atlantic Forest face several problems due to the lack of diagnoses that consider the management of the areas and due to the lack of monitoring (Rodrigues *et al*., 2009). In the active restoration model, where native seedlings are introduced, it is desirable that silvicultural treatments are carried out, in addition to monitoring in order to guarantee greater biodiversity (Rodrigues *et al*., 2009). On the other hand, in the passive model, it is based exclusively on natural regeneration, only requiring fencing and forest protection in some cases (Zahawi; Reid; Holl, 2014).

In the case of studies with active or passive restorations in the Atlantic Forest, there is a consensus among researchers that passive models, despite being slower and generally accumulating less carbon in aerial biomass and using a lower diversity of forest species, are more advantageous in terms of low restoration costs (Brancalion *et al*., 2016; Zahawi; Reid; Holl, 2014). In active and passive restoration models, the consortium species with timber potential, native or exotic, such as eucalyptus can also be used (Brancalion *et al*., 2021). These essences can, in addition to contributing to the supply of wood, promote carbon storage and the recovery of the soil's chemical and physical properties. However, within this context, the influence of Eucalyptus on species diversity in the forest ecosystem is discussed on how it can help or harm ecological succession in areas subject to forest restoration (Brancalion *et al*., 2021).

In Brazil, there has long been a debate about incentive strategies for the restoration of the Atlantic Forest, guaranteeing the maintenance of its biodiversity. Forest restoration programs, such as the National Plan for the Recovery of Native Vegetation – PLANAVEG, try to encourage the planting of native and exotic plants so that goals in the country are achieved (Bustamante *et al*., 2019). Government initiatives are considered modest compared to the goals assumed, in addition to facing the problem of lack of resources, since the restoration of degraded areas is costly and for each situation a method is recommended (Bustamante *et al*., 2019).

In areas of mixed plantations of *Eucalyptus grandis* and *Eucalyptus urophylla* with a high diversity of native forest species in the Atlantic Forest, Amazonas; Forrester *et al*. (2018) observed that there was competition for resources such as water, light and nutrients with Eucalyptus, slowing the growth of native species. However, this was not enough to affect their survival or outperform native trees. According to the aforementioned authors, forest restorations with a high diversity of native forest species in the consortium with Eucalyptus can be used to restore Permanent Preservation Areas (APP), where Eucalyptus can be managed to generate income.

It should be noted that many of the negative effects attributed to the presence of Eucalyptus in areas of growth and natural regeneration of native trees depend on the characteristics of the production system, the structure of the landscape, the soil and the climate in which they are cultivated, and not the effects promoted by Eucalyptus itself. In the Atlantic Forest of Northern Espírito Santo and Bahia, in Semideciduous Seasonal

Forest, Eucalyptus can become important allies in the restoration of tropical forests, and their use and investment opportunities should be considered within the portfolio of options supported by financing public and private policies (Brancalion *et al*., 2021).

Most changes in soil chemical and physical properties in response to degradation and restoration depend on the reestablishment and the development of the plant community and the ecological succession (Guareschi *et al*., 2014; Castelli *et al*., 2015). According to the level of degradation and the distance from propagule sources, degraded and/or disturbed areas may respond in different ways, depending on the type of the forest restoration and the management. Thus, in forest restorations, the floristic and phytosociological composition can be different from natural ecosystems (Dodonov; Silva; Rosatti, 2014). In this context, this work aimed to evaluate the effectiveness of forest restoration combined or not with eucalyptus in reestablishing floristics and vegetation structure.

2 MATERIALS AND METHODS

2.1 Description of the study area

The study areas are located at Fazenda Rio Fundo (Rio Fundo farm) (11º06'30" South latitude and 37°19'60" West longitude) in the municipality of Itaporanga d´Ajuda and on the Rural Campus of the Federal University of Sergipe state (UFS) (10° 55' South latitude and 37°11' West longitude) in the municipality of São Cristóvão, both in the state of Sergipe. The climate in the four study areas is tropical with a dry summer season (As) with six or more dry months and an average temperature above 18°C throughout the year (Alvares *et al*., 2013).

The relief is mainly made up of gentle hills. The original vegetation is the Atlantic Forest Semideciduous Seasonal Forest (IBGE, 2012). The vegetation that occurs in the study region is a forest typology that includes semi-deciduous and deciduous species such as: ingá (*Inga uruguensis*), amescla (*Protium heptaphyllum*), embiruçu

(*Pseudobombax grandiflorum*), embaúba (*Cecropia pachystachya*) and murici (*Byrsonima crassifolia*) (Fontes, 2010). The soil in the four study areas was classified as Red Yellow Argisol, A moderate with sandy loam texture (EMBRAPA, 2013).

2.2 Description of successional forest restoration models

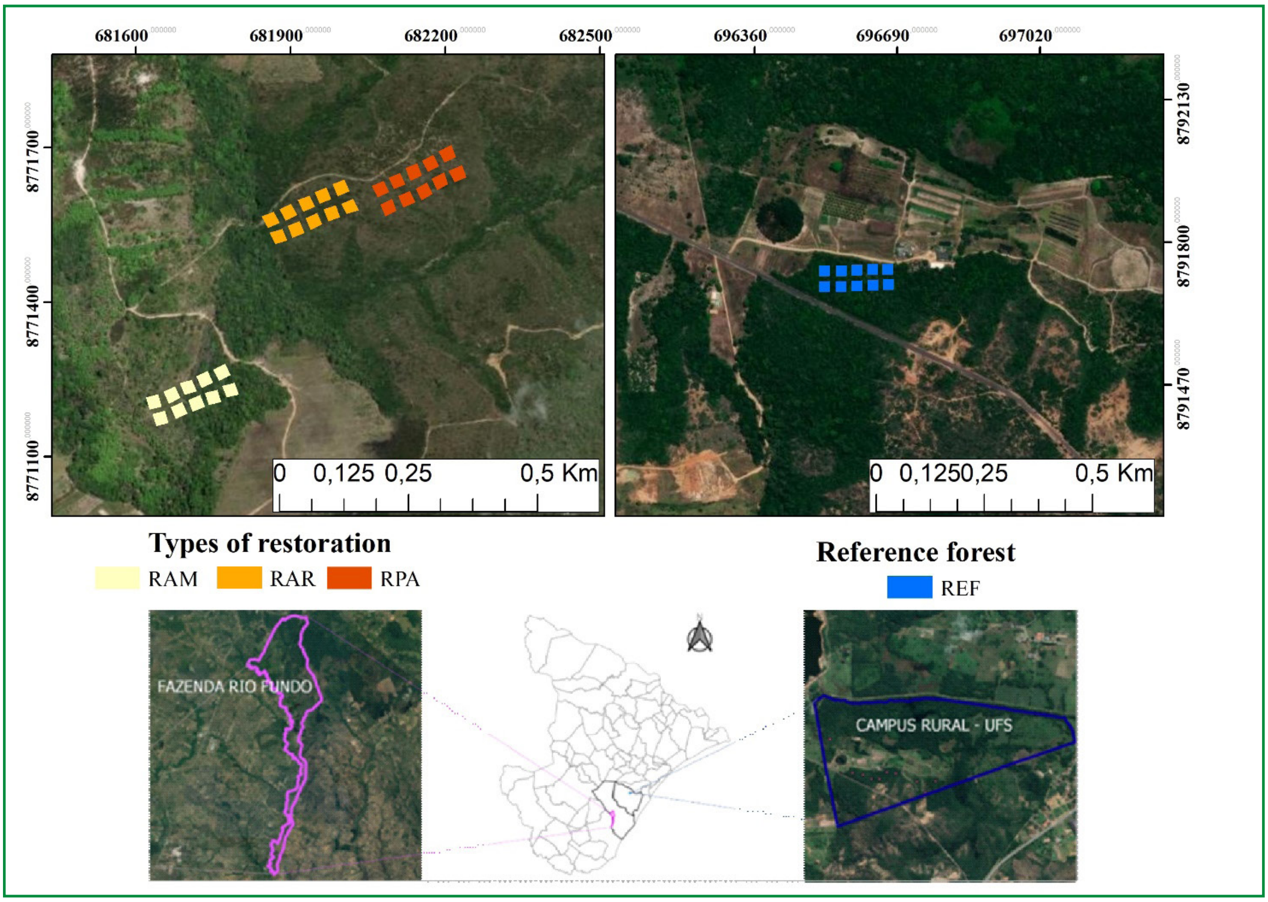
Rio Fundo farm has 1,563.44 ha and belongs to an industrial pulp and paper company in the municipality of Itaporanga d'Ajuda, SE state. The main activity at Rio Fundo farm is the planting of *Eucalyptus urophyla* for firewood production.

In 2012, Rio Fundo farm had an environmental liability, requiring restoration to comply with current environmental legislation due to the deforestation of APP areas. In 2013, the farm managers implemented 38.63 ha of forest restoration (Figure 1). In this way, a set of active and passive forest restorations were carried out. Three forest restoration areas were implemented in 2013 when the eucalyptus plantations were 7 years old. These eucalyptus plantations did not undergo any cutting or rotation until 2013. A secondary forest located on the UFS Rural Campus in the municipality of São Cristóvão, SE state, 8 km away from the forest restorations, was also used as a reference ecosystem.

In the first forest restoration area, all eucalyptus trees were cut with a chainsaw and the logs were removed manually, leaving the area completely deforested. In the same month, 32 native tree species were planted, spaced 4 x 4 m apart. This treatment was called Active Restoration (RAM) and consists of planting native species after clear-cutting eucalyptus plantations.

The following species were planted: *Anadenanthera colubrina*, *Centrolorobium robustum*, *Eritroxyllum deciduum*, *Swartizia apetala*, *Himatanthus bracteatus*, *Strypnodendron pulcherrinum*, *Eschweilera ovata*, *Cupania vernalis*, *Cupania oblongfolia*, *Cecropia pachystachya*, *Eriotheca pubencens*, *Inga laurina*, *Inga marginata*, *Inga vera*, *Miconia cinnamomifollia*, *Guapira opposita*, *Didymopanax morototonii*, *Erythrina velutina*, *Byrsonima sericea*, *Myrcia selloi*, *Guazuma ulmifolia*, *Tapirira guianensis*, *Vismia brasiliensis*, *Himatanthus bracteatus*, *Apeiba tibourbou*, *Tibouchina granulosa*, *Mimosa caesalpinifolia*, *Sapindus saponária*, *Curatella americana*, *Samanea tubulosa*, *Pterodum emarginatus* and *Aegiphila klotzchiana.*

Figure 1 – Location map of plots allocated at Rio Fundo farm, Itaporanga d'Ajuda and at the Rural Campus of the Federal University of Sergipe, São Cristóvão, Sergipe state, Brazil



Source: Authors (2023)

In where: RAM = Active restoration; RAR = Active Restoration combined with eucalyptus; RPA = Passive restoration, REF = Secondary forest.

In the second forest restoration area, 50% of the eucalyptus individuals were thinned using a chainsaw and the logs were removed manually. Subsequently, at the removed eucalyptus sites, 32 native tree species were planted (4 x 4 m spacing), the same species being planted in RAM. This area received the acronym "RAR" because it is characterized by the planting of native species after cutting down 50% of the eucalyptus individuals.

In the third forest restoration area, the eucalyptus was cleared with a chainsaw and the logs were removed manually. However, there was no planting of native trees and the area was fenced to encourage natural regeneration. Due to the technique used, this area was classified as Passive Restoration (RPA).

It should be noted that all activities (eucalyptus cutting and planting of native species, fencing) linked to RAM, RPA and RAR restorations were carried out between March and June 2013.

We considered a fourth area, which has the same forest typology (Semideciduous Seasonal Forest), soil type and topography as the ecological restoration areas mentioned in this study, which is located on the UFS Rural Campus, 8 km away from the other areas. It consists of a fragment of secondary forest in the initial stage of succession. This area was called secondary forest (REF) and was used as a reference ecosystem. It is noteworthy that data collection was carried out in the four areas described.

2.3 Collection of floristic and phytosociological data

In 2022, ten square plots (25 × 25 m) were demarcated, 50 m equidistant from each other in each treatment, using systematic sampling with plots of fixed area (Figure 1). In each plot, the circumference at breast height (CAP) of all trees was measured at 1.30 m from the ground and subsequently transformed into diameter at breast height (DBH).

CAP was measured with a tape measure. In the plots, all individuals above 5 cm CAP were measured. The total height (H) values of the trees were collected with a 10 m graduated (telescopic) pole. Trees larger than 10 m were measured with a digital clinometer.

To identify the species, botanical collections were made, which were later identified through botanical literature, in addition to the assistance of a parabotanist. Species not identified in the field were collected and identified by comparison in the herbarium of the Federal University of Sergipe state. The botanical nomenclature was based on APG IV (APG IV, 2016).

The Shannon diversity index (H´) was calculated for each area, using Equation (1) (Souza; Soares, 2013):

$$H' = -\sum_{i=1}^{s} p_i \, . \, ln(p_i) \tag{1}$$

where: *H´* is the Shannon index and *pi* is the proportion of individuals belonging to species i.

Pielou's equability (J) was calculated using Equation (2) (Souza; Soares, 2013):

$$J = \frac{H'}{H'_{max}} \tag{2}$$

The tree species inventoried were classified according to ecological groups, namely: pioneer and initial secondary (very fast growth rates, demanding on light, colonizers of gaps, seed bank and short useful life); late secondary (medium growth rates, shade tolerant, seedling bank and medium shelf life) and climax (slow growth rates, shade tolerant, seedling bank, large seeds and long shelf life) (Budowski, 1965).

2.4 Statistical analysis

To verify normality and homoscedasticity for the diversity and structure parameters, the Shapiro-Wilk and Barlett tests were applied. Subsequently, the data were subjected to analysis of variance (ANOVA), adopting a significance level of 5%. A Tukey test was performed at 5% significance for the diversity and structure parameters. The experimental design used was completely randomized. The data obtained in each plot within an area was considered a replication. There are 10 plots (replications) in each study area.

The floristic similarity between the fragments was determined, through cluster analysis, based on the basic presence/absence matrix of the sampled tree species. Euclidean distance was used as a measure of floristic similarity between the studied areas and a measure of simple connection (Ludwig; Reynolds, 1988).

3 RESULTS

One thousand, seven hundred and ninety-seven (1,797) tree individuals were inventoried, distributed in 59 species, and 26 families, being recorded in the 40 sampled plots, in a total sampled area of 25,000 m2 (2.5 ha). In REF, the largest number of trees was quantified, much higher than forest restorations (Tables 1, 2, 3 and 4). It appears that *Curatella americana* occurs in all areas under restoration with a high number of individuals. In REF, only two individuals were quantified. In the RAM area this species presented the highest IVI (Table 1). However, in the RAR and RPA areas, eucalyptus trees (*Eucalyptus urophylla*) have a greater number of individuals and IVI (Tables 2 and 3).

Table 1 – Floristic composition and phytosociological parameters active restoration area (RAM) in the municipality of Itaporanga d'Ajuda, Sergipe state, Brazil, 2022

Common name	Scientific name	GE	NI	AB	DR	DoR	IVI (%)
angico-branco	*Anadenanthera colubrina*	SI	20	0,162354912	6,39	5,621	5,670
Araribá	*Centrolorobium robustum*	ST	14	0,185669202	4,47	6,428	3,967
arco-de-pipa	*Eritroxyllum deciduum*	SI	2	0,005604243	0,64	0,194	0,944
arruda-vermelha	*Swartizia apetala*	ST	8	0,061666572	2,56	2,135	2,230
Bambu	*Bambusa vulgaris*	P	19	0,179764633	6,07	6,224	5,431
banana-de-macaco	*Himatanthus bracteatus*	P	2	0,004913193	0,64	0,170	0,936
Barbatimão	*Strypnodendron pulcherrinum*	P	6	0,042462857	1,92	1,470	2,129
biriba-branca	*Eschweilera ovata*	CL	5	0,053397597	1,60	1,849	1,482
Camboatá	*Cupania vernalis*	CL	11	0,028555978	3,51	0,989	3,501
camboatá-de-folha-larga	*Cupania oblongfolia*	SI	2	0,004753401	0,64	0,165	0,935
Embaúba	*Cecropia pachystachya*	P	17	0,29881452	5,43	10,346	7,259
Embiruçu	*Eriotheca pubencens*	SI	5	0,025661984	1,60	0,888	1,829
Eucalipto	*Eucalyptus urophylla*	P	10	0,312816017	3,19	10,831	7,342
Goiaba	*Psidium guajava*	P	1	0,002381674	0,32	0,082	0,467
Ingá-caixão	*Inga laurina*	P	2	0,02949157	0,64	1,021	0,887
Ingá-mirim	*Inga marginata*	P	1	0,006238874	0,32	0,216	0,512
ingá-verdadeiro	*Inga vera*	SI	1	0,001911849	0,32	0,066	0,462
Jacatirão	*Miconia cinnamomifollia*	P	3	0,017767103	0,96	0,615	1,191
joão-mole	*Guapira opposita*	SI	1	0,00243706	0,32	0,084	0,468
Morototó	*Didymopanax morototonii*	P	1	0,00257831	0,32	0,089	0,470
Mulungu	*Erythrina velutina*	P	2	0,016095658	0,64	0,557	0,732
Murici	*Byrsonima sericea*	SI	11	0,161491974	3,51	5,591	4,702
murta-do-campo	*Myrcia selloi*	ST	2	0,008992254	0,64	0,311	0,983

To be continued ...

Table 1 – Conclusion

Common name	Scientific name	GE	NI	AB	DR	DoR	IVI (%)
Mutambo	*Guazuma ulmifolia*	P	13	0,109752135	4,15	3,800	3,984
pau pombo	*Tapirira guianensis*	P	9	0,085656474	2,88	2,966	3,280
pau-de-lacre	*Vismia brasiliensis*	P	1	0,004320181	0,32	0,150	0,490
pau-de-leite	*Himatanthus bracteatus*	SI	11	0,033865387	3,51	1,173	1,896
pente-de-macaco	*Apeiba tibourbou*	P	12	0,094703716	3,83	3,279	3,038
Quaresmeira	*Tibouchina granulosa*	P	2	0,005769367	0,64	0,200	0,613
Sabiá	*Mimosa caesalpinifolia*	P	7	0,033191127	2,24	1,149	1,795
sabonete-de-macaco	*Sapindus saponaria*	P	16	0,14078711	5,11	4,874	4,662
Sambaíba	*Curatella americana*	P	75	0,548181031	23,96	18,980	17,647
sete-cascas	*Samanea tubulosa*	P	4	0,051277017	1,28	1,775	1,351
Sucupira	*Pterodum emarginatus*	ST	7	0,105606626	2,24	3,656	3,631
Tamanqueiro	*Aegiphila klotzchiana*	P	10	0,059325005	3,19	2,054	3,083
TOTAL	**----------------------------------**		**313**	**2,888256611**	**100**	**100**	**100**

Source: Authors (2023)

In where: GE = Ecological group, being: Pioneer (P), Initial secondary (SI), Late secondary (ST) and Climax (CL); NI = Total number of sampled individuals; NI* = Non-identified; DR = Relative density; DoR = Relative dominance; IVI (%) = Percent Importance Value Index.

In RAM, 35 species were inventoried, in RAR, 22 species and in RPA, 11 species. The REF presents 29 species, with RAM being the only restoration that reached a number of species similar to the REF (Tables 1, 2, 3 and 4). It should be noted that RAM has the species *Psidium guajava* and *Bambusa vulgaris*, which are exotic species.

Table 2 – Floristic composition and phytosociological parameters in an active restoration area (RAR) in the municipality of Itaporanga D'ajuda, Sergipe state, Brazil, 2022

Common name	Scientific name	GE	NI	AB	DoA	DR	DoR	IVI
Andira	*Andira legalis*	SI	1	0,001838558	0,0030	0,20	0,045	0,527
angelim-amargoso	*Andira nitida*	SI	1	0,006549942	0,0107	0,20	0,162	0,566
angico-branco	*Anadenanthera colubrina*	SI	6	0,05441985	0,0885	1,22	1,344	2,633
Araribá	*Centrolorobium robustum*	ST	1	0,003279308	0,0053	0,20	0,081	0,539
Araticum	*Annona crassiflora*	P	23	0,069584053	0,1132	4,68	1,719	5,246
arruda-vermelha	*Swartizia apetala*	ST	5	0,010514412	0,0171	1,02	0,260	2,648
Camboatá	*Cupania vernalis*	CL	6	0,018887156	0,0307	1,22	0,467	1,896
Embaúba	*Cecropia pachystachya*	P	1	0,01640219	0,0267	0,20	0,405	0,647
Embiruçu	*Eriotheca pubencens*	SI	14	0,067685971	0,1101	2,85	1,672	4,174
Eucalipto	*Eriotheca pubencens*	SI	253	2,975801299	4,8419	51,53	73,515	46,125

To be continued ...

Table 2 – Conclusion

Common name	Scientific name	GE	NI	AB	DoA	DR	DoR	IVI
folha-de-lobo	*Coccoloba mollis*	SI	1	0,002723539	0,0044	0,20	0,067	0,535
ingá-de-metro	*Inga edulis*	CL	1	0,004357344	0,0071	0,20	0,108	0,548
Ipê-branco	*Tabebuia insignis*	P	2	0,009054484	0,0147	0,41	0,224	1,099
jacarandá-branco	*Swartizia macrostachya*	CL	2	0,008132499	0,0132	0,41	0,201	0,647
Murici	*Byrsonima sericea*	SI	80	0,283704668	0,4616	16,29	7,009	12,212
Mutambo	*Guazuma ulmifolia*	P	2	0,026098068	0,0425	0,41	0,645	1,240
pau pombo	*Tapirira guianensis*	P	10	0,058753082	0,0956	2,04	1,451	2,052
pau-de-leite	*Himatanthus bracteatus*	SI	3	0,00844683	0,0137	0,61	0,209	1,607
Sabiá	*Mimosa caesalpinifolia*	P	7	0,087044385	0,1416	1,43	2,150	1,636
sabonete-de-macaco	*Sapindus saponaria*	P	1	0,002326925	0,0038	0,20	0,057	0,531
Sambaíba	*Curatella americana*	P	67	0,322677894	0,5250	13,65	7,972	11,650
Tamanqueiro	*Aegiphila klotzchiana*	P	4	0,009586618	0,0156	0,81	0,237	1,239
TOTAL	**-------------------------**	**----**	**491**	**4**	**7**	**100**	**100**	**100**

Source: Authors (2023)

In where: GE = Ecological group, being: Pioneer (P), Initial secondary (SI), Late secondary (ST) and Climax (CL); NI = Total number of sampled individuals; NI* = Non-identified; DR = Relative density; DoR = Relative dominance; IVI (%) = Percent Importance Value Index.

In the RAM area, 59% of pioneer species were observed, and 18% of late secondary and climatic species (Table 1). The highest percentage of late secondary and climatic species was found in the RAR area (Table 2). The largest number of initial and pioneer secondary species with 91% of its composition was quantified in the RPA area (Table 4). The RAM area presents superiority in the composition of climax and late secondary species with 15% and 26% respectively, which together correspond to 41% (Table 2).

It is observed that the REF presents characteristics of a secondary forest in the initial stage of succession, due to the greater dominance of initial secondary species, such as *Cordia trichotoma*, presenting DoR = 13.696 and IVI = 10%, and the presence of secondary and climax, to a lesser extent, such as *Cupania vernalis* with IVI=4.61, *Byrsonima sericea* with IVI=7.85, *Duguetia lanceolata* with IVI=3.73 and *Pterodon emarginatus* with IVI=5.16 (Table 4).

Table 3 – Floristic composition and phytosociological parameters of the species sampled in a passive restoration area (RPA) in the municipality of Itaporanga D'Ajuda, Sergipe, Brazil, 2022

Common name	Scientific name	GE	NI	AB	DoA	DR	DoR	IVI
angelim-amargoso	*Andira nitida*	SI	1	0,003644	0,0058	0,35	0,205	1,039
arco-de-pipa	*Eritroxyllum deciduum*	SI	1	0,002037	0,0033	0,35	0,114	1,009
arruda-vermelha	*Swartizia apetala*	ST	1	0,002166	0,0035	0,35	0,122	1,011
embaúba	*Cecropia pachystachya*	P	4	0,012411	0,0198	1,39	0,697	2,406
embiruçu	*Eriotheca pubencens*	SI	8	0,029015	0,0464	2,79	1,628	6,600
eucalipto	*Eriotheca pubencens*	SI	154	1,198998	1,9161	53,66	67,287	48,862
murici	*Byrsonima sericea*	SI	9	0,031936	0,0510	3,14	1,792	5,062
mutambo	*Guazuma ulmifolia*	P	5	0,030958	0,0495	1,74	1,737	2,869
sabiá	*Mimosa caesalpinifolia*	P	2	0,012885	0,0206	0,70	0,723	1,328
sambaíba	*Curatella americana*	P	101	0,456082	0,7289	35,19	25,595	28,809
sete-cascas	*Samanea tubulosa*	P	1	0,00179	0,0029	0,35	0,100	1,004
TOTAL	**-----------------------------------**	**---**	**287**	**2**	**3**	**100**	**100**	**100**

Source: Authors (2023)

In where: GE = Ecological group, being: Pioneer (P), Initial secondary (SI), Late secondary (ST) and Climax (CL); NI = Total number of sampled individuals; NI* = Non-identified; DR = Relative density; DoR = Relative dominance; IVI (%) = Percent Importance Value Index.

Table 4 – Floristic composition and phytosociological parameters in an area of initial secondary forest (REF) in the municipality of São Cristóvão, Sergipe state, Brazil, 2022

Common name	Scientific name	GE	NI	AB	DoA	DR	DoR	IVI (%)
amescla	*Protium heptaphyllum*	SI	41	0,343603347	0,5515	5,81	4,397	5,448
angico-branco	*Anadenanthera colubrina*	SI	5	0,075743429	0,1216	0,71	0,969	1,144
araçá	*Psidium cattleyanum*	ST	3	0,006252482	0,0100	0,42	0,080	0,461
araticum	*Annona crassiflora*	P	1	0,007161972	0,0115	0,14	0,092	0,370
biriba	*Rollinia mucosa*	SI	26	0,241794158	0,3881	3,68	3,094	3,136
biriba-branca	*Eschweilera ovata*	P	34	0,314673594	0,5050	4,82	4,027	4,994
café-do-mato	*Tabernaemontana*	ST	3	0,015286753	0,0245	0,42	0,196	0,499
camboatá	*Cupania vernalis*	CL	37	0,191058984	0,3066	5,24	2,445	4,609
candeia	*Plathymenia foliolosa*	SI	15	0,083259203	0,1336	2,12	1,065	1,941
embaúba	*Cecropia pachystachya*	P	1	0,01260539	0,0202	0,14	0,161	0,393
embiruçu	*Eriotheca pubencens*	SI	3	0,009181649	0,0147	0,42	0,117	0,766
folha miúda	*Ficus organensis*	P	5	0,144457859	0,2318	0,71	1,848	1,437
guabiraba	*Campomanesia xanthocarpa*	CL	9	0,054335498	0,0872	1,27	0,695	1,534
ingá-de-metro	*Inga edulis*	CL	2	0,049314159	0,0791	0,28	0,631	0,890
joão-mole	*Guapira opposita*	SI	16	0,190542049	0,3058	2,27	2,438	2,738

Table 4 – Conclusion

Common name	Scientific name	GE	NI	AB	DoA	DR	DoR	IVI (%)
louro	*Cordia ecalyculata*	P	78	1,070362988	1,7179	11,05	13,696	10,003
massaranduba	*Manilkara huberi*	ST	1	0,005379437	0,0086	0,14	0,069	0,363
matataúba	*Schefflera morototoni*	P	4	0,029170555	0,0468	0,57	0,373	1,190
moleque duro	*Cordia leucocephala*	P	5	0,095343758	0,1530	0,71	1,220	1,228
murici	*Byrsonima sericea*	SI	48	0,692121717	1,1108	6,80	8,856	7,850
murta	*Myrtus communis*	SI	2	0,010762853	0,0173	0,28	0,138	0,433
NI	NI	NI	228	2,193162994	3,5199	32,29	28,064	23,043
pau pombo	*Tapirira guianensis*	P	31	0,720380472	1,1562	4,39	9,218	6,583
pau-de-leite	*Himatanthus bracteatus*	SI	44	0,489671456	0,7859	6,23	6,266	6,505
peroba	*Aspidosperma polyneuron*	ST	4	0,08548578	0,1372	0,57	1,094	1,723
pindaíba	*Duguetia lanceolata*	ST	29	0,209882159	0,3369	4,11	2,686	3,726
pororoca	*Myrsine coriacea*	P	6	0,042196352	0,0677	0,85	0,540	1,048
sambaíba	*Curatella americana*	P	2	0,024084758	0,0387	0,28	0,308	0,782
sucupira	*Pterodon emarginatus*	ST	23	0,407699101	0,6543	3,26	5,217	5,164
TOTAL	**--------------------**	**------**	**706**	**7,814974905**	**12,54263**	**100**	**100**	**100**

Source: Authors (2023)

In where: GE = Ecological group, being: Pioneer (P), Initial secondary (SI), Late secondary (ST) and Climax (CL); NI = Total number of sampled individuals; NI* = Non-identified; DR = Relative density; DoR = Relative dominance; IVI (%) = Percent Importance Value Index.

The studied areas were compared with a Tukey test at the level of 5% among themselves for each phytosociological parameter (Table 5). Among the restoration areas, in the RAM area, once it only has native species, after ten years of implementation, it was expected to find a structure similar to the REF area. The comparison between the studied areas of the phytosociological parameters, only RAM was similar to the REF in relation to the phytosociological parameter NE by the Tukey test at 5% significance. The RAR and RPA restorations did not present any phytosociological parameter statistically equal to the REF (Table 5).

RAM and REF were the ones with the highest Shannon diversity (SH) and significantly greater species uniformity (PI) compared to the RAR and RPA restoration areas (Table 5). In the RAM and REF areas, a more diverse and better distributed floristic composition was observed compared to the other restorations.

Table 5 – Phytosociology of restorations (RAM, RAR, RPA) and reference forest (REF)

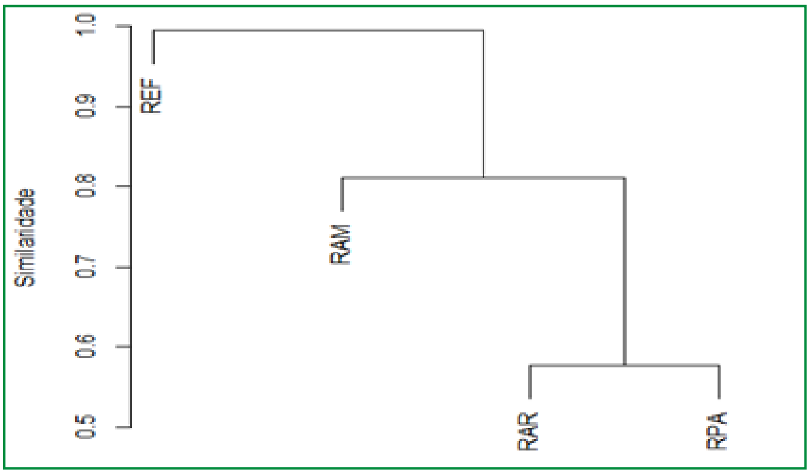
Attribute	Type of restoration			Native Forest
	RAM	RAR	RPA	REF
NI (0.625 ha $^{-1}$)	313c	491b	287c	706a
NE (0.625 ha $^{-1}$)	35a	22b	11c	29a
DAP (cm)	7,97b	7,63b	7,55b	9,20a
H (m)	5,78c	7,14b	6,86b	7,98a
AB (m². ha^{-1})	4,63c	6,59b	2,84d	12,55a
SH	2,90a	1,56b	1,09b	2,53a
PI	0,82a	0,51b	0,46b	0,75a

Source: Authors (2023)

In where: NA = Number of trees/treatment; NE = Number of species/treatment; DAP = Diameter at breast height; AB = Basal Area; AGB = Above-ground biomass; SH = Shannon diversity; PI = Pielou Equability; RAM = Active restoration with planting of native species; RAR = Active restoration combined with eucalyptus; RPA = Passive Restoration by natural regeneration; REF = Secondary Forest. Equal letters on the same line means that there is no significant difference between treatments using the Tukey test at 5% significance.

The RAR and RPA areas have a floristic similarity of 55% (Figure 3). It is observed that, among the 11 species found in RPA (Table 3), only three were not observed in the RAR area (Table 2): *Eritroxyllum deciduum*, *Eriotheca pubencens* and *Samanea tubulosa*. The RAM area showed greater similarity in relation to the REF, with 18% floristic similarity, while RAM with RAR and RPA was 22% (Figure 2).

Figure 2 – Dendrogram of the floristic similarity of the studied areas



Source: Authors (2023)

4 DISCUSSIONS

From the analysis of floristic data from each area, it is observed that in the RAR and RPA areas, even after ten years, there is a predominance of eucalyptus, making it necessary to manage this species so that the forest restoration process used in the areas can favor ecological succession. The presence of the species *Curatella americana* stands out with a large number of individuals in forest restoration areas. Due to its performance and adaptive potential, it can be considered a colonizing or even nucleating species for the recovery of degraded areas. This finding demonstrates that the species has the capacity to adapt to adverse environmental conditions (Calgaro *et al*., 2015), and can be used in restoration projects in degraded areas.

In RAR and RPA areas, lower Shannon diversity and Pielou evenness values were determined due to the high number of eucalyptus individuals present, even after ten years of intervention. These two areas were more similar floristically, although the highest percentage of late secondary and climax species was observed in RAR. In RPA, the percentage was lower, due to the lower diversity of species, with a predominance of eucalyptus.

In RAM, the fact of not having any eucalyptus individuals favored greater diversity, evenness, a more diverse floristic composition and greater floristic similarity among the restoration areas compared to the REF area. In this way, it can be stated that in the RAM area a better process of ecological succession was observed, in floristic terms, among forest restorations once it presents greater species richness.

However, RAM did not reach a structure similar to REF. It is observed that species richness in RAM recovers before the structure. These results are in line with Londe *et al*. (2020), who observed that from 13 years onwards, ecological restorations in semi-deciduous seasonal forests in the Atlantic Forest reach height and basal area values similar to a secondary forest. While species richness is achieved in ecological restorations from the first years, compared to secondary forests.

Other studies have shown that eucalyptus does not impede the ecological succession. In a study on a 20-year-old *Eucalyptus sp* plot, without management, Correia *et al*. (2022) observed pioneer species in the upper extract and non-pioneer species of natural regeneration. In this same study, eucalyptus was observed only in the upper extract, demonstrating that it did not act as an invasive species and the area is undergoing a process of ecological succession.

Seubert *et al*. (2017), studying three areas under natural regeneration, characterized by different ages after removal of Eucalyptus grandis stands, observed that the pioneers suffered a decrease in the number of species, both in the arboreal and regenerative strata, while that the shade-tolerant climax species showed inflows with the advancing age of abandonment of the areas.

The eucalyptus in RAR allowed higher values of NI, H and AB, since 50% of the remaining eucalyptus individuals were not cut. In the RAM area, despite the higher NE value, high NI and AB values were not observed.

In the ecological restoration of ecosystems, the increased diversity is always associated with increased productivity (and consequent carbon and biomass stock), which is among the most important functions of the ecosystem (Rosa; Marques, 2022). Throughout the ecological succession, there is an increase in biomass in tropical forests due to the increase in the diversity of species from more advanced successional stages, which have greater volume and a long life cycle, consequently contributing to a greater stock of biomass and carbon (Chazdon, 2019).

The ecological paradigm of this association is that ecosystem biodiversity is positively related to both ecosystem functions and services (Rosa; Marques, 2022). However, the relationships between biodiversity, ecosystem functions and services vary spatially and temporally, which makes understanding these relationships relevant and important for practical restoration actions (Rosa; Marques, 2022). Therefore, there is a need for evaluations over a longer period of the phytosociological parameters of restorations (RAM, RAR and RPA) to confirm that a greater diversity of species will result in better floristic and structural attributes.

The Shannon diversity observed in this study can be considered high in RAM and REF compared to Rabelo *et al*. (2015), who obtained a Shannon index of 2.88 for a Dense Ombrophylous Forest in the Atlantic Forest, municipality of Igarassu, state of Pernambuco. The observed patterns demonstrate that in areas of passive restoration with eucalyptus, the regrowth must be suppressed, given that more than 50% of the individuals in RPA are from eucalyptus, which favors a lower Shannon diversity.

Eucalyptus in RAR and RPA may be competing for light, water and nutrients with forest species in the tree extract, inhibiting the advancement of ecological succession, given that 10 years after restoration, these two areas have a high percentage of eucalyptus individuals.

5 CONCLUSIONS

The use of restorations with native forest species in consortium with eucalyptus was not able to promote a recovery in the species diversity and in the vegetation structure.

The restoration with the planting of native species without the presence of eucalyptus can recover species diversity and establish the ecological succession in the Atlantic Forest. However, during the period evaluated, it was not able to restore the structure similar to that one of a secondary forest.

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