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NATURAL REGENERATION IN MIXED PLANTING FOR ECOLOGICAL RESTORATION IN THE COASTAL PLAIN OF PARANÁ STATE, BRAZIL

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Resumo

Regeneração natural em plantio misto para restauração ecológica na planície litorânea paranaense. As pastagens ocupam aproximadamente 20% do território brasileiro e parte significativa dessas áreas encontra-se degradada e com passivos ambientais legais. A restauração ecológica é necessária para sanar esse passivo. O objetivo do presente estudo foi determinar a eficácia de um plantio de restauração florestal em uma área antes usada como pastagem de búfalos, através de parâmetros florísticos e fitossociológicos da regeneração natural. A área de estudo encontrava-se densamente povoada por gramíneas exóticas invasoras (*Urochloa* spp.) até 2006, quando, após eliminação das gramíneas, foram plantadas seis espécies arbóreas nativas em espaçamento 2,5 m x 1,6 m. Foram encontradas 73 espécies vegetais terrícolas, sendo a mais importante *Alchornea glandulosa* Poepp. & Endl. - heliófila que apresentou elevada abundância em todos os estratos. A metodologia de restauração empregada foi eficaz para desencadear a sucessão natural na área de estudo, acarretando, após 12 anos, em parâmetros florísticos e estruturais condizentes com o estágio inicial de desenvolvimento da Floresta Ombrófila Densa aluvial. Infere-se que a paisagem bem conservada na região tenha sido determinante para prover os propágulos e os dispersores que viabilizaram a riqueza de espécies observada, enquanto o plantio tende a ter contribuído com o controle de gramíneas e com a recuperação do ambiente florestal, facilitando a chegada e o desenvolvimento desses propágulos. Foram observados indícios de degradação do solo pelo uso como pastagem, sendo que em antigas áreas de banho dos búfalos nem o plantio de restauração e nem a regeneração natural se desenvolveram.
Palavras-Chave: Mata Atlântica; recuperação de áreas degradadas; fitossociologia; sucessão natural; ecologia da restauração.

Abstract

Pastures occupy approximately 20% of the Brazilian territory and a significant part of these areas are degraded and have legal environmental liabilities. Ecological restoration is necessary to remedy this liability. The objective of the present study was to determine the effectiveness of a forest restoration planting in an area previously used as buffalo pasture, through floristic and phytosociological parameters of natural regeneration. The study area was densely populated by invasive exotic grasses (*Urochloa* spp.) until 2006, when, after eliminating the grasses, six native tree species were planted at 2.5 × 1.6 m spacing. A total of 73 terrestrial plant species were found, the most important being *Alchornea glandulosa* Poepp. & Endl. - heliophilous, which showed high abundance in all strata. The restoration methodology employed was effective in triggering natural succession in the study area, resulting, after 12 years, in floristic and structural parameters consistent with the initial stage of development of the alluvial Dense Ombrophylous Forest. It is inferred that the well-preserved landscape in the region has been determinant in providing the propagules and dispersers that made the observed species richness possible, while the planting tends to have contributed with the control of grasses and with the recovery of the forest environment, facilitating the arrival and development of these propagules. Evidence of soil degradation by use as pasture was observed, and in former buffalo bathing areas neither restoration planting nor natural regeneration developed.
Keywords: Atlantic Forest; recovery of degraded areas; phytosociology; natural succession; restoration ecology.

INTRODUCTION

The conservation of natural ecosystems is fundamental for the maintenance of society, representing economic, social, and cultural benefits. The devastation of the Atlantic Forest, like that of many other ecosystems around the world, results in flooding, water supply problems, climate change, destruction of traditional lifestyles, loss of natural scenic beauty, timber supply crises, loss of soils, loss of molecules of chemical-pharmaceutical interest, loss of non-timber forest products, and spread of disease (BUSTAMANTE *et al*., 2019).

Ecological restoration is fundamental for the reestablishment of viable portions of the most fragmented native ecosystems and for the environmental regularization of properties in Brazil, thus contributing to the adequate provisioning of ecosystem services to society as a whole (STRASSBURG *et al*., 2020). The demand for ecological restoration in Brazil is highlighted for pastures, which cover approximately 20.0% of the national territory and are associated with extensive areas of environmental irregularity (CORBIN; HOLL, 2012; DORTZBACH *et al*., 2015).

However, for ecological restoration to contribute effectively to the adequate provision of ecosystem services, effective methodologies for monitoring and measuring results are needed, in order to identify whether the basic objectives of restoration projects - stability, self-perpetuating capacity, and similarity with original ecosystems - are being met. The achievement of such objectives depends directly on natural regeneration, so studies on the floristic and structural composition of this can be considered one of the most important tools for monitoring and evaluating areas under restoration (CHAZDON, 2012).

In this context, the objective of the present study was to evaluate the results of a silvicultural planting aimed at forest restoration of an area previously used as buffalo pasture, through floristic and phytosociological indicators of natural regeneration.

MATERIAL AND METHODS

The study area is located in the Guaricica Nature Reserve - a protected area of 8,600 ha, owned by the third sector organization Sociedade de Proteção da Vida Selvagem e Educação Ambiental - SPVS. The Reserve is located entirely in the municipality of Antonina, within the Environmental Protection Area of Guaraqueçaba, on the Northern coast of the State of Paraná, Brazil.

The climate of the Antonina region by the Köppen classification is Cfa, humid subtropical, with an average temperature of the coldest month above 18 °C, always humid, with rainfall above 1,000 mm year-1, distributed in all months of the year, presenting a transition zone always humid and without night frosts (ALVARES *et al*., 2013).

The study area is located on the coastal plain, at central coordinates 25° 18’ 45” S and 48° 41’ 50” W, near the Serra do Mar, with flat relief and altitude ranging from 3 to 15 m. The phytogeographic region corresponds to the Dense Ombrophylous Forest, alluvial typology, due to the influence of the Cachoeira River. The predominant soil class, according to the general soil map of the Guaricica Nature Reserve, is ‘Gleissolo háplico’ (SPVS, 2016).

The experiment that is the object of the present study consists of a heterogeneous (mixed) planting of six native tree species: *Citharexylum myrianthum* Cham., *Inga edulis* Mart., *Senna multijuga* (Rich.) H. S. Irwin & Barneby, *I. marginata* Willd., *Myrsine coriacea* (Sw.) R. Br. ex Roem. & Schult., and *Schizolobium parahyba* (Vell.) Blake, in spacing 2.5 × 1.6 m, totaling 3.64 ha of experimental area. The arrangement of species was random during the planting of the seedlings, with no pre-defined order.

The study area was used as buffalo pasture and was occupied by *Urochloa* spp. until the implementation of the experiment. The elimination of the grasses was done with mechanized mowing only in the rows, without intervention between the lines. Soil preparation was done with subsoiling and rotary hoeing on the planting line. The digging of the pits and planting were manual, occurring in 2006. No fertilization was applied and the grass around the seedlings was cleaned up with a machete or mower for 24 to 30 months. The direct surroundings of the study area, like itself, are composed of former pastures that gave way to restoration plantings in 2006, while the indirect surroundings feature abundant secondary native remnants (SPVS, 2016).

The data collection consisted of a sampling of natural regeneration in the experimental area, which was conducted between 08/12/2017 and 06/01/2018. For data collection purposes, the individuals of natural regeneration were separated into two size classes, one intended for the sampling of tree-sized individuals, with inclusion criteria diameter at breast height (DBH) ≥ 4.77 cm (circumference ≥ 15.0 cm), and another intended for the sampling of non-woody individuals (shrub, arborescent or herbaceous), with inclusion criteria DBH < 4.77 and total height (TH) ≥ 1.30 m. For the sampling of tree-sized individuals, 12 plots measuring 10.0 × 30.4 m (304.0 m²) were systematically allocated, respecting the alignment of the plantation, the width being four rows of planted trees and the length 19 planted trees. The sample covered 10.0% of the experiment area, totaling 0.36 ha. To sample non-tree bearing individuals, 10.0 × 5.0 m (50.0 m²) subplots were used, always placed at one end of each plot.

For the purposes of data analysis, the tree-sized individuals were separated into three vertical strata - upper, middle, and lower, while the non-tree-sized individuals were considered as a single vertical stratum, called the regenerating stratum. A graphic analysis of the frequency distribution of the tree TH variable was performed to determine the size of the class intervals corresponding to each vertical stratum. Based on the graphical analysis and field observations, the following ranges were defined for the vertical strata: TH < 9.0 m (lower), 9.0 m ≤ TH < 14.0 m (intermediate), and TH ≥ 14.0 m (upper).

The Importance Value Indices - IVI were calculated separately for each of the tree strata: upper, middle, lower, and regenerating. For the regenerating stratum, an adapted IVI (AIVI) was calculated using only density

(N) and Frequency (F), without using basal area (G). For the computation of the specific richness, all plant species located within the plots and that met the inclusion criteria of tree or herbaceous/shrub/arborescent size were considered. The shade tolerance levels and dispersal syndromes of the sampled species were surveyed based on literature, field observations, consultation of the herbarium of the Escola de Florestas Curitiba (EFC) and the following websites: Digital Flora of Rio Grande do Sul and Santa Catarina, Online Compendium Gerson Luiz Lopes - Unicentro - PR, SpeciesLink, and REFLORA. The conservation status considered was the one described by the Centro Nacional de Conservação da Flora – CNCFlora.

RESULTS

Considering all four vertical strata, 1,087 terrestrial plants reaching 1.3 m in height were sampled, among trees (70% of the sampled species), palms (3%), ferns (4%), shrubs (15%), and herbaceous plants (8%), adding up to 73 species. As for successional characteristics, 47% of the species found are shade tolerant and 53% are not shade tolerant. As for the dispersal syndrome, 85% are zoochoric, 11% anemochoric, and 4% autochoric. Among the 27 families found, the most important in number of species were Melastomataceae, Myrtaceae, Rubiaceae, Euphorbiaceae, and Lauraceae, which had 10, 9, 7, 5, and 5 species, respectively.

The main species were predominant in all plots, showing that the structure has a certain homogeneity. In the tree strata (upper, middle, and lower), *Alchornea glandulosa* and *Cyathea* cf. *delgadii* predominated, with frequent importance of *Nectandra* spp. In the regenerating stratum (herbaceous/shrubby/arborescent growth), *Myrcia multiflora* occurred in all plots, often with high abundance. Most species showed reduced abundance and frequency.

The largest portion of the basal area was occupied by the lower stratum (2.73 m² ha-1), followed respectively by the intermediate stratum (2.57 m² ha-1), and the upper stratum (1.35 m² ha-1). The natural regeneration adds up to 6.65 m² ha-1 with these three strata, while the planted trees add up to 11.22 m² ha-1, totaling 17.87 m² ha-1.

In the upper stratum (Table 1) the importance value index of shade intolerant species is 94.5%. The average height of natural regeneration in the upper stratum was 14.2 m and the zoochoric species represented 94.7% of the importance value, with *Mimosa bimucronata* (DC.) Kuntze being the only anemochoric species. The family Lauraceae has the largest number of species (three), while Euphorbiaceae, Arecaceae, Fabaceae, and Rubiaceae each have one species.

Table 1. Horizontal structure in the upper stratum of natural regeneration in mixed planting of six native tree species for restoration of alluvial Dense Ombrophylous Forest in Antonina (PR), Brazil.
Tabela 1. Estrutura horizontal no estrato superior da regeneração natural no plantio misto de seis espécies arbóreas nativas para restauração de Floresta Ombrófila Densa aluvial em Antonina (PR).

Species	Family	Class	Disp	Form	*Nr*	*Fr*	*Gr*	*IVI*
Alchornea glandulosa Poepp. & Endl.	Euphorbiaceae	IS	Zoo	Tree	55,7%	51,8%	41,4%	49,6%
Nectandra oppositifolia Nees	Lauraceae	IS	Zoo	Tree	18,2%	19,6%	23,6%	20,4%
Nectandra membranacea (Sw.) Griseb.	Lauraceae	IS	Zoo	Tree	12,5%	7,5%	12,1%	10,7%
Syagrus romanzoffiana (Cham.) Glassman	Arecaceae	TS	Zoo	Palm Tree	3,4%	7,5%	5,7%	5,5%
Mimosa bimucronata (DC.) Kuntze	Fabaceae	IS	Ane	Tree	3,4%	6,8%	5,7%	5,3%
Coussarea contracta (Walp.) Müll.Arg.	Rubiaceae	IS	Zoo	Tree	3,4%	5,0%	5,7%	4,7%
Ocotea sp. Aubl.	Lauraceae	IS	Zoo	Tree	3,4%	1,8%	5,7%	3,7%
TOTAL	-	-	-	-	100%	100%	100%	100%

Where: Class refers to successional class, where TS = shade tolerant species and IS = shade intolerant species; Disp refers to the predominant dispersal syndrome of the species, where Zoo = zoochoric, Ane = anemochoric, and Aut = autochoric; Nr, Gr, and Fr correspond to the relative values of abundance (N), dominance (G), and frequency (F); Form = life form; IVI = Importance Value Index.

In the middle stratum (Table 2) there were 15 shade intolerant species, representing 89% of the importance value, compared to 11.0% of the five shade tolerant species. Zoocoria accounts for 87.0% of the importance value and the remaining 13.0% belongs to the anemochoric species: *Pleroma trichopodum* DC., *M. bimucronata*, and *Vochysia bifalcata* Warm. In this stratum 20 species were found, with the families Euphorbiaceae with four species, Lauraceae with three species, and Melastomataceae also with three species, standing out in floristic richness. The average height verified in this stratum was 9.5 m.

Table 2. Horizontal structure in the intermediate stratum of natural regeneration in a mixed planting of six native tree species for restoration of an alluvial Dense Ombrophylous Forest in Antonina (PR), Brazil.
Tabela 2. Estrutura horizontal no estrato intermediário da regeneração natural em plantio misto de seis espécies arbóreas nativas para restauração de Floresta Ombrófila Densa aluvial em Antonina (PR).

Species	**Family**	**Class**	**Disp**	**Form**	***Nr***	***Fr***	***Gr***	***IVI***
Alchornea glandulosa Poepp. & Endl.	Euphorbiaceae	IS	Zoo	Tree	45,7%	44,3%	18,5%	36,2%
Nectandra oppositifolia Nees	Lauraceae	IS	Zoo	Tree	11,9%	11,2%	12,4%	11,8%
Nectandra membranacea (Sw.) Griseb.	Lauraceae	IS	Zoo	Tree	11,9%	8,2%	9,2%	9,8%
Pleroma trichopodum DC.	Melastomataceae	IS	Ane	Tree	5,6%	7,6%	9,2%	7,5%
Alchornea triplinervia (Spreng.) Müll.Arg.	Euphorbiaceae	IS	Zoo	Tree	4,0%	4,4%	6,1%	4,9%
Mimosa bimucronata (DC.) Kuntze	Fabaceae	IS	Ane	Tree	1,3%	6,7%	3,1%	3,7%
Tetrorchidium rubrivenium Poepp.	Euphorbiaceae	TS	Zoo	Tree	2,8%	1,6%	6,1%	3,5%
Syagrus romanzoffiana (Cham.) Glassman	Arecaceae	TS	Zoo	Palm Tree	1,3%	4,4%	3,1%	2,9%
Sapium glandulosum (L.) Morong	Euphorbiaceae	IS	Zoo	Tree	2,8%	1,3%	4,6%	2,9%
Miconia staminea (Desr.) DC.	Melastomataceae	IS	Zoo	Tree	2,0%	1,5%	4,6%	2,7%
Pera glabrata (Schott) Poepp. ex Baill.	Peraceae	TS	Zoo	Tree	2,0%	1,0%	4,6%	2,6%
Hyeronima alchorneoides Allemão	Phyllantaceae	IS	Zoo	Tree	1,3%	1,4%	3,1%	2,0%
Vochysia bifalcata Warm.	Vochysiaceae	IS	Ane	Tree	1,3%	1,1%	3,1%	1,8%
Miconia cabucu Hoehne	Melastomataceae	IS	Zoo	Tree	1,3%	0,8%	3,1%	1,7%
Euterpe edulis Mart.	Arecaceae	TS	Zoo	Palm Tree	0,8%	1,2%	1,5%	1,2%
Ocotea puberula (Rich.) Nees	Lauraceae	IS	Zoo	Tree	1,3%	0,6%	1,5%	1,1%
Randia armata (Sw.) DC.	Rubiaceae	IS	Zoo	Tree	0,8%	1,2%	1,5%	1,1%
Matayba guianensis Aubl.	Sapindaceae	TS	Zoo	Tree	0,8%	0,6%	1,5%	1,0%
Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.	Primulaceae	IS	Zoo	Tree	0,8%	0,4%	1,5%	0,9%
Amaioua guianensis Aubl.	Rubiaceae	IS	Zoo	Tree	0,8%	0,6%	1,5%	0,9%
TOTAL	-	-	-	-	100%	100%	100%	100%

Where: Class refers to successional class, where TS = shade tolerant species and IS = shade intolerant species; Disp refers to the predominant dispersal syndrome of the species, where Zoo = zoochoric, Ane = anemochoric, and Aut = autochoric; Nr, Gr, and Fr correspond to the relative values of abundance (N), dominance (G), and frequency (F); Form = life form; IVI = Importance Value Index.

In the lower stratum (Table 3) there were eight shade tolerant and 15 shade intolerant species. The importance value of the shade-tolerant species group was 55.0%, with *C.* cf. *delgadii* and *E. edulis* as the main representatives of this successional class. Regarding dispersal syndromes, five species are anemochoric, 17 are zoochoric, and one species is autochoric - *Pachystroma longifolium* (Nees) I. M. Johnst. Anemochoric species account for 54.0% of the value of importance, among which *C.* cf. *delgadii* is the main representative, while zoochoric species account for 46.0% and the only autochoric species represents less than 1.0%. The average height of this stratum was 5.3 m.

Table 3. Horizontal structure in the lower stratum of natural regeneration in mixed planting of six native tree species for restoration of alluvial Dense Ombrophylous Forest in Antonina (PR), Brazil.

Tabela 3. Estrutura horizontal no estrato inferior da regeneração natural no plantio misto de seis espécies arbóreas nativas para restauração de Floresta Ombrófila Densa aluvial em Antonina (PR).

Species	Family	Class	Disp	Form	*Nr*	*Fr*	*Gr*	*IVI*
Cyathea cf. *delgadii* Sternb.	Cyatheaceae	TS	Ane	Fern	39,7%	58,6%	15,4%	37,9%
Alchornea glandulosa Poepp. & Endl.	Euphorbiaceae	IS	Zoo	Tree	22,2%	14,4%	15,4%	17,3%
Euterpe edulis Mart.	Arecaceae	TS	Zoo	Palm Tree	5,6%	3,0%	9,7%	6,1%
Nectandra oppositifolia Nees	Lauraceae	IS	Zoo	Tree	4,1%	2,6%	7,0%	4,6%
Nectandra membranacea (Sw.) Griseb.	Lauraceae	IS	Zoo	Tree	3,6%	2,5%	7,0%	4,4%
Syagrus romanzoffiana (Cham.) Glassman	Arecaceae	TS	Zoo	Palm Tree	3,6%	3,5%	5,5%	4,2%
Miconia staminea (Desr.) DC.	Melastomataceae	IS	Zoo	Tree	3,6%	3,0%	5,5%	4,1%
Pleroma trichopodum DC.	Melastomataceae	IS	Ane	Tree	2,6%	1,3%	5,5%	3,1%
Pera glabrata (Schott) Poepp. ex Baill.	Peraceae	TS	Zoo	Tree	2,1%	1,1%	4,2%	2,5%
Neoblechnum cf. *brasiliense* (Desv.) Gasper & V.A.O. Dittrich	Blechnaceae	IS	Ane	Fern	2,1%	3,2%	1,3%	2,2%
Alchornea triplinervia (Spreng.) Müll.Arg.	Euphorbiaceae	IS	Zoo	Tree	1,5%	0,9%	4,2%	2,2%
Miconia cabucu Hoehne	Melastomataceae	IS	Zoo	Tree	1,5%	0,9%	2,9%	1,8%
Vochysia bifalcata Warm.	Vochysiaceae	IS	Ane	Tree	1,5%	1,0%	2,9%	1,8%
Tetrorchidium rubrivenium Poepp.	Euphorbiaceae	TS	Zoo	Tree	0,9%	0,7%	1,3%	1,0%
Cecropia pachystachya Trécul	Urticaceae	IS	Zoo	Tree	0,6%	1,0%	1,3%	1,0%
Sapium glandulosum (L.) Morong	Euphorbiaceae	IS	Zoo	Tree	0,9%	0,4%	1,3%	0,9%
Casearia sylvestris Sw.	Salicaceae	IS	Zoo	Tree	0,6%	0,4%	1,3%	0,8%
Pachystroma longifolium (Nees) I.M.Johnst.	Euphorbiaceae	TS	Aut	Tree	0,6%	0,2%	1,3%	0,7%
Mimosa bimucronata (DC.) Kuntze	Fabaceae	IS	Ane	Tree	0,6%	0,3%	1,3%	0,7%
Ocotea puberula (Rich.) Nees	Lauraceae	IS	Zoo	Tree	0,6%	0,2%	1,3%	0,7%
Hyeronima alchorneoides Allemão	Phyllantaceae	IS	Zoo	Tree	0,6%	0,3%	1,3%	0,7%
Psychotria cf. *mapourioides* DC.	Rubiaceae	TS	Zoo	Tree	0,6%	0,2%	1,3%	0,7%
Solanum pseudoquina A.St.-Hil.	Solanaceae	IS	Zoo	Tree	0,6%	0,3%	1,3%	0,7%
TOTAL	-	-	-	-	100%	100%	100%	100%

Where: Class refers to successional class, where TS = shade tolerant species and IS = shade intolerant species; Disp refers to the predominant dispersal syndrome of the species, where Zoo = zoochoric, Ane = anemochoric, and Aut = autochoric; Nr, Gr, and Fr correspond to the relative values of abundance (N), dominance (G), and frequency (F); Form = life form; IVI = Importance Value Index.

In the regenerating stratum (Table 4) a predominance of four species was observed, the most structurally important being the shade-tolerant Myrtaceae, *Myrcia multiflora*, which occurs exclusively in the regenerating stratum, but with great abundance and in all plots. The subsequent species in structural importance are *C.* cf. *delgadii* and *A. glandulosa*, the former shade tolerant and the latter shade intolerant. The fourth species in structural importance in the regenerating stratum is the shade intolerant Melastomataceae, *Leandra australis*, which also occurs in abundance notably above the rest and in eight of the 12 plots.

Table 4. Horizontal structure in the regenerating stratum of natural regeneration in mixed planting of six native tree species for restoration of alluvial Dense Ombrophylous Forest in Antonina (PR), Brazil.
Tabela 4. Estrutura horizontal no estrato regenerante da regeneração natural no plantio misto de seis espécies arbóreas nativas para restauração de Floresta Ombrófila Densa aluvial em Antonina (PR).

Species	Family	Class	Disp	Form	*Nr*	*Fr*	*IVIA*
Myrcia multiflora (Lam.) DC.	Myrtaceae	TS	Zoo	Tree	11,9%	6,6%	9,3%
Cyathea cf. *delgadii* Sternb.	Cyatheaceae	TS	Ane	Fern	10,2%	6,1%	8,1%
Alchornea glandulosa Poepp. & Endl.	Euphorbiaceae	IS	Zoo	Tree	9,7%	6,1%	7,9%
Leandra australis (Cham.) Cogn.	Melastomataceae	IS	Zoo	Shrub	9,2%	4,4%	6,8%
Neoblechnum cf. *brasiliense* (Desv.) Gasper & V.A.O. Dittrich	Blechnaceae	IS	Ane	Fern	5,6%	5,0%	5,3%
Matayba guianensis Aubl.	Sapindaceae	TS	Zoo	Tree	3,8%	3,3%	3,6%
Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.	Primulaceae	IS	Zoo	Tree	2,5%	3,3%	2,9%
Myrcia spectabilis DC.	Myrtaceae	TS	Zoo	Tree	3,1%	2,2%	2,6%
Pera glabrata (Schott) Poepp. ex Baill.	Peraceae	TS	Zoo	Tree	1,8%	3,3%	2,6%
Nectandra membranacea (Sw.) Griseb.	Lauraceae	IS	Zoo	Tree	2,5%	2,2%	2,4%
Leandra cf. *variabilis* Raddi	Melastomataceae	IS	Zoo	Shrub	2,5%	2,2%	2,4%
Piper aduncum L.	Piperaceae	IS	Zoo	Tree	1,8%	2,8%	2,3%
Ilex dumosa Reissek	Aquifoliaceae	TS	Zoo	Tree	1,5%	2,2%	1,9%
Syagrus romanzoffiana (Cham.) Glassman	Arecaceae	TS	Zoo	Palm	1,5%	2,2%	1,9%
Costus spiralis (Jacq.) Roscoe	Costaceae	TS	Zoo	Herb	2,0%	1,7%	1,8%
Vernonanthura polyanthes (Sprengel) Vega & Dematteis	Asteraceae	IS	Ane	Herb	2,3%	1,1%	1,7%
Nectandra oppositifolia Nees	Lauraceae	IS	Zoo	Tree	1,3%	2,2%	1,7%
Miconia staminea (Desr.) DC.	Melastomataceae	IS	Zoo	Tree	1,3%	2,2%	1,7%
Psychotria cf. *hoffmannseggiana* (Willd. ex Schult.) Müll.Arg.	Rubiaceae	TS	Zoo	Shrub	1,3%	2,2%	1,7%
Alchornea triplinervia (Spreng.) Müll.Arg.	Euphorbiaceae	IS	Zoo	Tree	1,0%	2,2%	1,6%
Miconia cabucu Hoehne	Melastomataceae	IS	Zoo	Tree	1,0%	1,7%	1,3%
Pleroma trichopodum DC.	Melastomataceae	IS	Ane	Tree	1,5%	1,1%	1,3%
Psidium cattleianum Sabine	Myrtaceae	TS	Zoo	Tree	1,0%	1,7%	1,3%
Cyathea cf. *phalerata* Mart.	Cyatheaceae	TS	Ane	Fern	1,3%	1,1%	1,2%
Sapium glandulosum (L.) Morong	Euphorbiaceae	IS	Zoo	Tree	0,8%	1,7%	1,2%
Miconia latecrenata (DC.) Naudin	Melastomataceae	IS	Zoo	Tree	0,8%	1,7%	1,2%
Psychotria leiocarpa Cham. & Schltdl.	Rubiaceae	TS	Zoo	Shrub	1,3%	1,1%	1,2%
Syzygium jambos (L.) Alston	Myrtaceae	TS	Zoo	Tree	1,0%	1,1%	1,1%
Euterpe edulis Mart.	Arecaceae	TS	Zoo	Palm	0,8%	1,1%	0,9%
Psychotria cf. *mapourioides* DC.	Rubiaceae	TS	Zoo	Tree	0,8%	1,1%	0,9%
Solanum pseudoquina A.St.-Hil.	Solanaceae	IS	Zoo	Tree	0,8%	1,1%	0,9%
Vochysia bifalcata Warm.	Vochysiaceae	IS	Ane	Tree	0,8%	1,1%	0,9%
Not identfied	Asteraceae	IS	Ane	Herb	0,5%	1,1%	0,8%
Leandra cf. *fallax* (Cham.) Cogn.	Melastomataceae	IS	Zoo	Shrub	0,5%	1,1%	0,8%

Species	Family	Class	Disp	Form	*Nr*	*Fr*	*IVIA*
Calyptranthes cf. *lucida* Mart. ex DC.	Myrtaceae	TS	Zoo	Tree	0,5%	1,1%	0,8%
Piper cernuum Vell.	Piperaceae	TS	Zoo	Shrub	0,5%	1,1%	0,8%
Cupania oblongifolia Mart.	Sapindaceae	TS	Zoo	Tree	0,5%	1,1%	0,8%
Not identified 2	Solanaceae	IS	Zoo	Herb	0,5%	1,1%	0,8%
Acnistus arborescens (L.) Schltdl.	Solanaceae	IS	Zoo	Shrub	0,8%	0,5%	0,7%
Sloanea guianensis (Aubl.) Benth.	Elaeocarpaceae	TS	Zoo	Tree	0,5%	0,5%	0,5%
Miconia cf. *jucunda* (DC.) Triana	Melastomataceae	IS	Zoo	Tree	0,5%	0,5%	0,5%
Myrcia brasiliensis Kiaersk.	Myrtaceae	TS	Zoo	Tree	0,5%	0,5%	0,5%
Piper sp. L.	Piperaceae	IS	Zoo	Shrub	0,5%	0,5%	0,5%
Ilex taubertiana Loes.	Aquifoliaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Calophyllum brasiliense Cambess.	Calophyllaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Erythroxylum cf. *cuspidifolium* Mart.	Erythroxilaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Erythroxylum deciduum A.St.-Hil.	Erythroxilaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Inga edulis Mart.	Fabaceae	IS	Zoo	Tree	0,3%	0,5%	0,4%
Nectandra leucantha Nees	Lauraceae	IS	Zoo	Tree	0,3%	0,5%	0,4%
Ocotea puberula (Rich.) Nees	Lauraceae	IS	Zoo	Tree	0,3%	0,5%	0,4%
Sida sp. 2 L.	Malvaceae	IS	Aut	Herb	0,3%	0,5%	0,4%
Sida sp. L.	Malvaceae	IS	Aut	Herb	0,3%	0,5%	0,4%
Leandra sp. *Raddi*	Melastomataceae	IS	Zoo	Shrub	0,3%	0,5%	0,4%
Tibouchina pulchra Cogn.	Melastomataceae	IS	Zoo	Tree	0,3%	0,5%	0,4%
Mollinedia sp. Ruiz & Pav.	Monimiaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Eugenia cf. *excelsa* O.Berg	Myrtaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Marlierea silvatica (O.Berg) Kiaersk.	Myrtaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Myrcia sp. DC.	Myrtaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Hyeronima alchorneoides Allemão	Phyllantaceae	IS	Zoo	Tree	0,3%	0,5%	0,4%
Psychotria nuda (Cham. & Schltdl.) Wawra	Rubiaceae	TS	Zoo	Shrub	0,3%	0,5%	0,4%
Zanthoxylum rhoifolium Lam.	Rutaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Casearia decandra Jacq.	Salicaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Casearia sylvestris Sw.	Salicaceae	IS	Zoo	Tree	0,3%	0,5%	0,4%
Allophylus edulis (A.St.-Hil. et al.) Hieron. ex Niederl.	Sapindaceae	TS	Zoo	Tree	0,3%	0,5%	0,4%
Solanum sanctae-catharinae Dunal	Solanaceae	IS	Zoo	Shrub	0,3%	0,5%	0,4%
TOTAL	-	-	-	-	100%	100%	100%

Where: Class refers to successional class, where TS = shade tolerant species and IS = shade intolerant species; Disp refers to the predominant dispersal syndrome of the species, where Zoo = zoochoric, Ane = anemochoric, and Aut = autochoric; Nr and Fr correspond to the relative values of abundance (N) and frequency (F); Form = life form; AIVI = adapted importance value index to the regenerating stratum.

Of the 65 species that occurred in the regenerating stratum, 32 are shade tolerant, adding up to 48.0% of structural importance, while the 33 shade intolerant species add up to the remaining 52.0%. The 55 zoochoric species add up to 79.5% of the value index of importance adapted for the regenerating stratum, the eight anemochoric species account for 19.7%, and the two autochoric species account for 0.8%. The average height of the regenerating stratum was 2.65 m.

DISCUSSION

The specific richness verified in the present study demonstrates that the well-preserved forests of the region studied are a rich source of propagules and dispersing agents. The landscape is a highly important factor in natural regeneration (CORBIN; HOLL, 2012). The Paraná coast is part of the largest continuous remnant of the Atlantic Dense Ombrophylous Forest (Atlantic Forest), which is composed of the Serra do Mar regions in the states of São Paulo, Paraná, and Santa Catarina, enabling biological flow over an extensive portion of the territory.

According to Kauano *et al*. (2012), the Northern coast of the State of Paraná, Brazil, has 68.6% of its area covered by forests in advanced stages of development, in addition to 9.1% of forests in intermediate stages.

All species found in the present study have already been listed in other studies conducted in the Guaricica Reserve (LIEBSCH *et al*., 2007; BORGO *et al*., 2011) and in other parts of the Atlantic Forest (VALENTE *et al*., 2011). The main families found in the experimental area also differ little from what has been described in other papers for the Atlantic Forest, both in the study region and in other regions, where the richest families are always Myrtaceae, Fabaceae, Lauraceae, Rubiaceae, and Melastomataceae, in different orders depending on the site. An important exception was that only two species of the family Fabaceae were found in natural regeneration, which is possibly related to the fact that four species of this family were planted, occupying this niche in the study area (STANTURF *et al*., 2014). Another exception is the high richness and importance of the Euphorbiaceae family, which does not occur in any of the cited studies and may be related to the high importance of *A. glandulosa* - a species belonging to this botanical family - in natural regeneration in the experimental area.

The outstanding structural importance of *A. glandulosa* in natural regeneration, in turn, may have been driven by the fact that this species was planted in restoration areas near the study area, providing greater availability of *A. glandulosa* propagules. Among the species found in the study area, one - *Euterpe edulis* Mart. - was classified as "Vulnerable" (VU), according to the CNCFlora; two species - *Ocotea puberula* (Rich.) Nees and *Tabebuia cassinoides* (LAM.) DC. - presented conservation status described as "Near Threatened" (NT) in the same classification; and three species - *Syagrus romanzoffiana* (Cham.) Glassman, *Tetrorchidium rubrivenium* Poepp., and *Solanum pseudoquina* A.St.-Hil. - presented conservation status "Least Concern" (LC).The rest of the identified species had a conservation status defined as "Not Evaluated" (NE).

The predominance of zoocoria in both floristic and structural diversity indicates that fauna played a key role in the composition of the vegetation. Fauna is the main dispersing agent in tropical and subtropical forests at all stages of development (CHAZDON, 2012). Rezende; Vieira (2019) point out that flying animals, especially birds and bats, are responsible for the arrival of propagules in the early stages of succession in the lowlands of the Amazon Region, but the results of the study indicate that the presence of dense populations of *Urochloa* spp. inhibits the development of these propagules. In the same study, a positive correlation was also observed between the species richness of natural regeneration, the elimination of invasive exotic grasses, and the planting of native tree species seedlings.

In this sense, it is possible to infer that the well-preserved landscape in the Guaricica Reserve has provided abundance of propagules and dispersing agents for natural regeneration in the area object of the present study, while the presence of invasive grasses and soil degradation tend to have inhibited to some extent the development of these propagules (CHEUNG *et al*., 2009; REZENDE; VIEIRA, 2019). It is thus noted that the restoration planting in the study area possibly contributed to natural regeneration through the control of *Urochloa* spp., the recovery of the productive properties of the soil, the recovery of the microclimatic conditions of the area and the attractiveness to fauna on account of the fruits and the gradual recomposition of the forest environment (CORBIN; HOLL, 2012; McDONALD *et al*., 2015).

Sobanski; Marques (2014) demonstrated that areas more susceptible to water accumulation in the Guaricica Reserve represent greater difficulty for the control of invasive exotic grasses and the reestablishment of natural regeneration, highlighting the importance of planting native tree species tolerant to such environmental conditions for forest restoration, they also describe that in sites with greater accumulation of water in the soil in Jirau/RO, Brazil, in lowland areas of the Amazon Region, there was no natural regeneration of tree species in the 12 months of observations. In the hillside areas of the study region, which have better drainage, it is possible that natural regeneration alone may be sufficient to outcompete invasive grasses, without requiring active restoration methods (CHEUNG *et al*., 2009).

The wide diametric and, consequently, vertical distribution of *A. glandulosa*, indicates that this species is renewing itself and will continue to importantly compose the forest structure with its next generations. *A. glandulosa* is an early secondary species that reaches up to 25 m in height and 70 cm in diameter, zoochoric and highly abundant both in the forests of the region and in other typologies of the Atlantic Forest biome (LORENZI, 1998). The presence of this species and many others intolerant to shade in the intermediate stratum, and especially in the lower and regenerating strata, indicates that the forest still has areas with significant luminosity in the understory, with frequent openings in the canopy. This situation may result from the concentrated mortality presented by the planted species *S. multijuga* in the experimental area, after reaching expressive dimensions, which led to the opening of clearings (SCHAFFER *et al*. 2020).

The species subsequent to *A. glandulosa* in importance in the upper and middle strata - *Nectandra oppositifolia* and *N. membranacea* - are also initial secondary species of zoochoric dispersal that reach large size and have expressive natural abundance in the Atlantic Forest (LORENZI, 1998; BORGO *et al*., 2011), while *C.* cf. *delgadii* - pteridophyte that dominates the understory in most of the experimental area - is anemochoric and shade tolerant. Joly *et al*. (2012) reports that the importance of species in the Cyatheaceae family can be considered an indicator of soil degradation.

E. edulis is often described as a species of high importance in the structure of the Atlantic Forest of the Southeastern and Southern regions (PRATA *et al*., 2011; JOLY *et al*., 2012; ZACARIAS *et al*., 2012). In the present study this species was frequent only in the lower and regenerating strata, which may be due to the fact that it is an early stage of development, to the fact that the forest started with a plantation in alignment, to factors related to degradation or even to natural characteristics of the site. In Prata *et al*. (2011), *T. rubrivenium* and *Hyeronima alchorneoides* were abundant in the regenerating stratum, while in the present study these species were observed in the forest tree strata.

Considering also the plantation, the forest canopy is dominated by the planted species *I. edulis*, *M. coriacea*, and *C. myrianthum* (SCHAFFER *et al*., 2020), with expressive presence of the naturally regenerated *A. glandulosa*, *N. oppositifolia*, and *N. membranacea*. The basal area in the forest subject of this study is composed mostly of planted trees (63.0%), indicating the high importance of this compartment in the formation of the community. The planted species showed discrete natural regeneration, demonstrating the occurrence of natural succession through propagules external to the experimental area (CHAZDON, 2012).

Secondary succession in tropical forests tends to occur with a predominance of shade intolerant species, which usually have competitive advantages in impacted environments, but it can also occur with a greater presence of shade tolerant species because of abiotic factors, such as water availability, and biotic factors, such as, in the case of clearings, the presence of remnant individuals of shade tolerant species (POORTER *et al*., 2019).

In the present study 72.0% of the species found in the tree strata are shade intolerant, while in Borgo *et al*. (2011), considering only undisturbed forests up to 15 years old, 70.0% of the species sampled in the tree strata are not shade tolerant. In Liebsch *et al*. (2007), 78.0% of the species making up the tree strata of approximately 20-year undisturbed forests are not shade tolerant. Therefore, following the trend described by Poorter *et al*. (2019), natural regeneration in the early stages of natural succession of the alluvial Dense Ombrophylous Forest in the Guaricica Reserve occurs predominantly through shade intolerant species.

Siminski *et al*. (2013) and Borgo *et al*. (2011) show that basal area is the main variable for determining successional stage in the Atlantic Forest. According to Siminski *et al*. (2013), the value for this variable should be between 15 and 30 m² ha-1 for Atlantic Forest at an early stage of development, considering an inclusion criterion identical to that employed in the present study. The basal area found in the area of the present study (17.87 m² ha-1) is within this range and is similar, although somewhat smaller, to those described in: Borgo *et al*. (2011) for early stage submontane formation in Guaricica Reserve (22.55 m² ha-1), Liebsch *et al*. (2007) in natural forests of the submontane formation with 20 years in the same reserve (21.5 m² ha-1), or Scheer (2009) in an alluvial forest in Guaraqueçaba (PR) at 9 years without disturbance (22.2 m² ha-1).

With regard to the relatively small basal area in the study area (17.87 m² ha-1), but which, considering the parameters proposed by Siminski *et al*. (2013), is within the expected for stretches of Atlantic Forest at an early stage of development, it should be noted that the deep and better drained soils of the submontane forests lead to higher basal areas for this formation in relation to the forests on the floodplain (SANCHEZ *et al*., 2013). Furthermore, the basal area specifically in the experimental area was also negatively influenced by soil degradation, resulting from use as buffalo pasture, and by the abrupt exit of most of the planted *S. multijuga* individuals less than 10 years after the restoration planting - whose basal area may not yet have been replenished by vegetation development (SCHAFFER *et al*., 2020).

CONCLUSIONS

- Based on the results, it is possible to state that the restoration methodology employed was effective in triggering natural succession in the study area, resulting in floristic and structural parameters consistent with the initial stage of development of the alluvial Dense Ombrophylous Forest.
- It is inferred that the well-preserved landscape in the region was a determining factor in providing the propagules and dispersers that made the observed species richness possible, while the plantation played the role of grass control and recovery of the environment for the arrival and development of these propagules.
- Evidence of past soil degradation from use as buffalo pasture was observed in both the floristics and the structure of natural regeneration in the experimental area.

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