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Original Article

Floristic and structural diversity of riverine forest remnants in the Pampa biome

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ABSTRACT

Riverine forests have high floristic diversity and are heterogeneous, even when they are near each other. Therefore, we aimed to compare three riverine forest remnants of Southern Brazil located in the Pampa biome regarding floristic and structural biodiversity, to: i) check whether the studied forest fragments maintain heterogeneity and high floristic richness as seen in riverine forests, even when close to each other, and ii) indicate the predominant successional groups in each remnant. A total of 81 sampling units were established, and all trees with diameter at breast height ≥ 15 cm were measured. We sampled 1,659 individuals, 67 species, and 34 families. The richness and structure of the three communities differed, confirming the high heterogeneity of riverine forests. One of the remnants had a higher predominance of pioneer species and individuals, which differentiated it from the other two. The latter, in turn, showed higher similarity in floristic and structural composition, with a predominance of secondary and late successional individuals and species. Differences in soil moisture, in the size and shape of fragments may be factors that contributed to the floristic and structural diversity observed. The remnants, although small and surrounded by monocultures, are heterogeneous and important for biodiversity conservation.

Keywords: Pampa Biome; Phytogeography; Phytosociology; Riparian forest; Successional groups

Introduction

Occupying 178,243 km^2 of Rio Grande do Sul (RS), Brazil, the Pampa Biome corresponds to 63% of the original state territory (IBGE 2019), extending into Argentina and Uruguay, and is comprised of a combination of phytophysiognomies, including grassland areas, shrub formations, riverine forests, known as galleries, and humid areas. The existence of different environments accounts for the diversity of species reported in this biome (Bencke 2016). Andrade *et al.* (2023) mention the occurrence of 12,503 species (including plants, animals, bacteria, and fungi), of which 3,642 are vascular plants. However, this diversity is endangered by the expanding agriculture and silviculture, associated with the indiscriminate use of herbicides and with the presence of invasive exotic species (Pillar *et al.* 2009; Caumo *et al.* 2021). In 2021, the Brazilian Pampa lost 2,426 ha of native vegetation (Souza *et al.* 2020;

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MapBiomas 2022) and it has a low number of protected areas, which are not enough to preserve the ecosystems of this biome (Wizniewsky & Foletto 2017).

Gallery forests are narrow forest patches associated with streams and small-sized rivers and are characterized as heterogeneous formations with high floristic and structural diversity affected by biotic (species) and abiotic factors (e.g., temperature, luminosity, relief, soil drainage) (Sampaio *et al.* 2000; Ribeiro-Filho *et al.* 2009; Matos & Felfili 2010). Despite their importance in protecting watercourse margins and in providing food and shelter to the native fauna and flora, the fragmentation of riparian forest areas has led to biodiversity loss, reduced habitat heterogeneity, and increased edge effect (Jin *et al.* 2023).

This study aimed to compare the floristic and structural composition of tree communities of the riverine forests situated inside a monoculture plantation of *Eucalyptus saligna* Sm., in the Pampa, guided by the following questions: i) Do the riparian forest remnants studied maintain the high heterogeneity and floristic richness that is typical of this type of plant formation, even when they are near each other? and ii) What are the predominant successional groups in each forest remnant? We have hypothesized that (1) as the remnants studied are riparian forests, they have high heterogeneity and floristic richness; and (2) this diversity has increased due to the existence of different successional groups, since the remnants have different sizes and shapes, both in width and length, which can favor edge effects, and differ in soil moisture. Additionally, (3) remnant 1 has a higher number of pioneer species and individuals as it is narrower.

Material and methods

Study area

The municipality of Pantano Grande is in the Central Depression of RS (PMPG 2018), inserted in the Pampa biome, where the vegetation is predominantly grassland (IBGE 2019), and gallery forests are located within this matrix (Fig. 1). The study region, called Vale do Rio Pardo (Pardo River Valley) is part of one of the largest forestry hubs in RS, with over 70,000 hectares of cultivated area, and crops grown since the early 20th century for the formation of windbreaks, shelter for cattle, and generation of thermal

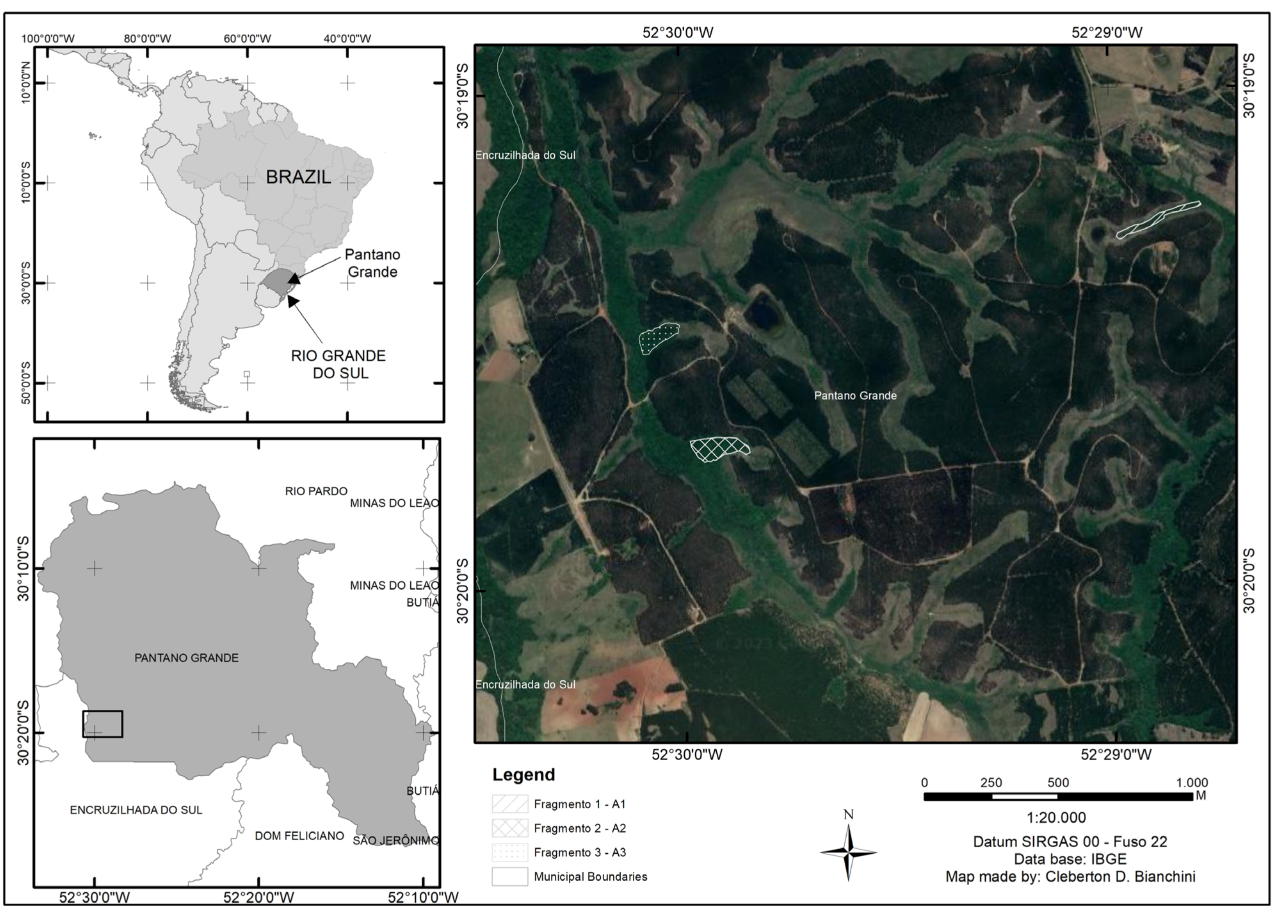

Figure 1. Location of the municipality of Pantano Grande in Rio Grande do Sul and delimitation of the three study fragments (Fragment 1, Fragment 2, and Fragment 3) inserted in a horticultural forest comprised of *Eucalyptus saligna* plantation.

energy. Large-scale plantations started only in the 1970's (Ageflor 2020), partly replacing extensive cattle breeding, practiced in native fields (Azevedo & Fialho 2015). The region is inserted in a subtropical humid area, with mean annual temperature between 16 and 18°C and annual rainfall from 1,600 to 1,900 mm (Peel *et al.* 2007). Soil is classified as umbric, dystrophic red Argisol, characterized as a generally deep soil, with high variation in drainage and B-horizon significantly more clayish with base saturation <50% (Streck *et al.* 2018).

The three remnants are home to small streams ranging from 1 to 3 meters wide and were designated Fragment 1, Fragment 2, and Fragment 3 (Fig. 1). They are located inside an *E. saligna* forest plantation, with approximately 10-year-old trees. Fragment 1 (30°19'16.07"S, 52°28'53.29" W), with 0.70 hectares and 135 meters in altitude, is a long and very narrow remnant. Fragments 2 (30°19'43.07"S, 52°29'55.07" W) and 3 (30°19'29.43"S, 52°30'3.19"W), with 1.33 and 0.91 hectares, and 91 e 78 meters in altitude, respectively, are larger (wider) and closer to each other. The three remnants occurred in a sloped area, along three streams, and did not undergo flooding. Although they are surrounded by *E. saligna* plantations, they are protected from anthropogenic activities, since this is a requirement of the licensing environmental agency for the forestry activity in the state. Moreover, there is no information on deforestation in the past.

Floristic and phytosociological structure

A total of 81 sampling units (SU) of 100 m² each were performed, 20 in Fragment 1 (A1), 34 in Fragment 2 (A2), and 27 in Fragment 3 (A3), distributed with five meters of distance between each SU along transects (lines), 10 meters apart. In each SU, all individuals with DBH (diameter at breast height 1.30 m from the soil) ≥ 15 cm were sampled. Species were identified by using a specific bibliography (Sobral *et al.* 2013), comparing with herbaria material, and through consultations with specialists. During sampling, soil moisture was measured at thirty random points using an AT Delta-T Device HH2 moisture meter, version 4.0.

Families were determined based on Angiosperm Phylogeny Group IV (APG IV 2016) and the Pteridophyte Phylogeny Group Systems (for tree ferns) (PPG I 2016), and the nomenclature adopted for the species followed the Brazilian Flora and Fungi (https://floradobrasil.jbrj.gov.br/). When the botanical material collected was fertile, it was deposited at the HVAT herbarium of the Science Museum of the University of Taquari Valley – Univates. Dead trees still standing and that fit the inclusion criteria (DBH ≥ 15 cm) were also considered (and noted down) but were not included in general phytosociological calculations. Nevertheless, dead trees were essential for the classification into successional stages. The classification of successional groups of species into pioneer, initial secondary, and late secondary followed Vaccaro *et al.* (1999), Grings and Brack (2009), Ferreira *et al.* (2013), and Scipioni *et al.* (2013). In the latter category, species that were considered as climax by some authors were included.

Data analysis

The parameters of absolute and relative density (AD and RD), dominance (ADo and RDo), frequency (AF and RF), and the importance value index (IVI) were estimated (Mueller-Dombois & Ellenberg 1974). Data on successional groups were compared using the number of species and individuals per successional group using an ANOVA test followed by Tukey's test (significance of 5%) using InfoStat/L. Sampling sufficiency was obtained through the accumulation curve, processed based on the number of species in each sampled plot using the non-parametric "*Bootstrap*" estimator of the EstimateS software (Colwell 2005).

Using PRIMER-E, version 5.2.9 (Clarke & Gorley 2002), we performed the *Similarity percentage breakdown* (SIMPER). To check species composition patterns in each area, a Principal Coordinate Analysis – PCoA was applied in the Multiv program, version 3.31b, with a species abundance matrix without data transformation and the string distance as a similarity measure (Pillar 2009).

Results

Floristic and phytosociological composition

A total of 1,659 (93.4%) live tree individuals, belonging to 67 species, 55 genera, and 34 families, and 109 (6.6%) dead individuals were reported in the three remnants. Considering each remnant, the percentage of dead individuals was 5.52% in Fragment 1, 6.73% in Fragment 2, and 6.0% in Fragment 3, with higher soil moisture (45%) compared to the other fragments (24% and 26% in the Fragment 1 and 2, respectively). The richness in Fragment 2 was 52 species, which corresponded to 90.46% of the estimated value (57.48), followed by Fragment 3, with 41 sampled species, corresponding to 90.09% of the estimated value (45.51), and 33 species were reported in Fragment 1, corresponding to 86.84% of the estimated value (38) (Fig. 2). There were only two *Pinus elliottii* L. individuals in Fragment 1 (AD = 10.0 ind ha^{-1}) and *E. saligna* only occurred in Fragment 3, where five individuals were found (AD = 18.52 ind ha^{-1}).

Myrtaceae had the highest number of species, corresponding to 24.39% of the total species in Fragment 3, 19.23% in Fragment 2, and 18.18% in Fragment 1. Salicaceae, Sapindaceae, and Primulaceae had the highest numbers of species, particularly in Fragments 1 and 3; on the other hand, Lauraceae and Meliaceae had the highest numbers in Fragment 2. Myrtaceae had the highest number of individuals only in Fragment 1, whereas Euphorbiaceae had the highest number in Fragments 2 and 3 (Fig. 3).

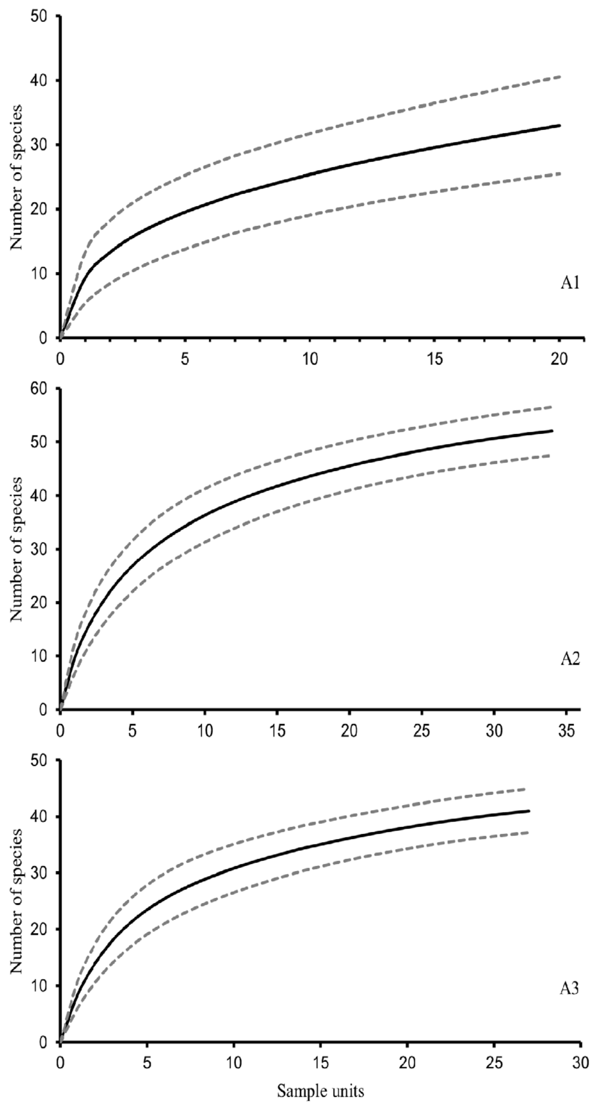

Figure 2. Accumulation curve of Fragment 1 (A1), Fragment 2 (A2), and Fragment 3 (A3) in the municipality of Pantano Grande, Rio Grande do Sul, Brazil.

In Fragment 1 (Table 1), *Myrsine gardneriana* had the highest absolute densities (AD = 510 ind ha^{-1}), followed by *Psidium cattleianum* (AD = 530 ind ha^{-1}) and *Myrcia palustris* (AD = 445 ind ha^{-1}). The three species also had the highest IVI. *Sebastiania ramosissima* (AD = 482.35 ind ha^{-1}), *Lithraea brasiliensis* (AD = 185.29 ind ha^{-1}), and *Casearia sylvestris* (AD = 176.47 ind ha^{-1}) were the species with the highest AD and IVI in Fragment 2 (Table 2). Different from the other two fragments, in Fragment 3, *Gymnanthes klotzschiana* had the highest AD (285.19 ind ha^{-1}), followed by *S. ramosissima* (AD = 259.26 ind ha^{-1}) and *M. gardneriana* (AD = 207.41 ind ha^{-1}) (Table 3), and consequently, the highest IVI's. The species mentioned also had a high frequency (AF).

According to the SIMPER analysis, *M. gardneriana*, *P. cattleianum*, and *M. palustris* contributed to the similarity among SU in Fragment 1. However, they contributed to the dissimilarity between SU's in Fragment 3, and together with *S. ramosissima*, they contributed to the dissimilarity in Fragment 2 (Table 4). Unlike Fragment 1, the dissimilarity between the SU in Fragments 2 and 3 was lower, due to higher species richness. This similarity among SU in the Fragments was due to the participation of *S. ramosissima, C. sylvestris*, and *L. brasiliensis*. However, *S. ramosissima* and *G. klotzschiana* contributed mostly to the similarity in Fragment 3.

PCoA showed that the remnants differ from each other (Fig. 4), clustering SU from each fragment based on species composition. All SU in Fragment 1 are close to each other due to the presence of *Ilex dumosa*, *P. cattleianum*, and *M. gardneriana*, which occurred nearly throughout the fragment and were the species with the highest IVI, except for *I. dumosa*. In Fragment 2, *L. brasiliensis*, *C. sylvestris*, and *Chrysophyllum marginatum* were responsible for the higher proximity of most SU, although some SU are more dispersed, interspersed with SU from Fragment 3 due to the presence of *S. ramosissima*, a species with the first and second highest IVI in Fragments 2 and 3, respectively, and to *Eugenia uruguayensis*. In addition, *Erythrina crista-galli*, *Myrciaria tenella*, and *Zanthoxylum rhoifolium* were reported only in Fragment 3. *Citronella gongonha*, on the other hand, reached dominance and considerable density compared to the other areas.

Successional groups

A total of 10 pioneer species were reported in Fragment 1, represented by 186 individuals, while 11 and 8 species were recorded in fragments 2 and 3, represented by 124 and 177 individuals, respectively. The initial secondary species were represented by 20 (A1), 33 (A2), and 27 (A3) species and 318 (A1), 491 (A2), and 264 (A3) individuals. Conversely, few late secondary species were found in the three fragments (two, eight, and five, respectively), represented by six, 64, and 22 individuals.

Fragment 1 had the highest number of pioneer species and individuals per SU (3.15 and 9.15, respectively) (Fig. 5), differing from the other fragments regarding both parameters ($p=0.0027$; $p<0.0001$). Fragments 2 and 3, on the other hand, did not differ in the number of pioneer species per SU; however, they differed in number of individuals, which was lower in Fragment 2. The three fragments did not differ regarding the mean number of initial secondary species per SU ($p=0.2929$), but they differed concerning the mean number of individuals per SU ($p=0.0052$). Fragment 3 had the lowest mean value, differing from fragments 1 and 2, which in turn were similar to each other. As to the mean number of late secondary species and individuals per SU, Fragment 1 differed from Fragment 2, which had the highest mean number. Fragment 3, on the other hand, did not differ from the other two fragments as it had intermediate mean numbers ($p=0.0013$; $p=0.0066$) (Fig. 5).

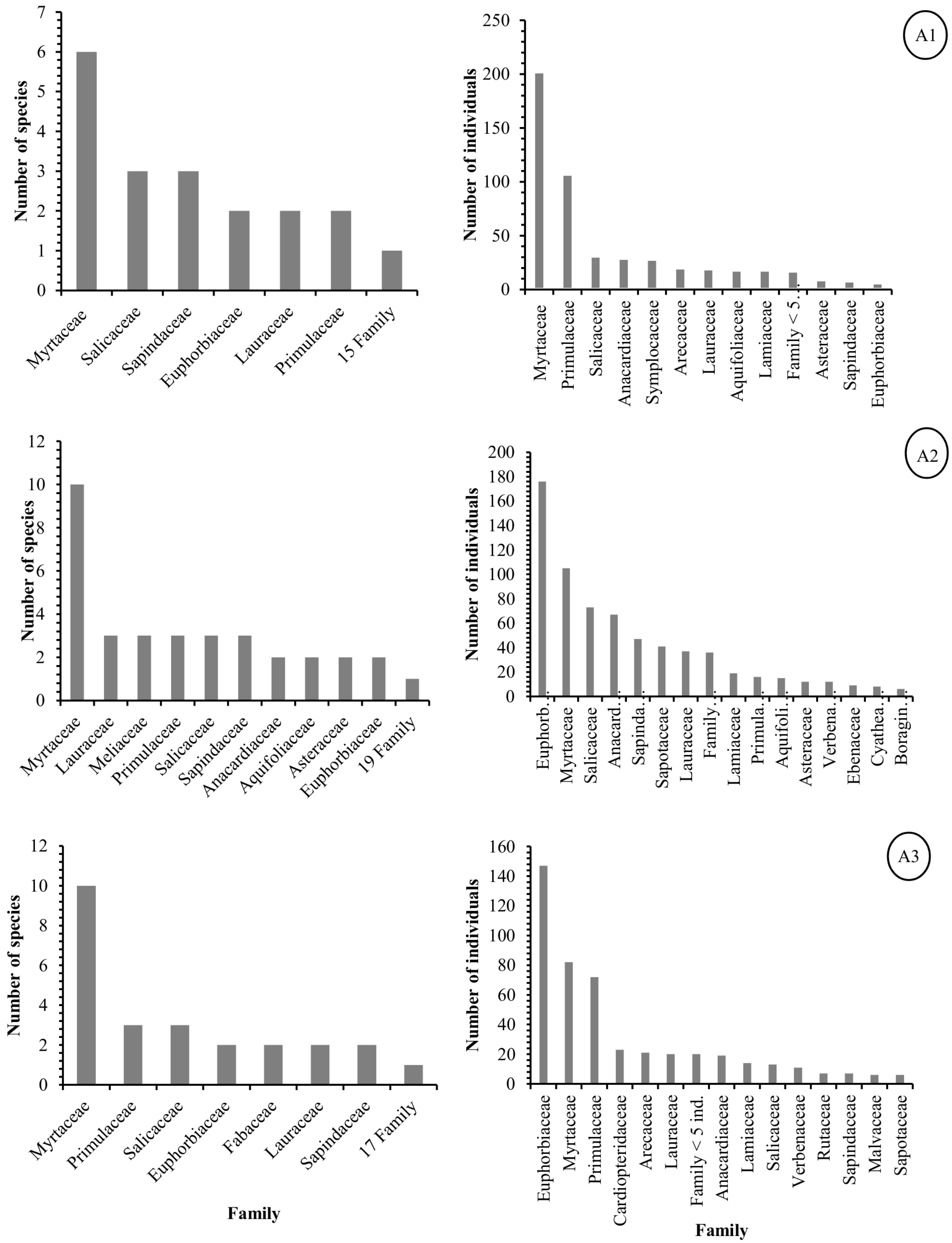

Figure 3. *Rank/*abundance of families in the three riverine forest fragments (A1 = Fragment 1, A2 = Fragment 2, and A3 = Fragment 3), in number of species and individuals in the municipality of Pantano Grande, Rio Grande do Sul, Brazil.

Table 1. List of species and families in order of VI (importance value) of Area 1, Pantano Grande municipality, Rio Grande do Sul, Brazil, with the other phytosociological parameters (Ni = number of individuals, DA = absolute density, absolute dominance, FA = absolute frequency).

List of species	Families	Ni	DA	DoA	FA	IVI
Myrsine gardneriana A. DC.	Primulaceae	102	510	5,05	95	17,43
Psidium cattleianum Sabine	Myrtaceae	106	530	2,65	100	14,35
Myrcia palustris DC.	Myrtaceae	89	445	3,38	90	13,95
Syagrus romanzoffiana (Cham.) Glassman	Arecaceae	20	100	2,73	55	7,26
Lithraea brasiliensis Marchand	Anacardiaceae	29	145	1,20	70	6,15
Casearia sylvestris Sw.	Salicaceae	29	145	1,32	65	6,14
Vitex megapotamica (Spreng.) Moldenke	Lamiaceae	18	90	1,24	60	5,13
Symplocos uniflora (Pohl) Benth.	Symplocaceae	28	140	0,95	50	4,99
Ilex dumosa Reissek	Aquifoliaceae	18	90	0,64	70	4,61
Ocotea pulchella (Nees & Mart.) Mez	Lauraceae	14	70	0,53	40	3,12
Moquiniastrum polymorphum (Less.) G. Sancho	Asteraceae	9	45	0,61	30	2,56
Myrsine laetevirens (Mez) Arechav.	Primulaceae	5	25	0,20	25	1,50
Citronella gongonha (Mart.) R.A.Howard	Cardiopteridaceae	3	15	0,47	15	1,42
Matayba elaeagnoides Radlk.	Sapindaceae	6	30	0,09	25	1,42
Gymnanthes klotzschiana Müll. Arg.	Euphorbiaceae	5	25	0,21	20	1,34
Cyathea atrovirens (Langsd. & Fisch.) Domin	Cyatheaceae	3	15	0,49	10	1,26
Cinnamomum amoenum (Nees & Mart.) Kosterm.	Lauraceae	5	25	0,20	15	1,15
Escallonia bifida Link & Otto	Escalloniaceae	3	15	0,06	15	0,82
Ficus luschnathiana (Miq.) Miq	Moraceae	2	10	0,17	10	0,74
Myrrhinium atropurpureum Schott	Myrtaceae	2	10	0,03	10	0,53
Eugenia hiemalis Cambess.	Myrtaceae	3	15	0,05	5	0,45
Chrysophyllum marginatum (Hook. & Arn.) Radlk.	Sapotaceae	1	5	0,10	5	0,38
Pinus elliottii Engelm.	Pinaceae	2	10	0,03	5	0,35
Allophylus edulis (A.St.-Hil. Et al.) Hieron. ex Niederl	Sapindaceae	1	5	0,06	5	0,34
Blepharocalyx salicifolius (Kunth) O.Berg	Myrtaceae	1	5	0,06	5	0,34
Sebastiania brasiliensis Spreng.	Euphorbiaceae	1	5	0,05	5	0,32
Prunus myrtifolia (L.) Urb.	Rosaceae	1	5	0,05	5	0,31
Myrceugenia myrtoides O. Berg	Myrtaceae	1	5	0,03	5	0,29
Erythroxylum argentinum O.E.Schulz	Erythroxylaceae	1	5	0,02	5	0,28
Xylosma prockia (Turcz.) Turcz.	Salicaceae	1	5	0,02	5	0,27
Casearia decandra Jacq.	Salicaceae	1	5	0,02	5	0,27
Dodonaea viscosa Jacq.	Sapindaceae	1	5	0,02	5	0,27
Styrax leprosus Hook. & Arn.	Styracaceae	1	5	0,01	5	0,26

Table 2. List of species and families in order of IVI (importance value) in Fragment 2, municipality of Pantano Grande, Rio Grande do Sul, Brazil, with the other phytosociological parameters (Ni = number of individuals sampled, AD = absolute density – ind ha^{-1}, ADo = absolute dominance – m^2 ha^{-1}, AF = absolute frequency – %).

List of species	Families	Ni	AD	ADo	AF	IVI
Sebastiania ramosissima (A. St.-Hil.) A. L. Melo & M. F. Sales	Euphorbiaceae	164	482.35	2.98	79.41	14.18
Lithraea brasiliensis Marchand	Anacardiaceae	63	185.29	5.68	73.53	12.03
Casearia sylvestris Sw.	Salicaceae	60	176.47	1.25	76.47	7.00
Ocotea pulchella (Nees & Mart.) Mez	Lauraceae	25	73.53	1.97	50.00	5.19
Vitex megapotamica (Spreng.) Moldenke	Lamiaceae	19	55.88	2.07	35.29	4.49
Chrysophyllum marginatum (Hook. & Arn.) Radlk.	Sapotaceae	41	120.59	0.69	47.06	4.43
Myrcianthes pungens (O.Berg) D. Legrand	Myrtaceae	37	108.82	0.92	44.12	4.40
Ilex brevicuspis Reissek	Aquifoliaceae	13	38.24	2.08	26.47	3.90
Eugenia uruguayensis Cambess.	Myrtaceae	20	58.82	0.33	44.12	2.89
Moquiniastrum polymorphum (Less.) G. Sancho	Asteraceae	11	32.35	0.87	29.41	2.54
Cupania vernalis Cambess.	Sapindaceae	23	67.65	0.43	23.53	2.43
Matayba elaeagnoides Radlk.	Sapindaceae	12	35.29	1.04	17.65	2.37
Myrsine gardneriana A. DC.	Primulaceae	12	35.29	0.72	26.47	2.33

Table 2. Cont.

List of species	Families	Ni	AD	ADo	AF	IVI
Citharexylum montevidense (Spreng.) Moldenke	Verbenaceae	12	35.29	0.62	26.47	2.22
Diospyros inconstans Jacq.	Ebenaceae	9	26.47	0.54	26.47	1.97
Myrcianthes gigantea (D. Legrand) D. Legrand	Myrtaceae	8	23.53	0.65	17.65	1.74
Gymnanthes klotzschiana Müll. Arg.	Euphorbiaceae	12	35.29	0.23	23.53	1.67
Nectandra megapotamica (Spreng.) Mez	Lauraceae	9	26.47	0.46	17.65	1.58
Eugenia hiemalis Cambess.	Myrtaceae	11	32.35	0.16	23.53	1.53
Blepharocalyx salicifolius (Kunth) O.Berg	Myrtaceae	10	29.41	0.22	20.59	1.46
Allophylus edulis (A.St.-Hil. Et al.) Hieron. ex Niederl	Sapindaceae	12	35.29	0.21	17.65	1.44
Myrsine coriacea (Sw.) R.Br. ex. Roem. & Schult.	Primulaceae	3	8.82	0.79	8.82	1.34
Casearia decandra Jacq.	Salicaceae	10	29.41	0.19	17.65	1.32
Myrcia palustris DC.	Myrtaceae	7	20.59	0.20	20.59	1.29
Luehea divaricata Mart. & Zucc.	Malvaceae	2	5.88	0.81	5.88	1.21
Cordia americana (L.) Gottshling & J.E.Mill.	Boraginaceae	6	17.65	0.42	11.76	1.17
Eugenia uniflora L.	Myrtaceae	6	17.65	0.18	17.65	1.12
Quillaja lancifolia D.Don.	Quillajaceae	4	11.76	0.39	11.76	1.05
Symplocos uniflora (Pohl) Benth	Symplocaceae	5	14.71	0.45	5.88	0.95
Schinus molle L.	Anacardiaceae	4	11.76	0.26	11.76	0.90
Alsophila setosa Kaulf.	Cyatheaceae	8	23.53	0.22	5.88	0.84
Cinnamomum amoenum (Nees & Mart.) Kosterm.	Lauraceae	3	8.82	0.32	5.88	0.71
Prunus myrtifolia (L.) Urb.	Rosaceae	3	8.82	0.28	5.88	0.66
Scutia buxifolia Reissek	Rhamnaceae	3	8.82	0.10	8.82	0.57
Ilex dumosa Reissek	Aquifoliaceae	2	5.88	0.21	5.88	0.54
Syagrus romanzoffiana (Cham.) Glassman	Arecaceae	2	5.88	0.28	2.94	0.52
Celtis iguanaea (Jacq.) Sarg.	Cannabaceae	3	8.82	0.04	8.82	0.50
Myrrhinium atropurpureum Schott	Myrtaceae	3	8.82	0.02	8.82	0.48
Guettarda uruguensis Cham. & Schltdl.	Rubiaceae	3	8.82	0.04	5.88	0.40
Xylosma pseudosalzmanii Sleumer	Salicaceae	3	8.82	0.04	5.88	0.39
Ruprechtia laxiflora Meisn.	Polygonaceae	2	5.88	0.04	5.88	0.35
Trichilia elegans A.Juss.	Meliaceae	2	5.88	0.02	5.88	0.33
Trichilia claussenii C.DC.	Meliaceae	2	5.88	0.07	2.94	0.28
Eugenia involucrata DC.	Myrtaceae	2	5.88	0.01	2.94	0.22
Ficus luschnathiana (Miq.) Miq	Moraceae	1	2.94	0.05	2.94	0.21
Styrax leprosus Hook. & Arn.	Styracaceae	1	2.94	0.04	2.94	0.20
Annona emarginata (Schltdl.) H.Rainer	Annonaceae	1	2.94	0.04	2.94	0.20
Dasyphyllum brasiliense (Spreng.) Cabrera	Asteraceae	1	2.94	0.03	2.94	0.18
Cabralea canjerana (Vell.) Mart.	Meliaceae	1	2.94	0.02	2.94	0.17
Campomanesia xanthocarpa (Mart.) O.Berg	Myrtaceae	1	2.94	0.01	2.94	0.17
Myrsine laetevirens (Mez) Arechav.	Primulaceae	1	2.94	0.01	2.94	0.16
Citronella gongonha (Mart.) R.A.Howard	Cardiopteridaceae	1	2.94	0.01	2.94	0.16

Table 3. List of species and families in order of IVI (importance value) in Fragment 3, municipality of Pantano Grande, Rio Grande do Sul, Brazil, with the other phytosociological parameters (Ni = number of individuals sampled, AD = absolute density – ind ha^{-1}, ADo = absolute dominance – m^2 ha^{-1}, AF = absolute frequency – %).

List of species	Families	Ni	AD	ADo	AF	IVI
Gymnanthes klotzschiana Müll.Arg.	Euphorbiaceae	77	285.19	2.64	74.07	11.28
Sebastiania ramosissima (A. St.-Hil.) A. L. Melo & M. F. Sales	Euphorbiaceae	70	259.26	2.06	74.07	10.16
Myrsine gardneriana A. DC.	Primulaceae	56	207.41	2.67	33.33	8.20
Citronella gongonha (Mart.) R.A. Howard	Cardiopteridaceae	23	85.19	3.07	33.33	6.29
Syagrus romanzoffiana (Cham.) Glassman	Arecaceae	21	77.78	2.99	37.04	6.20
Ocotea pulchella (Nees & Mart.) Mez	Lauraceae	18	66.67	2.61	51.85	6.16
Lithraea brasiliensis Marchand	Anacardiaceae	19	70.37	2.11	40.74	5.25
Myrsine coriacea (Sw.) R.Br. ex. Roem. & Schult	Primulaceae	11	40.74	2.40	29.63	4.55
Citharexylum montevidense (Spreng.) Moldenke	Verbenaceae	11	40.74	1.40	25.93	3.33

Table 3. Cont.

List of species	Families	Ni	AD	ADo	AF	IVI
Blepharocalyx salicifolius (Kunth) O.Berg	Myrtaceae	14	51.85	0.59	33.33	2.96
Myrcia palustris DC.	Myrtaceae	16	59.26	0.57	29.63	2.93
Myrcianthes gigantea (D. Legrand) D. Legrand	Myrtaceae	12	44.44	0.55	37.04	2.91
Vitex megapotamica (Spreng.) Moldenke	Lamiaceae	14	51.85	0.73	22.22	2.67
Eucalyptus saligna Sm.	Myrtaceae	5	18.52	1.77	7.41	2.57
Eugenia uniflora L.	Myrtaceae	11	40.74	0.21	37.04	2.48
Eugenia uruguayensis Cambess.	Myrtaceae	10	37.04	0.28	33.33	2.34
Casearia decandra Jacq.	Salicaceae	10	37.04	0.26	29.63	2.17
Zanthoxylum rhoifolium Lam.	Rutaceae	7	25.93	0.42	25.93	1.99
Luehea divaricata Mart. & Zucc.	Malvaceae	6	22.22	0.73	18.52	1.96
Chrysophyllum marginatum (Hook. & Arn.) Radlk.	Sapotaceae	6	22.22	0.42	22.22	1.76
Matayba elaeagnoides Radlk.	Sapindaceae	5	18.52	0.29	18.52	1.41
Erythrina crista-galli L.	Fabaceae	3	11.11	0.49	11.11	1.19
Myrsine parvula (Mez) Otegui	Primulaceae	5	18.52	0.37	3.70	0.90
Myrcianthes pungens (O.Berg) D. Legrand	Myrtaceae	5	18.52	0.17	7.41	0.84
Myrciaria tenella (DC.) O. Berg	Myrtaceae	4	14.81	0.05	11.11	0.78
Prunus myrtifolia (L.) Urb.	Rosaceae	3	11.11	0.08	11.11	0.74
Eugenia hiemalis Cambess.	Myrtaceae	4	14.81	0.09	7.41	0.67
Celtis iguanaea (Jacq.) Sarg.	Cannabaceae	3	11.11	0.09	7.41	0.60
Symplocos uniflora (Pohl) Benth	Symplocaceae	3	11.11	0.08	7.41	0.59
Nectandra megapotamica (Spreng.) Mez	Lauraceae	2	7.41	0.14	7.41	0.59
Scutia buxifolia Reissek	Rhamnaceae	2	7.41	0.06	7.41	0.50
Banara tomentosa Clos	Salicaceae	2	7.41	0.05	7.41	0.49
Allophylus edulis (A.St.-Hil. et al.) Hieron. ex Niederl	Sapindaceae	2	7.41	0.04	7.41	0.48
Styrax leprosus Hook. & Arn.	Styracaceae	1	3.70	0.12	3.70	0.35
Ilex brevicuspis Reissek	Aquifoliaceae	1	3.70	0.07	3.70	0.29
Psidium cattleianum Sabine	Myrtaceae	1	3.70	0.02	3.70	0.24
Guettarda uruguensis Cham. & Schltdl.	Rubiaceae	1	3.70	0.02	3.70	0.24
Calliandra tweedii Benth.	Fabaceae	1	3.70	0.02	3.70	0.24
Ruprechtia laxiflora Meisn.	Polygonaceae	1	3.70	0.01	3.70	0.23
Xylosma pseudosalzmanii Sleumer	Salicaceae	1	3.70	0.01	3.70	0.23
Trichilia elegans A.Juss.	Meliaceae	1	3.70	0.01	3.70	0.23

Table 4. Species that contributed with 90% similarity between the SU of three riverine forest fragments in the municipality of Pantano Grande, Rio Grande do Sul, Brazil, using the SIMPER analysis (Bray-Curtis matrix)

Species	Fragment 1	Fragment 2	Fragment 3
	ANOSIM (50.55)	ANOSIM (30.15)	ANOSIM (26.72)
Myrsine gardneriana A. DC.	27.67	1.25	7.33
Psidium cattleianum Sabine	27.40	–	–
Myrcia palustris DC.	21.13	–	2.60
Lithraea brasiliensis Marchand	5.11	13.93	4.18
Casearia sylvestris Sw.	4.08	15.21	–
Ilex dumosa Reissek	3.38	–	–
Vitex megapotamica (Spreng.) Moldenke	2.95	2.42	–
Sebastiania ramosissima (A. St.-Hil.) A. L. Melo & M. F. Sales	–	37.94	24.18
Chrysophyllum marginatum (Hook. & Arn.) Radlk.	–	5.44	–
Myrcianthes pungens (O. Berg) D. Legrand	–	4.93	–
Ocotea pulchella (Nees & Mart.) Mez	–	4.16	4.90
Eugenia uruguayensis Cambess.	–	3.45	2.24
Citharexylum montevidense (Spreng.) Moldenke	–	1.06	–
Ilex brevicuspis Reissek	–	0.99	–
Gymnanthes klotzschiana Müll.Arg.	–	–	29.15
Syagrus romanzoffiana (Cham.) Glassman	–	–	3.50

Table 4. Cont.

Species	Fragment 1	Fragment 2	Fragment 3
	ANOSIM (50.55)	ANOSIM (30.15)	ANOSIM (26.72)
Citronella gongonha (Mart.) R.A.Howard	–	–	3.37
Myrcianthes gigantea (D. Legrand) D. Legrand	–	–	2.94
Eugenia uniflora L	–	–	2.18
Blepharocalyx salicifolius (Kunth) O.Berg	–	–	2.12
Casearia decandra Jacq.	–	–	1.91

Cutting bridge 90%

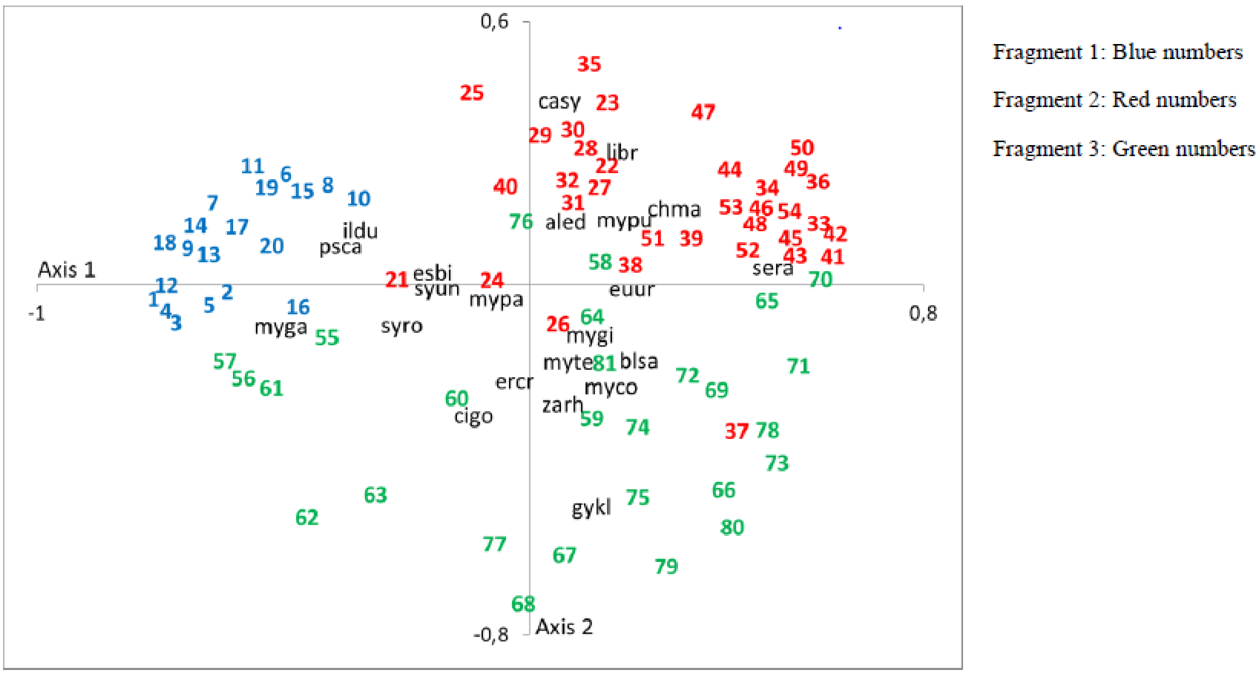

Figure 4. Principal Coordinates Analysis (PCoA) showing the ordination of sampling units (SU) and indicator species in three fragments of riverine forest (numbers in blue = SU of Fragment 1; numbers in red = SU of Fragment 2; numbers in green = SU of Fragment 3) on the first two axes. Species: casy = *Casearia sylvestris*, libr = *Lithraea brasiliensis*, chma = *Chrysophyllum marginatum*, aled = *Allophylus edulis*, mypu = *Myrcianthes pungens*, sera = *Sebastiania ramosissima*, ildu = *Ilex dumosa*, psca = *Psidium cattleianum*, esbi = *Escallonia bifida*, syun = *Symplocos uniflora*, mypa = *Myrcia palustris*, euur = *Eugenia uruguayensis*, myga = *Myrsine gardneriana*, syro = *Syagrus romanzoffiana*, mygi = *Myrcianthes gigantea*, myte = *Myrciaria tenella*, blsa = *Blepharocalyx salicifolius*, ercr = *Erythrina crista-galli*, myco = *Myrsine coriacea*, cigo = *Citronella gongonha*, zarh = *Zanthoxylum rhoifolium*, gykl = *Gymnanthes klotzschiana*.

Discussion

The three remnants had significant floristic diversity and heterogeneity, each displaying a unique plant community structure characterized by distinct successional groups. The richness in the three gallery forest areas was similar to other studies conducted in the same region (Jurinitz & Jarenkow 2003; Venzke & Martins 2013) on riparian forests of the Seasonal Semideciduous Forest, RS. Caumo *et al.* (2021) also reported high floristic diversity in areas of grassland vegetation, adjacent to the areas of the present study and inserted in the same commercial plantation.

Myrtaceae was the richest family, corroborating the findings of other studies conducted in regions near our study area (Jurinitz & Jarenkow 2003; Lindenmaier & Budke 2006; Soares & Ferrer 2009; Scipioni *et al.* 2013; Oliveira *et al.* 2015; Araújo *et al.* 2016). Fabaceae have also been registered as a highly rich family in distant remnants of water courses or riparian forests (Lucheta *et al.* 2015; Grasel *et al.* 2017; Teixeira *et al.* 2018). However, this did not occur in the present study, where only two species were reported (*Calliandra tweedii* Benth. and *E. crista-galli*), both with few individuals. Araújo *et al.* (2016) reported no species of Fabaceae in two riparian forests in the Pampa biome.

Floristic heterogeneity of riparian forests was observed in our study, based on phytosociological data. *G. klotzschiana* (Euphorbiaceae), for example, typical of environments with high water saturation (Scipioni *et al.* 2015), with reported

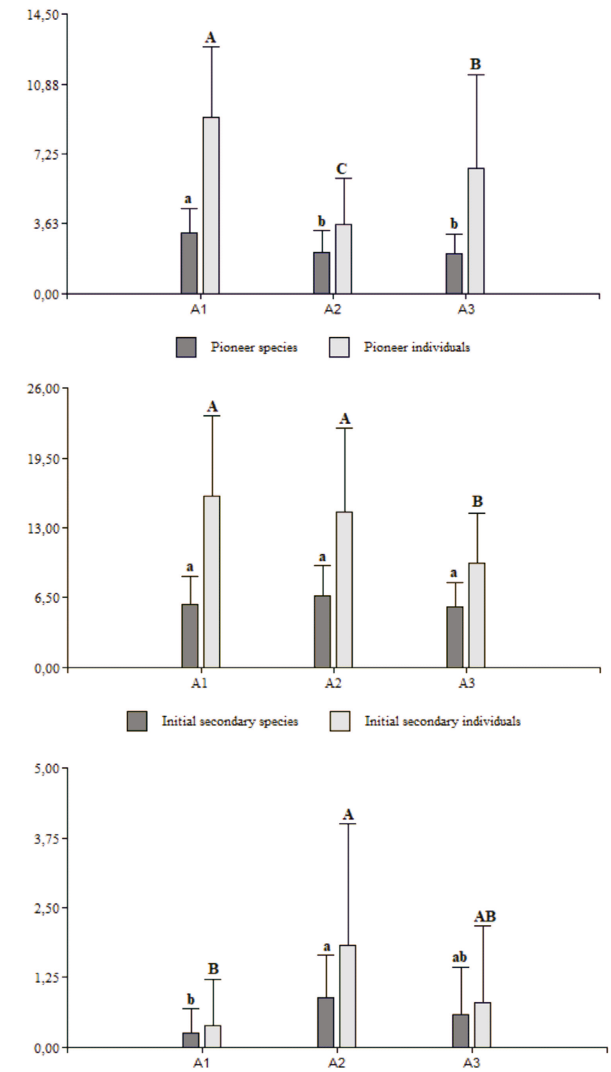

Figure 5. Mean number of pioneer, initial secondary, and late secondary species and individuals per sampling unit in three riverine forest fragments (A1 = Fragment 1, A2 = Fragment 2, and A3 = Fragment 3) in the municipality of Pantano Grande, Rio Grande do Sul, Brazil. Different lowercase letters indicate statistical differences among the three fragments for pioneer species, initial secondary, and late secondary species ($p<0.05$). Different uppercase letters indicate statistical differences among the three fragments for pioneer species, and initial secondary and late secondary species ($p<0.05$).

occurrence in different Brazilian states, had a high number of individuals and the highest IVI. In Fragment 3, where the soil was more flooded, *G. klotzschiana* reached the highest density and frequency values, ranking first in IVI. Other studies conducted in riparian forests have also reported this species as one of the most important in forests under these humidity conditions (Longhi *et al.* 2008; Rovedder *et al.* 2014; Oliveira *et al.* 2015; Araújo *et al.* 2016; Teixeira *et al.* 2018). On the other hand, *S. ramosissima*, from the same family, prefers humid but not saturated environments (Souza *et al.* 2017) as is the case of Fragment 2, where it reached the highest IVI. The high soil moisture in Fragment 3 also favored the presence of species such as *E. crista-galli*, *C. gongonha*, *Syagrus romanzoffiana*, and *M. gardneriana*, not reported in Fragments 1 and 2 (Silva *et al.* 2009; Silva *et al.* 2012). Differences between fragments were also observed by Sampaio *et al.* (2000) in two gallery forests in Brasília (Federal District), under similar abiotic conditions in nearby patches, in the same forest, and by Rodrigues and Nave (2001), who compared 43 studies in riparian forests in Brazil.

In Fragment 1, the fact that 107 individuals (AD = 535 ind ha^{-1}) of the genera *Myrsine* and *M. gardneriana* were reported with the highest IVI can be an indication that this area is in the early to intermediate successional stage, considering that species of this genus, according to Freitas and Carrijo (2008) and Scipioni (2012), are characterized as pioneers or initial secondary. Additionally, it has higher richness and density in narrow areas, probably favored by edge effects (Scipioni 2012). This is what we believe is happening in Fragment 1, as its narrow shape must favor the presence of pioneer and initial secondary species, which will therefore remain in this successional stage. Additionally, the presence of *P. cattleianum* and *M. palustris* (initial secondary species that also had the highest IVI in Fragment 1), with AD of 530 and 445 ind ha^{-1}, respectively, suggests that the fragment is at an earlier successional stage compared to the other two fragments, which have lower densities of these species. However, we understand that the cause is the shape of the fragment, which favors edge effects, as described by Ibáñez *et al.* (2014).

There was little variation in the percentage of dead individuals among the three fragments and these values were lower, but close to the reported by Soares and Ferrer (2009) (7.5%) and Longhi *et al.* (2008) (8.17%). According to Longhi *et al.* (2008), this may indicate an intermediate successional stage, consistent with the successional stage defined for the three fragments studied due to the presence of more medium-stage indicator species. Inversely, Vaccaro *et al.* (1999) observed higher percentages (7.7%) of dead individuals in an initial secondary forest (7.7%) ('capoeirão') with dominance of species and individuals classified as initial secondary. Thus, it is not possible to state whether the successional stage is responsible for the number of dead individuals in the present study.

The PCoA also confirmed heterogeneity between the fragments. Fragment 1 formed a separate group from the other fragments, indicating that it was more differentiated due to lower richness, difference in floristic composition, and species sharing. It is likely that its narrow shape and shorter extension, compared with the other two fragments, may have contributed to this difference. In addition, smaller areas tend to have lower floristic diversity yet a higher number of species and pioneer individuals that benefit from the edge effect, while larger, circular, and close areas have higher diversity (Pirovani *et al.* 2014; Liu *et al.* 2018). Silva and Souza (2014) and Ibáñez *et al.* (2014) also claim that in smaller areas, such as Fragment 1, the shape and degree of isolation have higher influence from external factors, because of the intensity of edge effects that cause them to be more susceptible to physical changes. According to Pirovani *et al.* (2014), the size and shape of forest fragments are among the factors that can affect floristic composition, determining the higher diversity and floristic similarity observed between Fragments 2 and 3, which sets them apart from Fragment 1. Aside from these factors, the existing connectivity between Fragments 2 and 3, as both occur along two tributaries of the same stream, may be affected by both the similarity and diversity between them.

The proximity between SU of Fragment 2 and Fragment 3 shown in the PCoA was due to species sharing and the number of individuals per SU. Factors such as size and shape, similar in Fragments 2 and 3, can be determinants for a higher similarity between them, as reported in two Restinga areas in the municipality of Bertioga, São Paulo, by Guedes *et al.* (2006). The authors also considered that the exposure of riparian forests to the same climatic conditions and propagation sources are causes for the higher floristic and structural similarity between them. This corroborates the findings in Fragments 2 and 3 of the present study, as shown by the SIMPER analysis. The species with the highest IVI in the three fragments are indicators of similarity and dissimilarity between SU and fragments and the higher similarity in species composition between Fragments 2 and 3 contributed to distance them even more from Fragment 1. This also was observed by Silva *et al.* (2019), who carried out a phytosociological survey of ferns in the same areas as the present study.

The three fragments did not differ from each other regarding the number of species classified as initial secondary. In Fragment 2, *S. ramosissima* and *C. sylvestris*, with the highest numbers of individuals, are characterized as initial secondary and are associated with more shaded and humid environments, factors provided by the larger size of the area and lower edge effect (Souza *et al.* 2017). These abiotic characteristics also led to the presence of late secondary species, such as *Casearia decandra* Jacq., *Myrcianthes pungens*, *Alsophila setosa* Kaulf., *Banara tomentosa* Clos, and the genus *Trichilia* P. Browne (Longhi *et al.* 2006; Venzke & Martins 2013). According to Fávero *et al.* (2015), the dominance of typical understory species, which requires specific conditions generated by canopy and emerging trees, indicates maturity and older disturbances, corroborating what was observed in Fragment 2.

Pinus elliottii and *Eucalyptus saligna* were the only exotic species reported in the remnants. The first is considered an invasive exotic species in RS (Secretaria Estadual do Meio Ambiente 2013) and the second is considered an invasive species in several studies conducted around the world (Gordon *et al.* 2012; Lorentz & Minogue 2015). Despite the proximity to crops, the degree of preservation of the three communities is confirmed by the low number of exotic species and individuals in the study remnants and the natural absence of *E. saligna*. This shows that the diversity of the studied remnants has not been endangered by the invasion of exotic species so far, probably because according to Davis *et al.* (2005) and Lozano *et al.* (2023), more preserved areas are less susceptible to colonization and establishment of exotic species.

The three fragments were different, both floristically and structurally, with relevant species diversity, probably favored by factors that can affect and limit this diversity, such as the size and shape of the fragments and soil moisture. The narrow shape associated with the smaller size of Fragment 1 may be the abiotic factor responsible for the higher number of pioneer species and individuals. Conversely, Fragments 2 e 3, with a higher occurrence of initial and late secondary species and individuals, were larger and wider. The specific characteristics of each area cause them to be heterogeneous, confirming one of our hypotheses and showing that they play an essential part in biodiversity conservation even when they are small and surrounded by monocultures. This is confirmed by Awade and Metzger (2008) and Zanella *et al.* (2012), as they claim that floristic heterogeneity occurs even in small areas due to an array of factors that interact with each other, along with the responses by each species, thus providing the attributes typical of each site. Small remnants also contribute to species richness and abundance (Machado *et al.* 2016).

Although the three fragments are classified as intermediate successional stages, pioneer species and individuals predominated in Fragment 1, probably due to their size and shape. On the other hand, early and late secondary species and individuals predominated in Fragments 2 and 3, with larger and wider sizes. Furthermore, we believe that the higher soil humidity in Fragment 3 favored the presence of species characteristic of wetter environments, which constitutes another factor responsible for the heterogeneity and higher diversity. Although they are small and surrounded by monocultures, the remnants are heterogeneous and important for biodiversity conservation. Additionally, the plant diversity found in this study reveals how riverine forests of the Pampa biome are important for the preservation of species in space and over time, of the associated fauna, and the ecological processes involved.

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Author contributions

CRO, EMF, and MTeixeira developed the ideas and designed the experimental methods. CRO, MTeixeira, MToldi, and EMF contributed to data collection. CRO, VLS, MToldi, and EMF contributed to the data analysis and interpretation. CRO, VLS, and EMF wrote and reviewed the manuscript. All authors contributed critically and gave final approval for publication.

Conflicts of Interest

All authors of the manuscript entitled Floristic and structural diversity of riverine forest remnants in the Pampa biome declare that there is no conflict of interest of a personal, scientific, commercial, political or financial nature in the process of evaluation and publication of the aforementioned article.

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