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Similarities between native and restored forest remnants in hydroelectric reservoir surroundings in Paraná

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ABSTRACT

Introduction: Due to the demand for the implementation of hydroelectric projects to enrich the Brazilian energy matrix, there is an inevitable need to restore the new Permanent Preservation Areas (APPs) resulting from the formation of the reservoirs of these projects. Objective: The main objective of this study is to evaluate and compare the characteristics of the remaining vegetation formations (middle stage secondary forest) and restored ones (reforested areas) that extend along the margins of the reservoir of the Salto Santiago Hydroelectric Power Plant, located in the municipality of Bonito do Iguaçu River - PR. The purpose of the analysis is to identify variations in the diversity and structure of the studied communities, in addition to defining the stages of succession of the evaluated communities. Methodology: To meet the objective of the study, the analyzes were performed using temporary plots. Three 20x100m plots were installed in the restored areas and 5 plots of 20x100m in the remaining forest. In these plots, all individuals with DBH (diameter at breast height) greater than or equal to 10 cm were measured and identified. Still, smaller plots were allocated to evaluate the regenerating individuals, in which the individuals were identified and counted. Initially, the phytosociological parameters of both communities were estimated and, later, for the analyzes of similarity and indicator species, the plots were divided into subplots of 10x10m, totaling 160 plots. Main Results: In total, 52 species belonging to 25 botanical families were recorded in the remaining areas, compared to 37 species distributed in 17 families in the restored areas. The estimated basal area for the remaining areas was 26.7 m². ha-1, while in the restored areas it was 6.8 m². ha-1. The density of individuals was higher in the remaining areas (904 individuals/ha) in relation to the restored areas (310 individuals/ha). The dominant species were identified as Cupania vernalis in the remaining areas and Mimosa bimocrunata in the restored areas, with the latter being native to the region and frequently used during the restoration process. Conclusion: The results of this study highlighted significant differences between the remaining and restored areas in relation to species composition, density and basal area. The low similarity between communities, as demonstrated by the Jaccard index, does not exclude an overlapping trend as observed in the NMDS analyses. The dominant presence of indicator species suggests promising progress in restoration, while the remaining areas remain in a post-disturbance stage of succession. The research contributes to the understanding of the dynamics of regeneration of plant formations in areas of hydroelectric reservoirs, emphasizing the viability of restoration with species native to the region.

Keywords: Native, Forest, Hydroelectric.

1 INTRODUCTION

The process of forest recovery is quite dynamic, resulting from a series of biotic and abiotic factors of the environment, in which the complementary requirements of each species must be observed. The regeneration of mixed forests involves the concept of secondary succession, understood as the orderly replacement of species over time, in a given location, until the formation of a generally stable plant community (MARTINS, 2005).

Investigating the patterns and dynamics of heterogeneous reforestation with native species is important in streamlining restoration processes (natural regeneration), aiming to reduce efforts related to the recovery process of degraded areas, especially those related to flora and fauna interactions.

According to Sousa Júnior (2005), in the case of artificial reservoirs, the new bank is considered a permanent preservation area and must be revegetated with native species. It is noteworthy that even species native to the site may present different behaviors depending on the seed matrices, in addition to the fact that the vegetation around the reservoir ends up being subjected to greater amounts of humidity, due to the proximity of the water resource, therefore, research with species and matrices to be implemented in these places is necessary to expand the possibilities of success in the restoration process.

Depending on the difference in level reached by the reservoir, the new banks are located in areas of slopes with soil types and original vegetation cover composed of another type of vegetation that does not forest riparians (SOUSA JÚNIOR, 2005). In these new banks created by the reservoir, the environment is sometimes not favorable to the growth of tree species, due to characteristics such as small depth and the presence of impediment layers, combined with water deficit and low fertility, according to Davide and Botelho (1999). In the riparian condition, the physical factors of the soil, determined directly by the hydrological behavior of the site, are the main determinants of the distribution and composition of species, in contrast to the chemical factors of the sediment, determined indirectly by the dynamics of the river (JOHNSON *et al*., 1985). In addition, the variability of soils that occur in forest areas is very high, and sometimes the area has undergone degradation processes and may have lost its previous properties or will be highly altered, not supporting the implantation of the same previously existing species (MARTINS, 2005).

Among the factors that influence tree growth are the chemical and physical characteristics of the soil, the water regime, soil moisture, topography and competition with weeds. In addition to these factors, the vegetation present in the area is a good indicator of the conditions of the site (BOTELHO *et al*., 1995). According to Faria (1996), the success of projects for the recovery of these areas through mixed reforestation depends, among other things, on the correct choice of species.

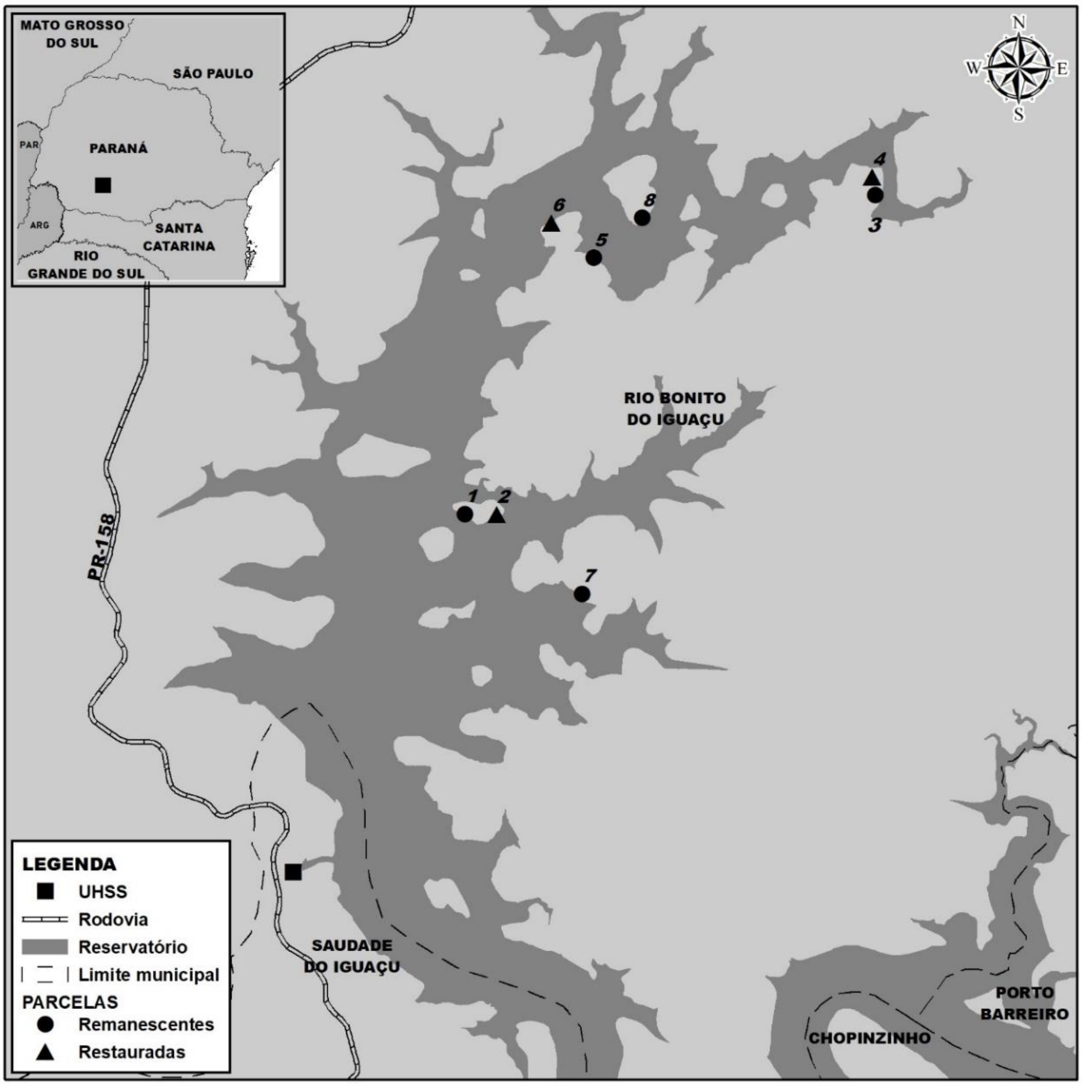
Thus, the objective of the present study was to compare the remaining and restored vegetation formations of the banks of the reservoir of the Salto Santiago Hydroelectric Power Plant, in the portion that surrounds the municipality of Rio Bonito do Iguaçu-PR., to evaluate the restoration process carried out in relation to diversity and similarity with the remaining vegetation.

2 METHODOLOGY

The study area is located on the banks and islands of the reservoir of the Salto Santiago Hydroelectric Power Plant, which is located in the middle course of the Iguaçu River, in the State of Paraná. It is located 340 km west of Curitiba, between the municipalities of Rio Bonito do Iguaçu and Saudade do Iguaçu, with geographic coordinates of 25°36' south latitude and 52°37' west longitude. It is located downstream of the Segredo Hydroelectric Power Plant and upstream of the Salto Osório Hydroelectric Power Plant. The reservoir has a perimeter of approximately 770 km and bathes the territory of 8 municipalities.

The plots were randomly distributed (Figure 01), with the objective of covering the diversity in terms of physiognomic and structural characteristics in each forest fragment. This was carried out in the section of the reservoir that comprises exclusively the municipality of Rio Bonito do Iguaçu. In this area, there were the most advanced restored areas in terms of development, with plantations of 9 to 10 years old. In addition, for comparison purposes, there were also well-preserved remaining areas with secondary forests in the middle stage of regeneration (Brasil, 1994).

Figure 01: UHSS reservoir, region that involves the municipality of Rio Bonito do Iguaçu-PR.



The sampling and data collection for the phytosociological floristic studies took place in 2016, which was divided into three levels of approach. The vegetation analyses were obtained using rectangular plots with an area of 2000 m² (20 m x 100 m), with the longest length being parallel to the reservoir margin. At this level of approach, called Stock 1, all tree individuals with diameters at 1.30 m from the ground (DBH) greater than or equal to 10 cm were identified and measured for the estimation of phytosociological parameters. Also, in a second level of approach, subplots of 100 m² (10 m x 10 m) were installed to evaluate the stock of individuals with DBH < 10 cm and with a total height equal to or greater than 3 m, it was called **Stock 2**. Finally, at the third level of approach, subplots of 10 m² (10 m x 1 m) were installed to evaluate the stock of individuals with total height less than 3 m and greater than 0.3 m and was called **Stock 3**. In the case of stock 2 and 3, the density of regenerating individuals was evaluated. These procedures were indicated by Figueiredo Filho *et al*. (2013).

In all, three plots were sampled in the restored community, totaling 6,000 m² and five plots in the remaining area, totaling 10,000 m². In relation to stock 2, 500 m² (five subplots) were sampled in the remaining area and 300 m² in the restored area (three subplots). In stock 3, 50 m² (five subplots) were sampled in the remaining area and 30 m² (three subplots) in the restored area.

To evaluate the horizontal structure of the forest, the traditional phytosociological parameters (Absolute and Relative Density, Absolute and Relative Dominance, Absolute and Relative Frequency and Importance Value Index) of the tree community (Stock 1) were estimated. The similarity between the two ecosystems was evaluated by subdividing the plots into subplots of 10x10m and the Jaccard Similarity Index was used, which, according to Durigan (2012) is one of the most used indices in surveys that aim to evaluate floristic seedings between communities and indicates the proportion of species shared between the samples in relation to the total number of species.

Also, to better evaluate the dissimilarity (or similarity) of species composition, multivariate analysis of nMDS (Non-Metric Multidimensional Scaling) was used. This method uses a distance coefficient to construct the similarity matrix, which, in this case, the Bray-Curtis distance was used because it presents the abundance of species per plots of each phytophysiognomy. nMDS is an iterative technique that aims to minimize STRESS (Standard Residuals Sum of Square), a measure of how much the positions of objects in a three-dimensional configuration deviate from the original distances or similarities after scaling. After the randomization of scores and axes and the calculation of the distance matrix between the sampling units, there is a correlation with the distance matrix constructed from the original data (PROVETE *et al*., 2011).

Finally, in order to find species that characterize the evaluated communities, the *Indicator Value Method (IndVal),* developed by Dufrêne & Lagendre (1997), was used, which combines measures of the degree of specificity of a species in an ecological state (e.g., a type of habitat), and the fidelity (or frequency of occurrence) of this species within that state. This method provides an indicator value for each species, in the form of a percentage. According to McGeoch and Chown (1998), this method is robust to differences in methodology and sample size, in addition to deriving indicators from any site classification. It is noteworthy that, for the multivariate analyses and the Indicator Value, the plots were divided into subplots due to the extensive size of each plot, and the number of individuals was used for processing.

3 RESULTS

Considering all stocks, 52 species belonging to 25 botanical families were observed in the remaining community, with only one exotic species found (*Hovenia dulcis*). In relation to Stock 1, the remaining area presented 46 species, belonging to 41 genera, distributed in 27 botanical families.

On the other hand, 37 species belonging to 17 families were recorded in the restored areas. It is noteworthy that in these areas, 3 exotic species (*Eucalyptus* sp., *Hovenia dulcis* and *Psidium guajava) were recorded*. In relation to Stock 1 of the restored area, it presents an arboreal stratum with 18 species, belonging to 16 genera, distributed in 12 botanical families.

Table 01 shows the species richness found in the 3 strata for the two communities evaluated and the collection records are stored in the HUCO collection between numbers 7,321 and 7,368.

Table 01. Species richness for the two communities evaluated

Family	**Species**	**Phyto**	**Rem.**	**Res.**
Anacardiaceae	*Schinus terebinthifolia* Raddi	FES/FOM	X	X
Annonaceae	*Annona sylvatica* A.St.-Hil.	FES	X	
Araucariaceae	*Araucaria angustifolia* (Bertol.) Kuntze	FES/FOM		X
Arecaceae	*Syagrus romanzoffiana* (Cham.) Glassman	FES/FOM	X	X
Asparagaceae	*Cordyline spectabilis* Kunth & Bouché	FES/FOM	X	
Boraginaceae	*Cordia americana* (L.) Gottschling & J.S.Mill.	FES	X	
Cannabaceae	*Celtis iguanaea* (Jacq.) Sarg.	FES/FOM	X	
Cannabaceae	*Trema micrantha* (L.) Blume	FES/FOM		X
Cardiopteridaceae	*Citronella paniculata* (Mart.) R.A.Howard	FES/FOM	X	
Celastraceae	*Monteverdia ilicifolia* (Mart. ex Reissek) Viral	FES/FOM	X	
Euphorbiaceae	*Sapium glandulosum* (L.) Morong	FES/FOM	X	
Euphorbiaceae	*Gymnanthes klotzschiana* Müll.Arg.	FES/FOM	X	X
Euphorbiaceae	*Sebastiania brasiliensis* Spreng.	FES/FOM	X	
Fabaceae	*Albizia Edwallii* (Hoehne) Barneby & J.W.Grimes	FES/FOM	X	
Fabaceae	*Anadenanthera colubrina* (Old.) Brenan	FES	X	X
Fabaceae	*Ateleia glazioveana* Members.	FES/FOM	X	
Fabaceae	*Bauhinia forficata* Link	FES/FOM	X	
Fabaceae	*Erythrina crista-galli* L.	form	X	
Fabaceae	*Erythrina falcata* Benth.	FES/FOM	X	
Fabaceae	*Inga virescens* Benth.	form	X	
Fabaceae	*Muellera campestris* (Mart. ex Benth.) M.J. Silva & A.M.G. Azevedo	FES/FOM	X	X

Family	Species	Phyto	Rem.	Res.
Fabaceae	*Machaerium stipitatum* Vogel	FES/FOM	X	
Fabaceae	*Mimosa bimucronata* (DC.) Kuntze	FES/FOM	X	X
Fabaceae	*Mimosa regnellii* Benth.	form		X
Fabaceae	*Mimosa scavenges* Benth.	form		X
Fabaceae	*Myrocarpus frondosus* Allemão	FES	X	
Fabaceae	*Parapiptadenia rigida* (Benth.) Brenan	FES/FOM	X	
Fabaceae	*Peltophorum dubium* (Spreng.) Taub.	FES/FOM	X	X
Fabaceae	*Senegalia tenuifolia* (L.) Britton & Rose	FES/FOM	X	X
Lamiaceae	*Vitex megapotamica* (Explosive.) Moldenke	FES/FOM	X	X
Lauraceae	*Cryptocarya aschersoniana* Mez	FES/FOM	X	
Lauraceae	*Nectandra lanceolata* Nees	FES/FOM	X	X
Lauraceae	*Nectandra megapotamica* (Spreng.) Mez	FES/FOM	X	X
Lauraceae	*Ocotea puberula* (Rich.) Nees	FES/FOM		X
Malvaceae	*Luehea Spread* Mart.	FES/FOM	X	X
Meliaceae	*Cedrela fissilis* Vell.	FES/FOM		X
Meliaceae	*Trichilia catigua* A.Juss.	FES	X	
Meliaceae	*Trichilia elegans* A.Juss.	FES/FOM	X	
Myrtaceae	*Campomanesia guazumifolia* (Cambess.) O.Berg	FES/FOM	X	
Myrtaceae	*Xanthocarpa Campomanesia (* Mars.) O.Berg	FES/FOM	X	X
Myrtaceae	*Eucalyptus* sp.	-		X
Myrtaceae	*Eugenia pyriformis* Cambess.	FES/FOM		X
Myrtaceae	*Eugenia uniflora* L.	FES/FOM	X	X
Myrtaceae	*Psidium cattleyanum* Sabine	FES/FOM		X
Myrtaceae	*Psidium guajava* L.	-		X
Phytolaccaceae	*Phytolacca dioica* L.	FES/FOM	X	
Phytolaccaceae	*Seguieria langsdorffii* MOQ.	FES/FOM	X	
Rhamnaceae	*Hovenia dulcis* Thunb.	-	X	X
Rosaceae	*Prunus myrtifolia* (L.) Urb.	FES/FOM	X	
Rutaceae	*Balfourodendron riedelianum* (Engl.) Engl.	FES	X	X
Rutaceae	*Citrus aurantium* L.	-		X
Rutaceae	*Helietta apiculata* Benth.	FES	X	
Rutaceae	*Zanthoxylum rhoifolium* Lam.	FES/FOM	X	X
Salicaceae	*Casearia decandra* Jacq.	FES/FOM	X	X
Salicaceae	*Casearia sylvestris* Sw.	FES/FOM	X	X
Sapindaceae	*Allophylus edulis* (A.St.-Hil. et al.) Hieron. ex Niederl.	FES/FOM	X	X
Sapindaceae	*Cupania vernalis* Cambess.	FES/FOM	X	X
Sapindaceae	*Diatenopteryx sorbifolia* Radlk.	FES/FOM	X	X
Sapindaceae	*Matayba elaeagnoides* Radlk.	FES/FOM		X
Simaroubaceae	*Castela tweedii* Planch.	FES/FOM	X	
Solanaceae	*Cestrum intermedium* Sendtn.	FES/FOM	X	
Solanaceae	*Solanum granulosoleprosum* Dunal	FES/FOM	X	X
Solanaceae	*Solanum paniculatum* L.	FES/FOM		X
Urticaceae	*Cecropia pachystachya* Trécul	FES	X	X
Verbenaceae	Ruiz & Pav.) Juices.	FES	X	

Legend: Phyto = Naturally occurring phytophysiognomy; Rem. = Forest remnant; Res. = Restored area; FES = Seasonal Semideciduous Forest; FOM = Mixed Ombrophilous Forest.

In a survey carried out in the Iguaçu National Park, by Souza (2015) in plots allocated in an ecotone area between Mixed Ombrophilous Forest and Seasonal Semideciduous Forest, 90 species, 57 genera and 34 families were observed (adopting the inclusion criterion of trees with DBH above 5 cm). It is noteworthy that the Iguaçu National Park has been a conservation unit without interference for decades, hence the high species richness, different from the areas surrounding reservoirs where the influence of the adjacent community may occur. In this sense, Pezzatto (2004), working on the bank of the reservoir of the Salto Caxias Hydroelectric Power Plant, downstream of the UHSS, also on the Iguaçu River, divided his research area into compartments, and in compartment A (the same inclusion criterion as stock 1 of this work) 51 species, 45 identified genera and 26 families were identified, using the inclusion limit of 10 cm DBH. This value is very close to the present study, as mentioned in the work by Isernhagen *et al*. (2001) who, in a floristic survey carried out in ecotone environments between Mixed Ombrophilous Forest and Seasonal Semideciduous Forest at the Santa Clara Hydroelectric Power Plant, Pinhão-PR, recorded 44 species from 26 families.

In the case of Recovered Permanent Preservation Areas in the vicinity of reservoirs, it is worth highlighting the work of Melo and Durigan (2007) in restoration reforestation (aged 7, 9 and 13 years) in the Middle Paranapanema Valley, where the original vegetation of the region is classified as Seasonal Semideciduous Forest, which found between 20 and 29 species of tree characteristics per plots of 500 m². In other words, the species richness of the present work is superior to that of the aforementioned author, contributing to the natural process of ecosystem restoration.

Analyzing the parametric estimates of the horizontal structure of the two ecosystems evaluated, a Basal Area of 26.7 and 6.8 m².ha-1 were recorded for the area of forest remnant and restored, respectively. Regarding the density of individuals, 904 individuals per hectare were estimated for the forest remnant area and 310 individuals per hectare for the restoration area, as can be seen in Table 02.

Table 02. Estimation of the phytosociological parameters of the two communities evaluated with emphasis on the five main species.

Species	OF	DR	AGO	FR	DoA	Dor	ENER GY
	N.ha-¹	%	%	%	m². ha-¹	%	0 - 100%
Forest Remnant							
Cupania vernalis	326	36,06	70	11,25	8,77	32,85	26,70
Muellera campestris	132	14,6	68	10,93	3,06	11,48	12,34
Myrocarpus frondosus	63	6,97	36	5,79	1,67	6,25	6,33
Nectandra megapotamica	32	3,54	36	5,79	1,65	6,19	5,17
Luehea spread apart	40	4,42	32	5,14	1,50	5,60	5,06
Other species	311	34,41	380	61,10	10,05	37,63	44,4
Total	**904**	**100**	**622**	**100**	**26,7**	**100**	**100**
Restored Area							
Mimosa bimucronata	128	41,40	60,00	21,18	2,55	37,49	33,36
Mimosa scabrella	45	14,52	53,33	18,82	1,49	21,81	18,38

Species	OF	DR	AGO	FR	DoA	Dor	ENER GY
	N.ha-¹	%	%	%	m². ha-¹	%	0 - 100%
Forest Remnant							
Schinus terebinthifolia	48	15,59	40,00	14,12	0,68	10,00	13,24
Anadenanthera colubrina	15	4,84	16,67	5,88	0,45	6,67	5,80
Peltophorum dubium	10	3,23	20	7,06	0,12	1,81	4,03
Other species	64	20,42	93,00	32,94	1,51	22,22	25,19
Total	**310**	**100**	**283**	**100**	**6,8**	**100**	**100**

Legend: DA = absolute density; DR = relative density; AF = absolute frequency; RR = relative frequency; DoA = absolute dominance; DoR = relative dominance; IVI = importance value index; N.ha-¹ = number of trees per hectare; m². ha-¹ = square meters per hectare

Regarding the main species found, it is noteworthy that the three main species of each community were also suggested as indicator species by the results of the methodology analyzed in the present study, since only these presented the IndVal higher than 50% in a significant way to 1% probability (pvalue < 0.01, as shown in Table 03.

Table 03. Significant indicator species of the evaluated communities

Community	Species	IndVal (%)	p-value
Remaining	*Cupania vernalis*	77,5	0,005**
	Muellera campestris	73,5	0,005**
	Myrocarpus frondosus	50,0	0,005**
Restored	*Mimosa bimocrunata*	76,0	0,005**
	Mimosa scabrella	66,3	0,005**
	Schinus terebinthifolia	57,8	0,005**

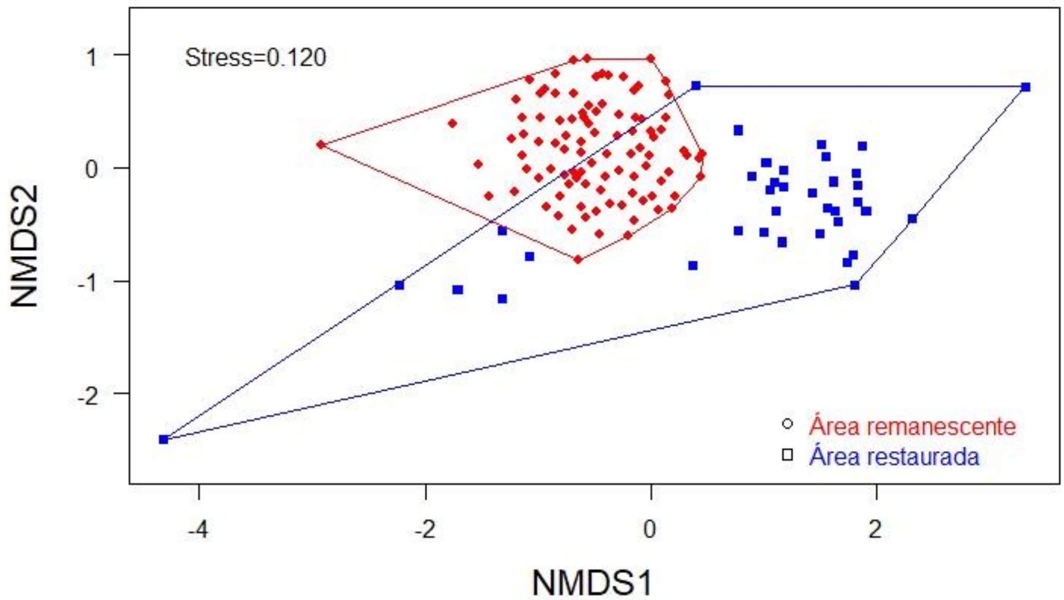
Legend: Indval = Indicator Value Method; p-value = probability value (significance)

According to Klein (1972), *Cupania vernalis* is common in secondary associations, such as capoeiras, capoeirões and semi-devastated forests. Also, according to Lorenzi (2002), this species is characteristic of high-altitude semideciduous forest and Atlantic rain forest, occurring in almost all forest formations in the South and Southeast regions of Brazil.

The species *Mimosa bimucronata* and Mimosa scabrella *are legumes of great importance in the* recovery of degraded areas, as they are part of the Fabaceae family and have symbiotic rhizobacteria in their roots, which stimulate the production of nitrogen in the soil, expanding the supply of vital nutrients to plants, contributing to the improvement of soil structure and fertility. as reported by several authors (BITENCOURT *et al.,* 2007; SILVA *et al.,* 2011; BARBOSA, 2014; LAURINDO et al., 2023; RUIZ, *et al*., 2023). Among the arboreal legumes occurring in plant formations in Brazil, *Mimosa bimucronata*, popularly known as maricá or hawthorn, is considered a typical species of the Atlantic Forest, with a wide distribution in this biome being widely cultivated in the Southeast region of Brazil for the formation of defensive hedges, due to the abundance of thorns on its branches (LORENZI, 2008). Being a pioneer species, *Mimosa bimucronata* is of great importance in the recovery of degraded areas, in which it is an indicator of the initial stage of regeneration, being a great nucleating species, as it provides shelter to the fauna, functions as a perch for avifauna, in addition to protecting the seedlings of several species from the trampling of cattle (BITENCOURT *et al.,* 2007). In relation to *Mimosa scabrella,* popularly known as bracatinga, Carpanezzi (1988) stated that this species is suitable for the recovery of degraded areas, maintaining a reasonable growth and with significant depositions of organic material and nitrogen in the soil. The predominance of pioneer species (maricá and bracatinga) in the arboreal stratum is justified by the fact that, according to the company's planting records, these were planted in a higher proportion than the non-pioneers, in order to maintain the natural dynamics of forest succession.

Analyzing the similarity between the two ecosystems, the value found for the Jaccard Simarity Index was 0.22, which is considered a low value. When analyzing the NMDS Graph, it is noticeable that although the two communities form distinct groups, there is an overlap between the two polygons formed because the use of ecological succession in the implementation of mixed forests is an attempt to give artificial regeneration a model following the conditions with which it occurs naturally in the forest (KAGEYAMA and GANDARA, 2001). In relation to the NMDS analysis, the Stress value found was 0.12, which is considered a considerable ordering, according to Clarke (1993), as shown in Graph 01.

Graph 01. NMDS graph of similarity between the two communities evaluated.



4 CONCLUSIONS

In view of the above, the importance of the species Mimosa bimucronata and Mimosa scabrella *in the context of the rehabilitation of degraded areas is highlighted,* since they play a fundamental role due to their association with nitrogen-fixing bacteria in the soil. In addition, it is important to emphasize that the results of this research can provide significant assistance for the formulation of projects for the recovery of these environments, collaborating to accelerate the process of environmental restoration, constituting a new forest, an element of the common good.

In addition, it is also important to consider the introduction of the species *Cupania vernalis* in these environments, due to the importance of the species in this context, mainly due to the fact that it is the main species in the forest remnant areas of the study region.

It is also concluded that the restored forest is in an initial stage of succession with a development converging with nearby forest remnants, mainly with species typical of the region. It is noteworthy that the surrounding forest remnants are in the process of post-disturbance development, as evidenced by the characteristics of the community. Despite the low similarity calculated, it is evident that temporally the forests are distant, mainly due to the fact that the main species of the restored areas are typical of early succession, which favors the later propagation of later species. This study corroborates the planning of restoration projects, especially in ecotone regions between these two phytophysiognomies, which are widely occurring in the State of Paraná, also contributing to research on this theme.

Finally, it is noteworthy that, due to the high size of the new permanent preservation areas coming from the reservoir of the hydroelectric plant, the sample reflects part of the reality of the place, and there may be regions with different behaviors. Still, for more effective conclusions, the monitoring of the areas should be carried out, as well as the correlation with abiotic factors and the development of the ecosystem.

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