Effect of planting mixed and facilitating species on the regenerating community

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Abstract

Ecological restoration is essential to recovering degraded ecosystems and reestablishing fundamental environmental processes such as stability, succession, and resilience. This study evaluated whether the mixed planting of eight native forest species and the facilitator species Baccharis dracunculifolia influences Floristic community composition and diversity indices, phytosociological parameters, patterns of species community composition between treatments, and the effect of overgrowth and light on natural regeneration in areas undergoing ecological restoration. The experiment was conducted at the Canguiri Farm Experimental Station, Paraná, Brazil, using a randomized block design with two treatments and four replicates. Plots of 432 m² were monitored four and five years after planting (2023 and 2024). We do not find differences between treatments regarding Floristic composition. The results indicated that both treatments mixed planting (T1) and planting with facilitating species (T2) showed an increase in floristic richness, diversity, and abundance between 2023 and 2024, with T1 maintaining slightly higher values of diversity (Shannon index) and evenness (Pielou index) over time. *Baccharis semiserrata* and *B. dracunculifolia* stood out in the phytosociological parameters, being dominant in treatments and years. The PCoA analysis revealed significantly different floristic compositions between treatments in both years. Finally, a negative effect of light was observed on diversity and evenness in T1 in 2024 and on diversity and richness in T2 in 2023.

1. Introduction

Forest restoration is essential to recover degraded areas and gradually reestablish the original forest ecosystems' structural, functional, and ecological characteristics. This process can occur through natural mechanisms of ecological succession, human intervention, or a combination of both, promoting the reestablishment of biodiversity and ecosystem functions (Brancalion, 2015). Among the most promising approaches in this context, the simultaneous planting of species belonging to different ecological groups stands out, which offers substantial benefits for establishing resilient and diverse plant communities (Assis et al. 2013; Almeida 1998).

Forest restoration strategies vary according to their objectives. They may include rehabilitating environmental functions, such as improving soil quality and recovering the forest structure, preserving biodiversity, and environmental adaptation of rural areas or high-impact economic enterprises (Angelo and Souza, 2020). However, defining effective methodologies to achieve such objectives is challenging, requiring techniques based on scientific knowledge and validated practices (Silva 2015; Gama-Rodrigues 2006).

With the enactment of Federal Law No. 12,651/2012 (Brazil 2012), which established the Environmental Regularization Program (PRA), the search for alternatives to the traditional forest restoration model, based exclusively on the use of native species of the biome, tends to gain greater relevance (Martins et al. 2019). Thus, the restoration and environmental regularization of rural properties can be made viable through the restoration of permanent preservation areas (APP) and the creation or regulation of the Legal Reserve (RL). To this end, implementing new planting arrangements and diversifying species composition are promising strategies since they allow significant ecological interactions between the ecosystem components. Proving the efficiency of these models becomes a fundamental topic to be debated, especially given the challenges of reconciling productive demands with ecological restoration, seeking to ensure food sovereignty and income generation (Silva 2015; Leles et al. 2015; Gama Rodrigues 2006).

Among the strategies employed is facilitating species, such as *Baccharis dracunculifolia DC* (Asteraceae). Thus, these "facilitating" or "benefactor" plants facilitate the development of other plant species (beneficiaries) by improving the physical conditions of the habitat (e.g., temperature, humidity, and availability of organic matter in the soil (Ren et al. 2008; Li et al. 2017; Lu et al. 2018). This facilitating interaction has a practical side when applied to ecological restoration since facilitating species can provide shelter for the target native species (Padilla and Pugnaire, 2006).

Traditional ecological models focus primarily on plant competition. However, some research has shown that some plants benefit from nearby neighboring plants, a phenomenon known as facilitation (Castro et al. 2002; Gomez-Aparicio et al. 2004; Egerova et al. 2003; Sinchez-Velisquez et al. 2004; Blignaut and Milton 2005; Huber-Sannwald and Pyke 2005; Maestre et al.

2001, 2002). Increasing experimental evidence suggests that facilitation has a place in conventional ecological theory and a practical side when restoring degraded environments, especially in limiting habitats. When restoration fails due to adverse environmental conditions or intense herbivory, species that minimize these effects may improve the performance of nearby target species. Although there are few examples of applying this "nurturing" procedure worldwide, experimental data are promising and show increased plant survival and growth in areas close to the mother plants (Padilla and Pugnaire, 2006).

In a global scenario characterized by climate change and increasing environmental pressures, it is essential to develop forest restoration strategies that mitigate adverse impacts, promote ecosystem resilience, and meet socioeconomic demands. However, restoring degraded areas, especially in tropical and subtropical regions where ecological and socioeconomic challenges are more pronounced, requires innovative solutions adapted to local conditions. In this context, the combination of facilitator species and mixed plantings of native species presents itself as a promising approach to promote ecological gains and accelerate the process of environmental recovery. According to the IPCC (2019), forest restoration using a diverse mix of native species can help rebuild the climate resilience of tropical forests but is best implemented together with other sustainable forest management strategies and adaptation interventions.

Thus, the present study aimed to evaluate (i) the influence of two ecological restoration strategies, mixed planting with eight native forest species and the use of the facilitating species *Baccharis dracunculifolia*, on the floristic composition, diversity, phytosociological structure and dynamics of natural regeneration in a degraded area, over the years 2023 and 2024; and (ii) analyze the effects of vegetation cover and light intensity on diversity indices (species richness, Shannon diversity and Pielou uniformity) over time, comparing ecological restoration strategies (mixed planting of forest species and planting with facilitating species). Based on this, we sought to answer the following hypothesis: There is no significant difference between the restoration strategies used regarding floristic composition, diversity, phytosociological structure, and natural regeneration dynamics.

2. Materials and methods

2.1 Study area

The area for evaluating ecological restoration strategies is located at the Canguiri Farm Experimental Station of the Paraná Federal University, at an altitude of 900 meters, at coordinates 25°23'38.31" S and 49°7'37.56" (Fig. 1).

According to the Köppen climate classification, the region has a Cfb climate, characterized by humid temperate zones, regular rainfall throughout the year, and no defined dry season. The average temperature in the warmest months does not exceed 22°C (Alvares et al. 2013). Annual precipitation ranges from 1,100 to 2,000 mm, and the region is subject to severe and frequent frosts, occurring on average 10 to 25 days per year (Carvalho 2003). The area is flat, with latosol soil, located in a transition zone between the Mixed Ombrophilous Forest (FOM) and the natural grassland vegetation – grassy-woody steppe (IAT 2009), equidistant approximately 10 to 20 m from the secondary forest remnants of the FOM. Before the implementation of the experiment, the area was characterized by intense tractor circulation due to agricultural activity, which resulted in soil compaction.

2.2 Implementation of the experiment

The experiment (seedling planting) was implemented in December 2019 in a randomized block design (RBD) with two treatments. For mixed planting (T1), eight forest species with six individuals of each were used (*Casearia decandra* Jacq; *Cassia lepthophylla* Vogel; *Luehea divaricata* Mart. & Zucc; *Vitex megapotamica* (Spreng.) Moldenke; *Inga sessilis* (Vell.) Mart and *Araucaria angustifolia* (Bertol.) Kuntze), together with 18 individuals of *Mimosa scabrella* Benth and 18 individuals of the species *Solanum diploconos (Mart.) Bohs. For planting with the facilitating species (T2), 72 individuals of the species B. dracunculifolia* were used. Four replicates totaled four plots per treatment (Fig. 2).

Each plot had an area of 432 m² (24 x 18 m), consisting of 6 rows with 12 plants, spacing 3 m between rows and 2 m between plants, totaling 72 tree individuals per plot. Harrowing was carried out to prepare the soil, and the area was immediately demarcated. The plots were divided, and the planting alignment was carried out with 2 m wooden stakes, ropes, and flexible tapes of 30 and 50 mm.

At the end of February 2020, the first weeding of the seedlings was carried out manually, followed by the distribution of needles to reduce competing vegetation. The first semi-mechanized mowing was carried out along the planting line in May. Due to water shortages during the seedling establishment phase, irrigation was necessary in May, September, and November 2020. The irrigation system used a 2,000-liter tank and hoses for water distribution, with a manual application of 10 liters per seedling.

2.3 Experimental data collection

Natural regeneration was sampled in September 2023 and 2024, 4 and 5 years after planting. Each plot was subdivided into four subplots of 1 m x 1 m, totaling 16 subplots per treatment, and systematically distributed (Fig. 2).

Trees and shrubs with a diameter at ground level greater than 0.005 m were counted and taxonomically identified, while herbaceous plants were identified only. The botanical classification followed the proposal of Group IV of the Angiosperm Phylogeny (2016). The height of the regenerants was determined using a tape measure and a hypsometer, and the diameter was measured using a digital caliper.

2.4 Data analysis

The floristic composition was assessed based on the classical phytosociological descriptors: absolute density, absolute frequency, relative frequency, relative density, absolute dominance, relative dominance, importance value index, and cover value index (Moro and Martins 2011), and was analyzed and compared using the vegan package (Oksanen et al. 2025). Shannon diversity, abundance, Pielou evenness, and richness indices were calculated as Magurran (2013) described using the vegan package (Oksanen et al. 2025). Diversity index values were analyzed and compared using Generalized Estimating Equations (GEE) using the vegan package (Højsgaard et al. 2006).

To investigate the species composition patterns in the T1 and T2 treatments, Principal Coordinate Ordination Analyses (PCoA) based on the Bray-Curtis metric were performed. Furthermore, the difference between the centroids of each group was assessed using Permutative Analysis of Variance (PERMANOVA), considering a significance level of $p < 0.05$, using the package (Paradis and Schliep, 2019).

To assess the effect of canopy openness and light on diversity measures (Shannon and Pielou Species Richness), Pielou evenness, and individual abundance, we performed generalized linear models of the "Gaussian" family using the vegan package (Oksanen et al., 2025).

3. Results

3.1. Floristic composition of the community and diversity indices

The 2023 T1 treatment recorded 152 individuals in 26 species and 14 families. The T2 treatment sampled 170 individuals belonging to 24 species and 14 families. In the following year, the values observed in both treatments increased. In the T1 treatment, 345 individuals were counted, covering 50 species and 29 families. In the T2 treatment, 267 individuals were recorded, distributed in 53 species and 26 families. In 2023, the most representative families in T1 were Asteraceae, with nine species; Poaceae, four species; and Myrtaceae, three species. About T2, the family with the greatest richness was Asteraceae, with ten species; the other families had one species each, except Rosaceae, with two species. In 2024, the most representative families in the T1 treatment were Asteraceae and Poaceae; the same occurred in T2.

The comparison between strategies T1 and T2 in 2023 and 2024 did not indicate significant differences ($p > 0.05$) for any of the parameters analyzed (Table 1). However, some important variations can be observed between treatments and years. The

Shannon index (H') showed higher values in T1 in both years, being 1.39 in 2023 and 2.03 in 2024, compared to 1.12 and 1.93 in treatment T2.

Although these differences were not significant ($p > 0.14$ in 2023 and $p > 0.58$ in 2024), the data suggest that T1 maintained slightly greater diversity over time. The Pielou index (J') was also slightly higher in T1, indicating a more equitable species distribution. In 2023, the values were 0.89 in T1 and 0.82 in T2. In 2024, the indices were similar (0.85 and 0.83, respectively).

Abundance was similar between treatments in 2023 (9.50 and 10.6), slightly higher in T2. In 2024, however, abundance was higher in T1 (21.6) compared to T2 (16.7). A similar pattern was observed regarding species richness: in 2023, T1 presented greater richness (4.88) compared to T2 (4.19). In 2024, the difference was also greater in T1 (10.9 versus 9.69).

Table 1
– Mean values (± standard deviation) of diversity indices (Shannon and Pielou), abundance, and species richness in treatments with mixed planting of native species and the facilitating species *Baccharis dracunculifolia* in 2023 and 2024.

Year	**2023**			**2024**		
Treatments	**Mixed**	**Facilitating**	**(*p*-value)**	**Mixed**	**Facilitating**	**(*p*-value)**
Shannon (H')	1.39 ± 0.30	1.12 ± 0.42	0.14	2.03 ± 0.31	1.93 ± 0.38	0.58
Pielou's (J')	0.89 ± 0.08	0.82 ± 0.20	0.15	0.85 ± 0.08	0.83 ± 0.20	0.96
Abundance	9.50 ± 4.46	10.6 ± 4.87	0.72	21.6 ± 6.02	16.7 ± 11.0	0.11
Richness	4.88 ± 1.36	4.19 ± 1.42	0.62	10.9 ± 2.69	9.69 ± 3.75	0.37

3.2. Phytosociological parameters

For the phytosociological parameters of the year 2023, in treatment T1, the species that presented the highest values of relative density (DeR), relative dominance (DoR), and relative frequency (FeR) were Baccharis semiserrata DC and *Adiantopsis chlorophylla* (Sw.) Fée. On the other hand, in the treatment with the facilitator species, the species *B.dracunculifolia* and *B. semiserrata* stood out in these indicators (Table 2; Table 3).

Table 2

– Estimate the phytosociological parameters in decreasing order of the Importance Value (IVI) of the shrub, tree, and herbaceous components of mixed planting treatments with eight native forest species in 2023.

Families	Species	DA	DR(%)	FA	FR(%)	DoA	DoR(%)	IVI(%)	CV(%)
Asteraceae	*Baccharis semiserrata DC.*	52.00	34.21	16,00	20.51	36963.86	95.58	50.10	64.89
Pteridaceae	*Adiantopsis chlorophylla (Sw.) Fée*	16.00 .	10.53	6.00	7.69	11:05	0.03	6.08	5.28
Poaceae	*Lolium multiflorum Lam.*	9.00	8.55	7.00	8.97	37.43	0.10	5.87	4.32
Asteraceae	*Hypochaeris chillensis (Kunth) Britton*	9.00	5.92	6.00	7.69	8.06	0.02	4.54	2.97
Poaceae	*Stenotaphrum secundatum (Walter) Kuntze*	9.00	5.92	5.00	6.41	18.83	0.05	4.13	2.98
Polygonaceae	*Rumex obtusifolius L.*	6.00	3.95	2.00	2.56	1035.80	2.68	3.06	3.31
Anacardiaceae	*Schinus terebinthifolia Raddi*	4.00	5.26	2.00	2.56	16.56	0.04	2.62	2.65
Myrtaceae	*Eugenia pyriformis Cambess.*	6.00	3.95	3.00	3.85	3.97	0.01	2.60	1.98
Loganiaceae	*Spigelia tetraptera Taub. ex-LBSM.*	8.00	2.63	4.00	5.13	6.14	0.02	2.59	1.32
Asteraceae	*Baccharis dracunculifolia DC.*	2.00	1.97	3.00	3.85	9.79	0.03	1.95	1.00
Asteraceae	*Austroeupatorium picturatum (Malme) RMKing & H.Rob.*	3.00	1.97	3.00	3.85	5.38	0.01	1.94	0.99
Myrtaceae	*Eugenia uniflora L.*	3.00	1.32	2.00	2.56	519.91	1.34	1.74	1.33
Pinaceae	*Pinus taeda L.*	2.00	1.32	2.00	2.56	9.18	0.02	1.30	0.67
Asteraceae	*Hypochaeris radicata L.*	2.00	1.32	2.00	2.56	4.16	0.01	1.30	0.66
Myrtaceae	*Campomanesia xanthocarpa (Mart.) O.Berg*	2.00	1.32	2.00	2.56	3.60	0.01	1.30	0.66
Plantaginaceae	*Plantago australis Lam.*	2.00	1.32	2.00	2.56	0.83	0.00	1.29	0.66
Poaceae	*Andropogon bicornis L.*	2.00	1.32	2.00	2.56	0.00	0.00	1.29	0.66
Bignoniaceae	*Anemopaegma sp.*	2.00	1.32	1.00	1.28	4.42	0.01	0.87	0.66
Asteraceae	*Conyza bonariensis (L.)*	2.00	1.32	1.00	1.28	3.15	0.01	0.87	0.66

Families	Species	DA	DR(%)	FA	FR(%)	DoA	DoR(%)	IVI(%)	CV(%)
	Cronquist								
Asteraceae	*Chromolaena laevigata (Lam.) RMKing & H.Rob.*	1.00	0.66	1.00	1.28	7.94	0.02	0.65	0.34
Asteraceae	*Taraxacum officinale FH Wigg.*	1.00	0.66	1.00	1.28	2.14	0.01	0.65	0.33
Asteraceae	*Senecio brasiliensis (Spreng.) Less.*	1.00	0.66	1.00	1.28	1.21	0.00	0.65	0.33
Rosaceae	*Rubus rosifolius Sm.*	1.00	0.66	1.00	1.28	0.93	0.00	0.65	0.33
Thelypteridaceae	*Christella dentata (Forssk.) Brownsey & Jermy*	1.00	0.66	1.00	1.28	0.30	0.00	0.65	0.33
Fabaceae	*Trifolium pratense L.*	1.00	0.66	1.00	1.28	0.29	0.00	0.65	0.33
Convolvulaceae	*Dichondra sp.*	1.00	0.66	1.00	1.28	0.00	0.00	0.65	0.33
Total		**152.00**	**100.00**	**78.00**	**100.00**	**38674.93**	**100.00**	**100.00**	**100.00**

Where: DA = Absolute density (ind ha-1); DR = Relative density (%); FA = Absolute frequency (%); FR = Relative frequency (%); DoA = Absolute dominance (m^2 ha^{-1}); DoR = Relative dominance (%); VI% = Relative importance value (%) and IVC (%) = Coverage importance value.

Table 3

– Estimate the phytosociological parameters in decreasing order of the Importance Value (IVI) of the shrub, tree, and herbaceous components of planting with the facilitating species *Baccharis dracunculifolia* in 2023.

Families	Species	DA	DR(%)	FA	FR(%)	DoA	DoR(%)	IVI(%)	ICV(%)
Asteraceae	*Baccharis dracunculifolia DC.*	52	30.59	11	16.42	2509.13	34.82	27,27	32.70
Asteraceae	*Baccharis semiserrata DC.*	22	12.94	9	13.43	3709.65	51.47	25.95	32.21
Anacardiaceae	*Schinus terebinthifolia Raddi*	20	11.76	6	8.96	86.76	1.20	7.31	6.48
Asteraceae	*Achyrocline satureioides (Lam.) DC.*	14	8.24	4	5.97	174.39	2.42	5.54	5.33
Asteraceae	*Hypochaeris radicata L.*	17	10.00	7	10:45	27.68	0.38	6.94	5.19
Pinaceae	*Pinus taeda L.*	2	1.18	2	2.99	381.37	5.29	3.15	3.23
Poaceae	*Lolium multiflorum Lam.*	8	4.71	5	7.46	9.92	0.14	4.10	2.42
Asteraceae	*Chromolaena laevigata (Lam.) RMKing & H.Rob.*	3	1.76	2	2.99	164.67	2.28	2.34	2.02
Fabaceae	*Trifolium pratense L.*	5	2.94	2	2.99	19.67	0.27	2.07	1.61
Asteraceae	*Conyza bonariensis (L.) Cronquist*	4	2.35	2	2.99	52.62	0.73	2.02	1.54
Pteridaceae	*Adiantopsis chlorophylla (Sw.) Fée*	4	2.35	1	1.49	3.04	0.04	1.30	1.20
Asteraceae	*Taraxacum officinale FH Wigg.*	3	1.76	2	2.99	5.08	0.07	1.61	0.92
Asteraceae	*Hypochaeris chillensis (Kunth) Britton*	3	1.76	3	4.48	5.04	0.07	2.10	0.92
Rutaceae	*Zanthoxylum kleinii (RSCowan) PGWaterman*	2	1.18	1	1.49	16.99	0.24	0.97	0.71
Convolvulaceae	*Ipomoea triloba L.*	2	1.18	1	1.49	3.39	0.05	0.91	0.61
Polygonaceae	*Rumex obtusifolius L.*	1	0.59	1	1.49	13.79	0.19	0.76	0.39
Myrtaceae	*Eugenia pyriformis Cambess.*	1	0.59	1	1.49	10.58	0.15	0.74	0.37
Asteraceae	*Austroeupatorium picturatum (Malme) RMKing & H.Rob.*	1	0.59	1	1.49	5.94	0.08	0.72	0.34
Rosaceae	*Rubus rosifolius Sm.*	1	0.59	1	1.49	1.91	0.03	0.70	0.31
Primulacea	*Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.*	1	0.59	1	1.49	1.72	0.02	0.70	0.31
Caryophyllacea	*Cerastium glomeratum Thuill.*	1	0.59	1	1.49	1.61	0.02	0.70	0.31
Loganiaceae	*Spigelia tetraptera Taub. ex-LBSM.*	1	0.59	1	1.49	1.15	0.02	0.70	0.30
Asteraceae	*Senecio brasiliensis (Spreng.) Less.*	1	0.59	1	1.49	0.68	0.01	0.70	0.30
Rosaceae	*Rubus niveus Thunb.*	1	0.59	1	1.49	0.21	0.00	0.69	0.30
Total		**170**	**100**	**67**	**100**	**7206.99**	**100**	**100**	**100**

In 2024, in the mixed planting treatment with eight native forest species, the species with the highest values of relative density, relative dominance, and relative frequency were *Baccharis semiserrata* DC and *Schinus terebinthifolia* Raddi. In the treatment with the facilitator species, the species *B. dracunculifolia* and *B. semiserrata* were the most prominent in these parameters, as shown in (Table 4 and Table 5).

Table 4

– Estimate the phytosociological parameters in decreasing order of the Importance Value (IVI) of the shrub, tree, and herbaceous components of the mixed planting treatments with eight native forest species in 2024.

Familia	Espécie	DA	DR (%)	FA	FR (%)	DoA	DoR (%)	IVI (%)	ICV (%)
Asteraceae	*Baccharis semiserrata DC.*	12	3.48	5	2.86	14450.34	85.82	30.72	44.65
Anacardiaceae	*Schinus terebinthifolia Raddi*	82	23.77	15	8.57	297.36	1.77	11.37	12.77
Primulaceae	*Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.*	67	19.42	16	9.14	41.55	0.25	9.6	9.83
Podocarpaceae	*Podocarpus lambertii Klotzsch ex Endl.*	28	8.12	10	5.71	101.56	0.6	4.81	4.36
Asteraceae	*Baccharis vulneraria Baker*	2	0.58	2	1.14	1824.81	10.84	4.19	5.71
Sapindaceae	*Allophylus edulis (A.St.-Hil. et al.) Hieron. ex Niederl.*	22	6.38	10	5.71	49.59	0.29	4.13	3.34
Asteraceae	*Hypochaeris radicata L.*	10	2.9	10	5.71	0	0	2.87	1.45
Rubiaceae	*Richardia brasiliensis Gomes*	10	2.9	10	5.71	0	0	2.87	1.45
Pteridaceae	*Adiantopsis chlorophylla (Sw.) Fée*	9	2.61	9	5.14	0	0	2.58	1.3
Poaceae	*Andropogon bicornis L.*	9	2.61	9	5.14	0	0	2.58	1.3
Poaceae	*Lolium multiflorum Lam.*	6	1.74	6	3.43	0	0	1.72	0.87
Rosaceae	*Prunus myrtifolia (L.) Urb.*	10	2.9	3	1.71	23.19	0.14	1.58	1.52
Poaceae	*Axonopus compressus (Sw.) P. Beauv.*	5	1.45	5	2.86	0	0	1.44	0.72
Asteraceae	*Senecio brasiliensis (Spreng.) Less.*	5	1.45	5	2.86	0	0	1.44	0.72
Rutaceae	*Zanthoxylum rhoifolium Lam.*	5	1.45	4	2.29	3.15	0.02	1.25	0.73
Asteraceae	*Vernonanthura tweediana (Baker) H.Rob.*	4	1.16	4	2.29	0	0	1.15	0.58
Asteraceae	*Baccharis dracunculifolia DC.*	4	1.16	3	1.71	5.36	0.03	0.97	0.6
Convolvulaceae	*Dichondra sp.*	3	0.87	3	1.71	0	0	0.86	0.43
Oxalidaceae	*Oxalis sp.*	3	0.87	3	1.71	0	0	0.86	0.43
Oleaceae	*Ligustrum lucidum W.T.Aiton*	4	1.16	2	1.14	8.83	0.05	0.78	0.61
Anacardiaceae	*Lithraea brasiliensis Marchand*	3	0.87	2	1.14	9.99	0.06	0.69	0.46
Styracaceae	*Styrax leprosus Hook. & Arn.*	3	0.87	2	1.14	5.75	0.03	0.68	0.45
Salicaceae	*Xylosma ciliatifolia (Clos) Eichler*	3	0.87	2	1.14	2.95	0.02	0.68	0.44
Amaranthaceae	*Alternanthera philoxeroides (Mart.) Griseb.*	2	0.58	2	1.14	0	0	0.57	0.29
Anemiaceae	*Anemia phyllitidis (L.) Sw.*	2	0.58	2	1.14	0	0	0.57	0.29
Asteraceae	*Austroeupatorium picturatum (Malme) R.M.King & H.Rob.*	2	0.58	2	1.14	0	0	0.57	0.29

Familia	Espécie	DA	DR (%)	FA	FR (%)	DoA	DoR (%)	IVI (%)	ICV (%)
Poaceae	*Homolepis glutinosa (Sw.) Zuloaga & Soderstr.*	2	0.58	2	1.14	0	0	0.57	0.29
Asteraceae	*Lactuca canadensis L.*	2	0.58	2	1.14	0	0	0.57	0.29
Liliaceae	*Lilium formosanum A. Wallace*	2	0.58	2	1.14	0	0	0.57	0.29
Poaceae	*Paspalum sp.*	2	0.58	2	1.14	0	0	0.57	0.29
Plantaginaceae	*Plantago australis Lam.*	2	0.58	2	1.14	0	0	0.57	0.29
Salicaceae	*Casearia decandra Jacq.*	2	0.58	1	0.57	10.09	0.06	0.4	0.32
Lauraceae	*Aiouea amoena (Nees & Mart.) R.Rohde*	1	0.29	1	0.57	2.6	0.02	0.29	0.15
Passifloraceae	*Passiflora actinia Hook.*	1	0.29	1	0.57	0.79	0	0.29	0.15
Rhamnaceae	*Hovenia dulcis Thunb.*	1	0.29	1	0.57	0.69	0	0.29	0.15
Pinaceae	*Pinus sp.*	1	0.29	1	0.57	0.26	0	0.29	0.15
Poaceae	*Andropogon leucostachyus Kunth*	1	0.29	1	0.57	0	0	0.29	0.14
Asteraceae	*Baccharis anomala DC.*	1	0.29	1	0.57	0	0	0.29	0.14
Asteraceae	*Bidens pilosa L.*	1	0.29	1	0.57	0	0	0.29	0.14
Apiaceae	*Centella asiatica (L.) Urb.*	1	0.29	1	0.57	0	0	0.29	0.14
Poaceae	*Cortaderia selloana (Schult. & Schult.f.) Asch. & Graebn.*	1	0.29	1	0.57	0	0	0.29	0.14
Convolvulaceae	*Ipomoea triloba L.*	1	0.29	1	0.57	0	0	0.29	0.14
Caryophyllaceae	*Paronychia communis Cambess.*	1	0.29	1	0.57	0	0	0.29	0.14
Brassicaceae	*Raphanus raphanistrum L.*	1	0.29	1	0.57	0	0	0.29	0.14
Rosaceae	*Rubus niveus Thunb.*	1	0.29	1	0.57	0	0	0.29	0.14
Polygonaceae	*Rumex obtusifolius L.*	1	0.29	1	0.57	0	0	0.29	0.14
Iridaceae	*Sisyrinchium micranthum Cav.*	1	0.29	1	0.57	0	0	0.29	0.14
Fabaceae	*Trifolium repens L.*	1	0.29	1	0.57	0	0	0.29	0.14
Plantaginaceae	*Veronica persica Poir.*	1	0.29	1	0.57	0	0	0.29	0.14
Asteraceae	*Youngia japonica (L.) DC.*	1	0.29	1	0.57	0	0	0.29	0.14
Total		345	100	175	100	16838.86	100	100	100

Table 5
– Estimate of phytosociological parameters in decreasing order of the Importance Value (IVI) of the shrub, tree, and herbaceous components of the mixed planting treatments with planting with the facilitating species *Baccharis dracunculifolia* in the year 2024.

Familia	Espécie	DA	DR (%)	FA	FR (%)	DoA	DoR (%)	IVI (%)	ICV (%)
Asteraceae	*Baccharis dracunculifolia DC.*	52	19.48	9	5.81	3187.26	38.56	21.28	29.02
Asteraceae	*Baccharis semiserrata DC.*	27	10.11	6	3.87	3565.83	43.14	19.04	26.63
Anacardiaceae	*Schinus terebinthifolia Raddi*	28	10.49	9	5.81	382.7	4.63	6.97	7.56
Rosaceae	*Prunus myrtifolia (L.) Urb.*	4	1.5	3	1.94	985.7	11.93	5.12	6.71
Poaceae	*Andropogon bicornis L.*	12	4.49	12	7.74	0	0	4.08	2.25
Primulaceae	*Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.*	22	8.24	5	3.23	18.1	0.22	3.89	4.23
Asteraceae	*Hypochaeris radicata L.*	10	3.75	10	6.45	0.01	0	3.4	1.87
Asteraceae	*Senecio brasiliensis (Spreng.) Less.*	9	3.37	9	5.81	0	0	3.06	1.69
Rubiaceae	*Richardia brasiliensis Gomes*	7	2.62	7	4.52	0	0	2.38	1.31
Poaceae	*Paspalum sp.*	6	2.25	5	3.23	0	0	1.82	1.12
Poaceae	*Axonopus compressus (Sw.) P. Beauv.*	5	1.87	5	3.23	0	0	1.7	0.94
Convolvulaceae	*Dichondra sp.*	5	1.87	5	3.23	0	0	1.7	0.94
Oxalidaceae	*Oxalis sp.*	5	1.87	5	3.23	0	0	1.7	0.94
Sapindaceae	*Allophylus edulis (A.St.-Hil. et al.) Hieron. ex Niederl.*	6	2.25	3	1.94	42.2	0.51	1.56	1.38
Poaceae	*Lolium multiflorum Lam.*	4	1.5	4	2.58	0	0	1.36	0.75
Asteraceae	*Baccharis calvescens DC.*	7	2.62	1	0.65	20.38	0.25	1.17	1.43
Asteraceae	*Lactuca canadensis L.*	3	1.12	3	1.94	0	0	1.02	0.56
Plantaginaceae	*Plantago australis Lam.*	3	1.12	3	1.94	0	0	1.02	0.56
Brassicaceae	*Raphanus raphanistrum L.*	3	1.12	3	1.94	0	0	1.02	0.56
Iridaceae	*Sisyrinchium micranthum Cav.*	3	1.12	3	1.94	0	0	1.02	0.56
Asteraceae	*Vernonanthura tweediana (Baker) H.Rob.*	3	1.12	3	1.94	0	0	1.02	0.56
Podocarpaceae	*Podocarpus lambertii Klotzsch ex Endl.*	3	1.12	2	1.29	52.38	0.63	1.02	0.88
Pinaceae	*Pinus sp.*	2	0.75	2	1.29	1.81	0.02	0.69	0.39
Asteraceae	*Gamochaeta americana (Mill.) Wedd.*	2	0.75	2	1.29	0.13	0	0.68	0.38
Asteraceae	*Achyrocline satureioides (Lam.) DC.*	2	0.75	2	1.29	0	0	0.68	0.37
Pteridaceae	*Adiantopsis chlorophylla (Sw.) Fée*	2	0.75	2	1.29	0	0	0.68	0.37
Liliaceae	*Lilium formosanum A. Wallace*	2	0.75	2	1.29	0	0	0.68	0.37

Familia	Espécie	DA	DR (%)	FA	FR (%)	DoA	DoR (%)	IVI (%)	ICV (%)
Primulaceae	*Lysimachia arvensis (L.) U. Manns & Anderb.*	2	0.75	2	1.29	0	0	0.68	0.37
Poaceae	*Saccharum villosum Steud.*	2	0.75	2	1.29	0	0	0.68	0.37
Malvaceae	*Sida rhombifolia L.*	2	0.75	2	1.29	0	0	0.68	0.37
Asteraceae	*Solidago chilensis Meyen*	2	0.75	2	1.29	0	0	0.68	0.37
Asteraceae	*Baccharis erioclada DC.*	1	0.37	1	0.65	3.33	0.04	0.35	0.21
Rutaceae	*Zanthoxylum rhoifolium Lam.*	1	0.37	1	0.65	3.2	0.04	0.35	0.21
Myrtaceae	*Myrcia guianensis (Aubl.) DC.*	1	0.37	1	0.65	1.43	0.02	0.35	0.2
Meliaceae	*Cabralea canjerana (Vell.) Mart.*	1	0.37	1	0.65	0.1	0	0.34	0.19
Fabaceae	*Trifolium repens L.*	1	0.37	1	0.65	0.08	0	0.34	0.19
Asteraceae	*Vernonanthura montevidensis (Spreng.) H.Rob.*	1	0.37	1	0.65	0.06	0	0.34	0.19
Oleaceae	*Ligustrum lucidum W.T.Aiton*	1	0.37	1	0.65	0.05	0	0.34	0.19
Poaceae	*Andropogon leucostachyus Kunth*	1	0.37	1	0.65	0	0	0.34	0.19
Anemiaceae	*Anemia phyllitidis (L.) Sw.*	1	0.37	1	0.65	0	0	0.34	0.19
Asteraceae	*Austroeupatorium inulaefolium (Kunth) R.M.King & H.Rob.*	1	0.37	1	0.65	0	0	0.34	0.19
Asteraceae	*Baccharis anomala DC.*	1	0.37	1	0.65	0	0	0.34	0.19
Apiaceae	*Centella asiatica (L.) Urb.*	1	0.37	1	0.65	0	0	0.34	0.19
Asteraceae	*Conyza canadensis (L.) Cronquist*	1	0.37	1	0.65	0	0	0.34	0.19
Araliaceae	*Cuphea calophylla var. mesostemon (Koehne) S.A.Graham*	1	0.37	1	0.65	0	0	0.34	0.19
Asteraceae	*Desmodium incanum (Sw.) DC.*	1	0.37	1	0.65	0	0	0.34	0.19
Lythraceae	*Homolepis glutinosa (Sw.) Zuloaga & Soderstr.*	1	0.37	1	0.65	0	0	0.34	0.19
Fabaceae	*Ipomoea triloba L.*	1	0.37	1	0.65	0	0	0.34	0.19
Poaceae	*Megathyrsus maximus (Jacq.) B.K.Simon & S.W.L.Jacobs*	1	0.37	1	0.65	0	0	0.34	0.19
Convolvulaceae	*Scutellaria racemosa Pers.*	1	0.37	1	0.65	0	0	0.34	0.19
Lamiaceae	*Stachys arvensis L.*	1	0.37	1	0.65	0	0	0.34	0.19
Lamiaceae	*Stenotaphrum secundatum (Walter) Kuntze*	1	0.37	1	0.65	0	0	0.34	0.19
Poaceae	*Taraxacum officinale F.H. Wigg.*	1	0.37	1	0.65	0	0	0.34	0.19
Total		**267**	**100**	**155**	**100**	**8264.76**	**100**	**100**	**100**

3.3 *Patterns of species community composition across treatments*

Principal Coordinate Analysis (PCoA) indicated that the first two axes explained 22.44% of the total data variation, with 13.87% attributed to the PCoA1 axis and 8.57% to the PCoA2 axis ($F = 13.84$, df = 1, $p < 0.001$, $R^2 = 16.62$; Fig. 3). In 2023, the treatments presented significantly different species compositions ($F = 5.09$, df = 1, $p < 0.001$, $R^2=14.52$. Figure 3), a pattern also observed in 2024 ($F = 4.31$, df = 1, $p < 0.002$, $R^2 = 12.57$; Fig. 3). When analyzing the treatments separately between the years, it was observed that treatment T1 presented differences in species composition between 2023 ($F = 16.09$, df = 1, $p < 0.001$, $R^2= 34.93$; Fig. 3) and 2024 ($F = 4.08$, df = 1, $p < 0.001$, $R^2= 11.99$; Fig. 3), a result similar to that observed in the treatment with the facilitator species.

3.4 *Effects of canopy cover and light intensity on diversity indices.*

We found a negative effect of luminosity on Shannon diversity and Pielou equitability and a negative effect of canopy openness on equitability for mixed planting in 2024. In the treatment with facilitating species, we observed a negative effect of luminosity on Shannon diversity and species richness in 2023 (Table 6).

Table 6
Relationships between canopy openness (%) and luminosity (lux) on the parameters of diversity, uniformity, and abundance of individuals under different forest restoration treatments (mixed planting of native species and planting with the facilitating species *Baccharis dracunculifolia*) in the years 2023 and 2024. Estimate values and (p value).

Year	**2023**				**2024**			
Treatment	**Mixed**		**Facilitating**		**Mixed**		**Facilitating**	
Variable	Canopy	Luminosity	Canopy	Luminosity	Canopy	Luminosity	Canopy	Luminosity
Shannon (H')	0.27 (0.79)	0.39 (0.70)	-1.03 (0.32)	**-2.19 (0.04)**	-2.13 (0.05)	**-2.60 (0.02)**	0.90 (0.39)	1.28 (0.22)
Pielou's (J')	-1.57 (0.14)	-0.57 (0.58)	0.07 (0.94)	-0.06 (0.95)	**-2.31 (0.03)**	**-2.75 (0.02)**	1.21 (0.25)	1.31 (0.21)
Abundance	1.75 (0.11)	0.79 (0.45)	-0.69 (0.50)	-1.21 (0.25)	-0.01 (0.99)	-0.07 (0.95)	-1.37 (0.20)	-1.13 (0.24)
Richness	0.99 (0.34)	0.54 (0.60)	-1.60 (0.13)	**-3.24 (0.007)**	-1.23 (0.24)	-1.50 (0.16)	-0.54 (0.60)	-0.18 (0.86)

4. Discussion

Here, we evaluated the influence of two ecological restoration strategies, mixed planting with eight native forest species and the use of the facilitator species *Baccharis dracunculifolia*, on the floristic composition, diversity, phytosociological structure and dynamics of natural regeneration in a degraded area, after five years of planting, for two consecutive years (2023 and 2024). We expected that there would be no significant differences between the restoration strategies used in terms of floristic composition, diversity, phytosociological structure, and dynamics of natural regeneration. Our results were partially corroborated since we found no differences between the treatments, only for the issue of luminosity and the species composition, which varied between years, showing that regeneration in the areas is dynamic over time.

Facilitation mechanisms are characterized by beneficial interactions between plants that allow for advantages for one or both related species over time. Such interactions can be caused by environmental changes, which favor the formation or evolution of species, or by other living beings (Losapio et al., 2021). A facilitator species enables the colonization of areas of reduced regeneration and severe environmental conditions, positively altering the dynamics and structure of the community through the creation of microenvironments (Liancourt and Dolezal, 2021).

Research by Bertness and Callaway (1994) elucidated how positive interactions influence the recruitment and spatial distribution of species and decrease physical stress and consumer pressure, thus regulating the process of ecological succession. On the other hand, Nélida and Florencia (2002) state that mixed plantations can promote the regeneration of a greater diversity of species in their understory than plantations of facilitating species, creating a greater variability of habitat conditions that can favor seed dispersers and germination and growth of tree species. The results of the present study demonstrate a robust and diverse floristic composition in both experimental treatments, the mixed plantation with eight native forest species and the plantation with the facilitator species *Baccharis dracunculifolia*. In 2024, mixed plantation, 50 species, and 29 families were recorded, while the treatment with *B. dracunculifolia* showed greater species richness (53) and families (32).

A similar result was found by (Siqueira et al. 2022), whose objective was to evaluate the potential role of *Baccharis dracunculifolia in facilitating* the recovery of a native plant community in a degraded Atlantic Forest in a short period. The study was developed in two abandoned pasture areas, one in which *B. dracunculifolia* was planted (Restored treatment) to promote restoration and a second area without intervention (Degraded = Control treatment). Even in a short period, the planting of *B. dracunculifolia* had a positive effect in promoting the assembly of the native plant community and possibly in decreasing the chances of invasion by exotic species. The Restored treatment had 17 exclusive native species, while the Degraded treatment had only three non-exclusive native species.

The use of facilitating plants in ecological restoration projects has become highly relevant, as they help to form communities in the early stages of natural succession and result in an increase in the richness and abundance of other species (Spadeto et al. 2017; Shaw 2018), as can be observed in our study. Furthermore, and importantly, these plants can create microsites capable of restoring the native plant community in areas highly invaded by exotic plant species (Perea et al. 2019).

The genus *B. dracunculifolia* has been identified as a facilitating species for other species (Peláez et al., 2019). For example, experimental field tests indicate that *B. dracunculifolia* has the potential to be a facilitating species in degraded environments of mountainous Neotropical regions; the predicted probability was 61% higher than that of exotic species (Perea et al., 2019).

B. dracunculifolia is a dioecious shrub with pioneer plant characteristics, such as rapid growth and development. It protects the soil against direct radiation exposure, either through the shading provided by its branches or through the coverage of organic matter. In addition, provides a large amount of ecosystem services, including a rich fauna of insects and pollinating species, which are important for the functioning and sustainability of the ecosystem (Fernandes et al. 2018).

As can be understood from the data collected in our study, the introduction of *B. dracunculifolia* into degraded areas facilitated the enrichment of plant species in these treatments. The Shannon index has a small but important increase from 2023 to 2024 in both treatments (mixed: from 1.4 to 2.1; with facilitator: from 1.1 to 1.8). This growth may be associated with the regeneration and colonization of native species, representing the optimized recovery of the area for both forms of interventions without major statistical differences.

Previous studies in mixed rainforests, such as those by Bambolim and Wojciechowski (2017), indicate that high H' values reflect the recovery of degraded areas and the presence of species with different ecological functions; a similar condition was found in the reality investigated in this study. Furthermore, the greater diversity observed in 2024 may be linked to introducing management practices, such as disturbance control and exclusion of anthropogenic pressures, as discussed by (Chazdon et al. 2021). These authors highlight that mild interventions, such as area protection and enrichment with native species, are crucial to increase floristic diversity and facilitate natural regeneration in degraded ecosystems.

Pielou's evenness index (J’) did not change significantly between years (mixed: 0.89 to 0.86; with facilitator: 0.78 to 0.88). Thus, although overall diversity (H') was increasing, the relative evenness of the distribution of individuals among species seemed relatively constant. This pattern may indicate that the most abundant species maintain community dominance to some degree while the less abundant species maintain proportional participation. This corroborates the results of studies such as that of Passos et al. 2021, which reported similar J' values for mixed tropical forest fragments, which supported the structural stability of the community even in scenarios of floristic change.

The community composition revealed differences in the dynamics of species composition between treatments T1 and T2 throughout the evaluated period. In the mixed treatment, the greater separation between 2023 and 2024 indicates significant changes in floristic composition. This result suggests that the mixed plantation, composed of eight forest species, can promote greater diversity and be more susceptible to variations in environmental conditions. The greater dispersion observed in 2024 reflects the increase in diversity resulting from more complex ecological interactions and the variable response of species to microhabitat conditions.

A similar result was obtained by (Guerin et al. 2021) in a study that compared the long-term results (24 to 53 years) of pure and mixed plantations of native tree species with a wide spectrum of reference ecosystems (degraded, secondary, and old forests). Furthermore, it verified whether pure plantations would be as successful in promoting natural regeneration as mixed plantations and whether they could potentially achieve the attributes of native forests in the same region. Contrary to expectations, pure and mixed plantations did not differ in tree density, species richness, and functional diversity. In general, pure plantations were as effective as mixed plantations in promoting the recovery of seasonal tropical forests in terms of structure and functionality in the long term. Regarding taxonomic diversity and richness, mixed plantations were more efficient, while pure plantations did not reach primary forests, did not differ from degraded secondary forests, and surpassed secondary forests in several attributes.

Studies such as that of Rodrigues et al. (2009) show that more diversified planting systems promote greater environmental heterogeneity, positively influencing natural regeneration. The results of this study corroborate this perspective by demonstrating that environments with lower levels of light favored increased diversity, equitability, and species richness. In the 2024 mixed planting, the shading promoted by greater canopy coverage contributed to reducing the dominance of some species, resulting in a more balanced community. In addition, it was observed that canopy openness harmed equitability. Similarly, in the treatment with facilitating species, the shading observed in 2023 favored diversity and richness, indicating that more shaded conditions are beneficial for the structure of natural regeneration.

The results of the PCoA analysis indicated that the treatments presented distinct floristic compositions in both years, with a greater difference between them in 2023. This pattern suggests that the initial effects of the restoration strategies, whether with mixed forest species or facilitator species, strongly influenced the plant community. In 2024, although the differences were still evident, the reduction in the distance between the treatments pointed to a possible floristic approximation over time, possibly due to the increased influence of natural processes, such as the dispersal and recruitment of shared species. When analyzing the temporal variation, both treatments presented significant changes between 2023 and 2024, with this variation being more pronounced in the mixed plantation, which may be related to canopy density and intensification of competition. The change was more subtle in the treatment with facilitator species, indicating a more stable succession, although still ongoing.

These different trajectories reflect the role of planting strategies in regeneration dynamics. Facilitator species, as highlighted by Reis et al. (2010), contribute to creating a more stable microclimate, reduce initial competition, and favor establishing successional species. Padilla and Pugnaire (2006) complement this view by stating that plant facilitation acts as a catalyst for restoration, especially in degraded areas. On the other hand, mixed plantings can promote greater floristic turnover and structural heterogeneity, which can increase diversity over time. Furthermore, Vieira et al. (2008) argued that more diverse plantings are more resilient, attract fauna, and reduce the risks of pests and diseases. Thus, the development time and the type of intervention adopted are fundamental factors in defining the floristic composition and the pace of ecological succession in areas under restoration.

The analyses of both interventions reveal that similar trajectories of ecological succession are promoted; according to Holl and Aide (2011), differences in planting strategies can significantly influence the direction and speed of succession processes and must be considered according to the context and environmental objectives.

Overall, restoration through mixed planting and with *B. dracunculifolia* optimally increased the richness of plant species in the restored environment, in which the latter stood out. The restoration of degraded areas is expected to lead to the emergence of Asteraceae and Poaceae, which are often among the first plant families to colonize these areas. These families are suitable for these environments due to their adaptability, rapid growth, and ability to utilize resources efficiently, as observed in the *B. dracunculifolia group*. This indicates that planting facilitating species can influence the environmental conditions of the restored area, favoring native species, thus softening environmental aggression by filtering solar radiation through the canopy's shade.

Conclusion

The results of this study highlight the potential of planting strategies in the ecological restoration of degraded areas, evidencing distinct trajectories in ecological succession. The mixed planting with eight native forest species and the treatment with the facilitator species *B. dracunculifolia* presented abundant and diverse floristic compositions. The species and family richness recorded in the treatment with *B. dracunculifolia* reinforces its role as an effective strategy in promoting natural regeneration under adverse environmental conditions. The mixed planting demonstrated excellent floristic dispersion over time, indicating more significant dynamics and the potential to promote environmental heterogeneity. Thus, combining mixed plantings and facilitating species, combined with continuous monitoring, can enhance ecosystems' functional restoration and biodiversity conservation.

Declarations

Ethics Statement Data/Material Availability

The datasets generated during this study are available from the corresponding author upon reasonable request and within the framework of cooperation agreements and scientific research projects.

Conflict of interest

The authors declare no conflict of interest.

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The study received no external or internal funding.

Author's contribution

Raimundo Junior: Conceptualization, Data analysis, Methodology, Writing-original draft, Writing-review, editing, and investigation. Alessandro Angelo: Conceptualization, Methodology, Data curation, Supervision, review. Nelson Luiz: Supervision, Writing Lorena Tavares: Supervision and writing; Roman Carlos: Supervision and writing Alexandre Mastella: Methodology; Chaiane Schneider: Methodology; Karen Souza: Methodology; Ingo Isernhagen: Conceptualization, Methodology, Data curation, Supervision; Elivane Salete Capellesso: Conceptualization, Methodology, Data curation, Supervision writing; Emi Silva Oliveira: Supervision writing

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References

1. Almeida DS (1998) Ecological recovery of fragmented landscapes. Available at: https://www.academia.edu/38369205/Ecology_of_Fragmented_Landscapes > Accessed: April 20, 2025
2. Angelo AC, Souza KKF (2020) Forest Restoration. *Forest Resources Management Program* . Santa. Cruz do Sul, 128 p.
3. Assis GB, Suganuma MS, Melo ACG, Durigan G (2013) Use of native and exotic species to restore riparian forests in the State of São Paulo (1957–2008). *Rev Agric Neotrop 4* :28-35.
4. Bambolim A, Wojciechowski JC (2017) Floristic and phytosociological composition of a remnant of mixed rainforest. *Rev Agric Neotrop 4* :28-35

5. Bertness MD, Callaway R. (1994) Positive interactions in communities. ***Trends in ecology & evolution*** *,9* (5):191-193.
6. Blignaut A and Milton SJ. (2005). Effects of multispecies clumping on survival of three succulent plant species translocated onto mine spoil in the succulent Karoo Desert, *South Africa. Restor Ecol 13* :15-19. **doi : 10.1111/j.1526-100X.2005.00003.x**
7. Brancalion PHS, Gandolfi S, Rodrigues RR (2015) *Forest Restoration.* 431 p.
8. B rasil . Decree-Law No. 12,651 of May 25, 2012. Protection of native vegetation. *Official Gazette [of the] Federative Republic of Brazil, Brasília, DF* , May 26, 2012. Available at: http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm. Accessed on: January 10, 2025.
9. Castro J, Zamora R, Hodar JA, et al. (2002). Using shrubs as nurse plants is a new technique for reforestation in Mediterranean mountains. *Restor Ecol 10* :297-305. **https://doi.org/10.1046/j.1526-100X.2002.01022.x**
10. Chazdon RL, Falk DA, Banin LF, et al. (2021) The intervention continuum in restoration ecology: rethinking the active-passive divide. *Restor Ecol (4*):3, 45-50. doi : 10.1111/rec.13535
11. Egerova J, Proffitt E, Travis SE. (2003). Facilitation of survival and growth of Baccharis halimifolia L by Spartina altemiflora Loisel in a created Louisiana salt marsh. *Wetlands 23:* 250-56. https://doi.org/10.1672/4-20
12. Fernandes GW, Yumi O, Belmiro MS, et al. (2018). Multitrophic interactions among fungal endophytes, bees, and Baccharis dracun culifolia : resin tapering for propolis production leads to endophyte infection. *Arthropod-Plant Interactions, 12* (3): 329–337.
13. Gama-Rodrigues AC, Barros NF, Gama-Rodrigues EF, et al. (2006) Agroforestry systems: scientific bases for sustainable development. Brazilian Society of Agroforestry Systems. Darcy Ribeiro State University of Northern Fluminense. *Embrapa Information Technology*
14. Gomez-Aparicio L, Zamora R, Gomez JM, et al. (2004). Applying plant facilitation to forest restoration: a meta-analysis of the use of shrubs as nurse plants. *Ecol Appl 14* :1128-38. **https://doi.org/10.1890/03-5084**
15. Guerin N, et al. (2021). Pure or mixed plantings equally enhance the recovery of the Atlantic forest. *Forest Ecology And Management. Amsterdam: Elsevier, 484* (9):2021. https ://10.1016/j.foreco.2021.118932
16. Holl KD, Aide TM (2011) When and where to actively restore ecosystems? *For Ecol Manag 261* :1558–1563. https://doi.org/10.1016/j.foreco.2010.07.004
17. Huber-Sannwald E, Pyke DA. (2005). Establishing native grasses in a large sagebrush-dominated site: an intermediate restoration step. *Rest Ecol 13* : 292-301. https://doi.org/10.1111/j.1526-100X.2005.00037.x
18. Intergovernmental Panel on Climate Change (IPCC). (2019) Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, F *ood Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* . Available at: https://www.ipcc.ch/report/srccl/. Accessed on: February 21 2025
19. Leles PSS, Oliveira Neto SN, Alonso JM (2015) Forest restoration at different spacings. In: Leles PSS, Oliveira Neto SN (eds) *Forest Restoration and the Guandu River Basin.* Seropédica: Rural Publisher, p. 120-156.
20. Li W, Li J, Liu S, et al. (2017). Magnitude of species diversity effect on aboveground plant biomass increases through successional time of abandoned farmlands on the eastern Tibetan Plateau of China. *Land Degradation and Development* 28(1): 370–378
21. Liancourt P, Dolezal J. (2021).Community - scale effects and strain: facilitation beyond conspicuous patterns. ***Journal of Ecology*** *, 109* (1):19-25.
22. Losapio, G, Schimid B, Bascompete J, *et al. (2021)* . An experimental approach to assessing the impact of ecosystem engineers on biodiversity and ecosystem functions. ***Ecology*** *, 102* (2):e 03243.
23. Lu R, Zheng J, Jia C, et al. (2018). Nurse effects of patch-canopy microhabitats promote herb community establishment in sandy land. *Ecological Engineering 118* :126–133.
24. Maestre FT, Bautista S, Cortina J, et al. (2001). Potential for using facilitation by grasses to establish shrubs on a semiarid degraded steppe. *Ecol Appl 11* :1641-55.

25. Maestre FT, Bautista S, Cortina J, et al. (2002). Microsite and mycorrhizal inoculum effects on establishing Quercus coccifera in a semi-arid degraded steppe. *Ecol Eng 19* :289–95.
26. Nélida JC, Florencia M. (2002). Facilitating regeneration of secondary forests using mixed and pure plantations of indigenous tree species, *Forest Ecology and Management, 163* (1).1–3.
27. Padilla, FM, & Pugnaire, FI (2006) The role of nurse plants in restoring degraded environments. *Frontiers in Ecology and the Environment, 4* (4), 196–202.
28. Passos MG, Prado GP, Fontana C, Bianchini E (2021) Structure and tree diversity in a mixed lojaphilous forest remnant, Southern Brazil. Forest Environment.Conservation of Nature. *Floresta Ambient. 28* (2).
29. Peláez M., et al. (2019). Nurse plant size and biotic stress determine quantity and quality of plant facilitation in oak savannas. *Forest Ecology and Management 437* :435–442.
30. Perea R., et al. (2019) Nurse shrubs to mitigate gate plant invasion along roads of montane Neotropics. *Ecological Engineering, 136* : 193–196.
31. Ren H, Yang L, Liu N. (2008). Nurse plant theory and its application in ecological restoration in lower subtropics of China. *Progress in Natural Science 18* (2): 137–142.
32. Rodrigues RR, Lima RAF, Gandolfi S, et al. (2009) On restoring high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. *Biol Conserv 142* :1242–1251.
33. Sanchez-Velasquez LR, Quintero-Gradilla S, Arag6n-Cruz F, et al. (2004). Nurses for Brosimum alicastrum reintroduction in secondary tropical dry forest. *Forest Ecol Manag 198* :401-04.
34. Shaw JA (2018). Ammophila arenaria as a nurse plant: Implications for management of an invasive species. *Ecological Restoration, 36* (3): 171–173.
35. Silva RJ (2015) Recovery of degraded areas through agroforestry systems: limits and possibilities. *South Am J Basic Educ Tech Technol 2* :165-169.
36. Siqueira WK, (2022).The role of baccharis (asteraceae) shrubs in the short-term restoration of Atlantic rainforest. *Nature Conservation Research . 7* (2):42–53.
37. Spadeto C., et al. (2017). Facilitative effects of tree species on natural regeneration in an endangered biodiversity hotspot. *Brazilian Journal of Botany, 40* (4): 943–950.
38. Vieira ICG, Veiga JB, Yared JAG, Salomão RP, Ohashi, Júnior, SB. Bases técnicas e referências para o programa de restauração florestal do Pará: um bilhão de árvores para a Amazônia. Instituto de Desenvolvimento Econômico, Social e Ambiental do Pará, 103 p., Belém, 2008.
39. Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Borman T, Carvalho G, Chirico M, De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlinn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J (2025). vegan: Community Ecology Package. R package version 2.7-0, https://vegandevs.github.io/vegan/.
40. Paradis E, Schliep K (2019). "ape 5.0: an environment for modern phylogenetics and evolutionary analyses inR." Bioinformatics, 35,526-528. doi:10.1093/bioinformatics/bty633<https://doi.org/10.1093/bioinformatics/bty633>.
41. Højsgaard S, Halekoh U, Yan J. (2006) The R Package geepack for Generalized Estimating Equations Journal of Statistical Software, 15, 2, pp1--11

Figures

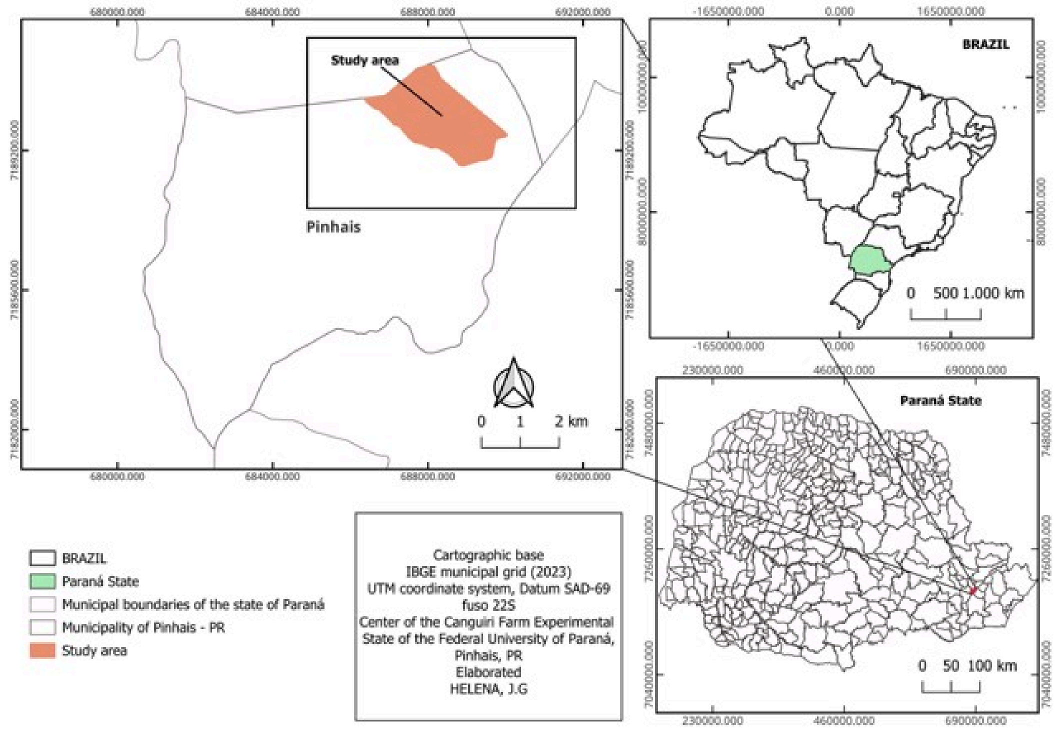

Figure 1

Location of the Canguiri Farm Experimental Station of the Paraná Federal University, Pinhais, PR

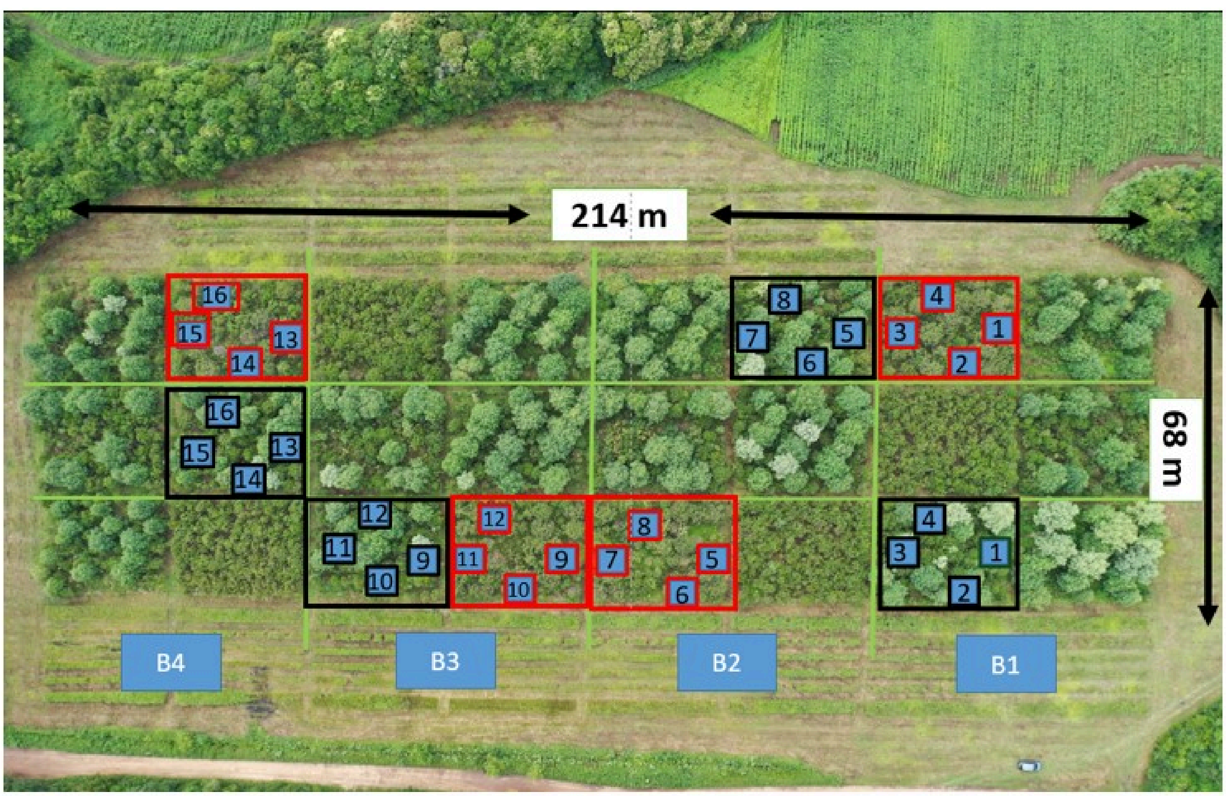

Figure 2

Layout of the treatments analyzed in the experiment: (Black rectangle) T1: Mixed planting with eight forest species, (Red rectangle) T2: Planting nursing species *Baccharis dracunculifolia* at the Canguiri Farm Experimental Station, Pinhais – PR.

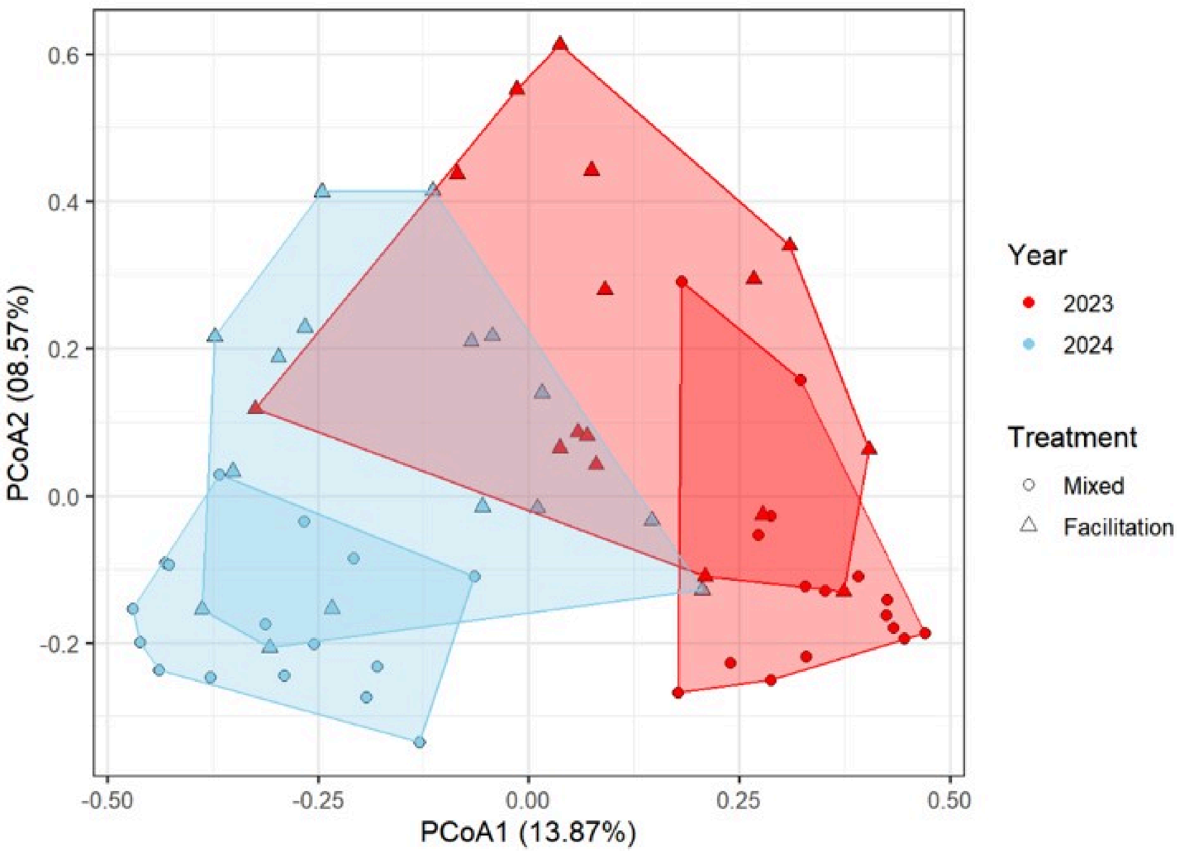

Figure 3

Principal coordinate analysis (PCoA) based on the composition of natural regeneration in plots under different forest restoration treatments (mixed planting of native species and planting with the facilitating species *Baccharis dracunculifolia*) in 2023 and 2024.