ISSN:1984-2295

Revista Brasileira de Geografia Física

Homepage: <https://periodicos.ufpe.br/revistas/rbgfe>

Vascular epiphytism on the Sinos River riparian forest: phytosociological and conservation analysis

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Artigo recebido em 23/09/2021 e Aceito em 19/10/2021

RESUMO

A biodiversidade de epífitos é um indicador da qualidade ambiental das bacias hidrográficas onde a riqueza dessas plantas tem relação inversa à degradação da vegetação. Foi realizado um inventário dos epífitos vasculares em três fragmentos de mata ciliar do Rio dos Sinos, RS, Brasil, nos municípios de Carará (CA, 560 m alt., Floresta Ombrófila Densa), Taquara (TA, 57 m alt., Floresta Estacional Semidecidual) e de Campo Bom (CB, 29 m alt., Floresta Estacional Semidecidual); comparada a riqueza e estrutura comunitária entre os sítios; e avaliado o grau de conservação e a qualidade ambiental utilizando indicadores botânicos. Em cada sítio foram selecionados 40 forófitos, divididos em cinco zonas de altura, nas quais foram registradas as espécies e suas notas de cobertura. O Valor de Importância específico (VI) foi calculado a partir da frequência e do valor de cobertura. Foram registradas 74 espécies em CA, 21 em TA e 20 em CB. O sítio de maior riqueza também apresentou uma grande heterogeneidade florística, está inserido em uma matriz rural e localiza-se em uma região mais elevada, com clima mais úmido em função da maior precipitação. *Vriesea incurvata* apresentou o maior VI em CA, *Pleopeltis pleopeltifolia* em TA e *Rhipsalis teres* em CB. Treze espécies estão ameaçadas de extinção, das quais 12 foram encontradas em CA. Os parâmetros botânicos obtidos suportam a ideia de que a mata ciliar de Carará apresenta uma estrutura comunitária mais complexa, com grau superior de conservação e melhor qualidade ambiental, quando comparada aos outros fragmentos.

Palavras-chave: epífito; Floresta Atlântica; estimador de riqueza; indicadores de qualidade ambiental.

Epitifismo vascular na mata ciliar do Rio dos Sinos: análises fitossociológicas e conservacionistas

ABSTRACT

Epiphyte biodiversity is an indicator of environmental quality in water basins, since there is an inverse relationship between richness of these plants and vegetation degradation. An inventory of vascular epiphytes was conducted in three fragments of riparian zone of the Sinos River, RS, Brazil, in the municipalities of Carará (CA, 560 m alt., Dense Humid Forest), Taquara (TA, 57 m alt., Semideciduous Seasonal Forest) and Campo Bom (CB, 29 m alt., Semideciduous Seasonal Forest); the richness and community structure was compared across sites, and the degree of conservation and environmental quality was assessed using botanical indicators. At each site, 40 phorophytes were selected, and then sorted within five height zones, at which the species and their coverage scores were recorded. The specific Importance Value (IV) was calculated based on the frequencies and coverage value. The study recorded 74 species in CA, 21 in TA and 20

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in CB. The site with the greatest epiphyte richness also presented great floristic heterogeneity, and located in a rural area, at a higher region where the type of forest is wetter and there is greater rainfall. *Vriesea incurvata* presented the highest VI in CA, *Pleopeltis pleopeltifolia* in TA and *Rhipsalis teres* in CB. Thirteen of the species are endangered, and 12 of which were found in CA. The botanical parameters obtained support the idea that the riparian forest of CA presents a more complex community structure, with a higher degree of conservation and better environmental quality, when compared to the TA and CB sites.

Keywords: epiphyte; Atlantic Forest; richness estimator; indicator of environmental quality.

Introduction

Riparian forests comprise the vegetation that forms naturally on the banks of the rivers, with the primary function to protect watercourses, biodiversity and the soil (Lind et al., 2019; Michez et al., 2017). According to floristic studies, riparian forests present heterogeneity in the dynamics, composition and structure of species (Miranda et al., 2021). These variations are due to the interaction between physical factors, such as topography and soil characteristics, and biological factors, such as associated vegetation formations, width of riparian forest, and disturbance history. The associations between these factors determine different ecological conditions among riparian forests (Cabette et al., 2017; Vieira and Tejerina-Garro, 2020).

The degradation of riparian forests due to agricultural activities and population density lead to loss of environmental quality throughout the watershed (Broetto et al., 2017; Turunen et al., 2021). Both in preserved areas and in those that are most impacted, knowledge of vegetation can serve as diagnostic of environmental quality (Martins; et al., 2016).

Epiphytism consists of the harmonic interaction between two species, in which the epiphyte uses the phorophyte only as support and does not rely on it for nutrients and water (Lehtonen et al., 2017). Studies emphasize the importance of epiphytes as indicators of environmental quality, since some species are sensitive to anthropogenic or natural changes (Galán et al., 2018). Moreover, these species are used to classify the successional stage of Atlantic Forest fragments, according to Resolution 33/94 of the Brazilian Environment Council (CONAMA, 2012).

There are about 31,000 species of vascular epiphytes worldwide, which are categorized into 79 plant families, accounting for up to 10% of all the forest plant species globally and play important functional roles, especially in tropical forests (Freitas et al., 2016; Zotz et al., 2021). The epiphytic flora is most developed in tropical and subtropical forests, and their abundance and diversity are mainly influenced by the change on

ecological conditions along gradients of altitude and latitude, as well as by the distribution of rainfall throughout the year (Ramos et al., 2021; Timsina et al., 2021). Epiphytes are considered to be important structural elements of forests (Quaresma et al., 2017), with an important ecological function in terms of maintaining biological diversity (González et al., 2017). These plants are distributed along gradients, which is determined in mesoscale by vegetation type, and takes into account the different forest communities present within the same region (Jiménez-López et al., 2020).

In Brazil, the knowledge of epiphytic flora is broader in the south and southeast regions (Menini Neto et al., 2020). In riparian forests of southern Brazil, studies on epiphytism have been conducted by Graeff et al. (2018), Rocha-Uriarte et al. (2016), Costa et al. (2020) and Bonnet et al. (2010; 2011), in the state of Paraná. In Rio Grande do Sul, among the research on epiphytes in riparian forests, there are the work of Machado et al., (2016) on the Uruguay River and that of Giongo and Waechter (2004); Guerrero et al (2018) on two streams located in the central depression of the State stand out.

The epiphytic flora of the riparian forests in Rio Grande do Sul is still poorly known, due to the fact that most of the research conducted on the state's vegetation formations are related to herbaceous (Mallmann et al., 2013), shrubby and/or arboreal species (Budke et al., 2004; Brackmann and Freitas, 2013). However, the qualitative characterization of herbaceous, trees, shrubs and epiphytic forest fragments in the Gravataí River Basin, in the state of Rio Grande do Sul, has been conducted by Oliveira et al. (2005).

The Sinos River Basin is located in lower northeastern slope of Rio Grande do Sul is the, which accounts for 1.5% of the state's total area and consists of an area of 3,820 km², with approximately 975,000 inhabitants. The Sinos River is the main watercourse of the basin, approximately 190 km long, with its headwaters in the municipality of Caraá and its mouth in the delta of the River Jacuí (FEPAM, 2021). Riparian forests

of the basin comprise fragments of Atlantic Forest (Nóbrega et al., 2020).

The surveys carried out in the Sinos River Basin were for the arboreal and shrub extracts and are very old, as can be seen in the surveys of Diesel and Siqueira (1991) carried out the phytosociological survey of herbaceous and shrubby stratum, and Daniel (1991) has analyzed the phytosociology of the arboreal/shrubby stratus in the municipalities of Parobé, Rolante and Canela. Few researches use the epiphytes in their surveys. Thus, the present study aimed to: i) conduct an inventory of vascular epiphytes in three fragments of Rio dos Sinos riparian forest, determining which species are generalists, exclusive and endangered; ii) compare the richness and community structure of these plants among the

sites; iii) analyze the floristic similarities among different forest fragments of the Sinos River Basin or other riparian forests; and iv) assess the degree of conservation and environmental quality of riparian forests using the botanical indicators.

Materials and methods

Study sites

The three riparian forest fragments studied are located, respectively, in the upper, middle, and lower sections of Sinos River, in northeastern Rio Grande do Sul (Figure 1). According to the Köppen climate classification (Peel et al., 2007), the general climate of the region is Cfa-type – humid mesothermal, with no dry period.

Figure 1: Location of Sinos River Basin in Brazil (A) and in Rio Grande do Sul state (B). Study areas in upper (1: Caraá), middle (2: Taquara) and lower (3: Campo Bom) sections of Sinos River.

Fragment 1: located in the upper section of Sinos River, in the municipality of Caraá (29° 42' 25,0" S and 50° 17' 27,8" W; 560 m alt.). This fragment consists of Dense Humid Forest and is located in the region of the Sinos River headwaters, within a rural matrix. Primary production includes the cultivation of sugar cane, corn, beans, rice and horticultural products (Fee, 2013), and the population density is 24.84 inhabitants km⁻² (IBGE, 2021). The mean annual temperature is 18.9 °C and annual rainfall is 2,400 mm (Rocha-Uriartt et al., 2015).

Fragment 2: located in the middle section of the Sinos River, in the municipality of Taquara

(29° 40' 46,8" S and 50° 45' 57,0" W; 57 m alt.). This is a fragment of Semideciduous Seasonal Forest, whose surroundings are characterized by the presence of industries, animal husbandry and agriculture. The population density is 119.35 inhabitants km⁻² (IBGE, 2021). The average annual temperature is 19.8 °C and mean annual rainfall is 1,800 mm (Rocha-Uriartt et al., 2015). The distance between fragments 1 and 2 is 37.4 km.

Fragment 3: located in the lower section of the Sinos River, in the municipality of Campo Bom (29° 40' 54" S and 51° 3' 35" W; 29 m alt.). This is a fragment of Semideciduous Seasonal Forest embedded in an urban and industrial matrix. The

population density is 992.79 inhabitants km⁻² (IBGE, 2021). The average annual temperature is 19.5 °C and mean annual rainfall is 1594.5 mm (Rocha-Uriartt et al., 2015). The distance between fragments 2 and 3 is 26.8 km.

Phorophyte selection

For each fragment, a parallel transect up to 10 meters away from the watercourse was plotted. The phorophytes were selected by the method of point-centered quarters (Cottam and Curtis, 1956). Four trees with epiphytes and minimum diameter at breast height (DBH) of 10 cm were selected at each point. In total, 40 trees were selected at each riparian forest fragment.

Floristic composition

Monthly visits were made *in situ* at the sites, during two years, for the floristic inventory. The survey was conducted through direct observation of epiphytic plants in the environment with the aid of binoculars (Bushnell® - 96m AT 1000M) and phorophyte climbing techniques. Species were identified using specialized literature, comparisons to the material determined in herbarium and consultations with specialists. Scientific names were checked in Flora do Brasil (2020). The classification scheme adopted for fern families was Smith et al. (2006), with modifications made to Smith et al. (2008) and for angiosperms, the APG IV (2016) was used. Representative fertile specimens were deposited in the Anchieta Herbarium (PACA) at the Anchieta Research Institute, at Universidade do Vale do Rio dos Sinos, in Rio Grande do Sul, Brazil. The degree of endangerment of inventoried species was verified in the Red Book of Brazilian Flora (Martinelli and Moraes, 2013) and in the Final List of Endangered Flora Species of Rio Grande do Sul (State Decree No. 42,099, published on January 1st, 2003). The species were classified according to the type of relationship with the host tree, in the following ecological categories (Benzing, 1995). Estimates of specific richness using nonparametric estimator *Jackknife* 1 were calculated using the software EstimateS 9.1.0 (Colwell, 2005).

Similarity

A cluster analysis was performed based on the data of presence or absence of species in the studied sites and in other surveys conducted in Rio Grande do Sul, on secondary forests in the Sinos River Basin (Barbosa et al., 2015) and on a Gallery Forest located in the state's central depression (Giongo and Waechter, 2004). A dendrogram for

floristic similarity was constructed with the Dice-Sorensen index through UPGMA (Unweighted Arithmetic Mean). This analysis was performed using the PAST (Paleontological Statistics Software Package for Education and Data Analysis) software, version 2.17 (Hammer et al., 2001).

Community structure

The phorophytes were divided into five zones (1: base, 2: low trunk, 3: high trunk; 4: inner crown and 5: outer crown) into which the occurring species were logged (number of zones of occurrence of the species: nz). Coverage scores (1, 3, 5, 7 and 10) were given to each species according to Kersten and Waechter (2011). The absolute and relative frequencies of species per phorophyte and zone were determined (Waechter, 1998). The specific Importance Value (VI) was obtained from the arithmetic mean of the sum of the relative frequencies in phorophytes and on the intervals and relative coverage.

Results

Floristic composition

In the three riparian forest fragments studied, 86 species were inventoried, across 46 genera and 16 families. Among these, there were eight families of angiosperms (Araceae, Begoniaceae, Bromeliaceae, Cactaceae, Commelinaceae, Gesneriaceae, Orchidaceae and Piperaceae), seven families of ferns (Aspleniaceae, Blechnaceae, Dryopteridaceae, Hymenophyllaceae, Polypodiaceae, Pteridaceae and Thelypteridaceae) and one family of lycophyte (Lycopodiaceae). The holoeiphytes were the most frequent (70 species, or 81%), followed by accidental holoeiphytes (seven species, or 8%), facultative (five species, or 6%) and secondary hemieiphytes (four species, or 5%).

In Caraá, 74 species were inventoried, belonging to 15 families, and Orchidaceae (18 species), Polypodiaceae (14 species) and Bromeliaceae (13 species) were the richest (Table 1). In Taquara, 21 species were found, belonging to four families, among which Bromeliaceae (seven species) was the richest, followed by Polypodiaceae (six species) and Orchidaceae (five species) (Table 2). In Campo Bom, the 20 species found belong to six families, and Bromeliaceae and Polypodiaceae (six species each) and Cactaceae (four species) were the richest (Table 3). The rarefaction curve in Caraá, Taquara and Campo Bom tended to asymptote, and 92, 26 and 23

species were estimated in each fragment, respectively (Figure 2).

Figure 2: Rarefaction curves and species richness estimator (Jackknife 1: triangles; Caraá: white; Taquara: black; Campo Bom: gray) for Caraá (○), Taquara (+) e Campo Bom (■) sites.

Table 1: Ecological category (EC), degree of threat and phytosociological structure of species of vascular epiphytes inventoried in Caraá, in descending order of specific Importance Value (VI).

Family	Species	EC	np	nz	Rp%	Rz%	rN%	VI%
Bromeliaceae	<i>Vriesea aff. incurvata</i> Gaudich.	HC	33	78	7.3	10.2	17	11.5
Bromeliaceae	<i>Aechmea calyculata</i> (E.Morren) Baker	HF	21	41	4.6	5.4	8	6
Polypodiaceae	<i>Niphidium crassifolium</i> (L.) Lellinger	HC	20	37	4.4	4.8	7.2	5.5
Piperaceae	<i>Peperomia tetraphylla</i> (G. Forst.) Hook. & Arn.	HC	27	53	5.9	6.9	3.4	5.4
Polypodiaceae	<i>Campyloneurum nitidum</i> (Kaulf.) C.Presl	HC	20	33	4.4	4.3	4.1	4.3
Polypodiaceae	<i>Microgramma squamulosa</i> (Kaulf.) de la Sota.	HC	18	30	4	3.9	4.1	4
Bromeliaceae	<i>Vriesea carinata</i> Wawra	HC	13	22	2.9	2.9	4.3	3.3
Orchidaceae	<i>Octomeria diaphana</i> Lindl	HC	11	25	2.4	3.3	3.4	3
Cactaceae	<i>Rhipsalis teres</i> (Vell.) Steud	HC	10	22	2.2	2.9	2.8	2.6
Piperaceae	<i>Peperomia rotundifolia</i> (L.) Kunth	HC	11	22	2.4	2.9	2.2	2.5
Aspleniaceae	<i>Asplenium gastonis</i> Fée	HC	13	18	2.9	2.3	1.8	2.3
Dryopteridaceae	<i>Mickelia scandens</i> (Raddi) R.C. Moran et al.	HS	9	16	2	2.1	2.7	2.2
Polypodiaceae	<i>Campyloneurum austrobrasillianum</i> (Alston) de la Sota	HC	11	17	2.4	2.2	1.8	2.1
Polypodiaceae	<i>Pleopeltis pleopeltidis</i> (Fée) de la Sota	HC	11	15	2.4	2	1.5	2
Polypodiaceae	<i>Serpocaulon catharinae</i> (Langsd. & Fisch.) A.R.Sm.	HC	10	17	2.2	2.2	1.3	1.9
Piperaceae	<i>Peperomia alata</i> Ruiz & Pav.	HC	9	17	2	2.2	1.5	1.9

Gesneriaceae	<i>Sinningia douglasii</i> (Lindl.) Chautems	HF	9	17	2	2.2	1.4	1.9
Bromeliaceae	<i>Tillandsia geminiflora</i> Brongn.	HC	8	16	1.8	2.1	1.4	1.7
Piperaceae	<i>Peperomia pereskiaefolia</i> (Jacq.) Kunth	HC	9	13	2	1.7	1.4	1.7
Orchidaceae	<i>Epidendrum densiflorum</i> Hook.	HC	7	12	1.5	1.6	1.7	1.6
Polypodiaceae	<i>Pleopeltis hirsutissima</i> (Raddi) de la Sota	HC	8	14	1.8	1.8	1.1	1.5
Cactaceae	<i>Lepismium</i> <i>houlettianum</i> (Lem.) Barthlott	HC	6	11	1.3	1.4	1.8	1.5
Bromeliaceae	<i>Tillandsia aeranthos</i> (Loisel.) L.B.Sm.;	HC	8	12	1.8	1.6	1.2	1.5
Orchidaceae	<i>Acianthera luteola</i> (Lindl.) Pridgeon & M.W.Chase	HC	6	13	1.3	1.7	1.3	1.4
Dryopteridaceae	<i>Rumohra adiantiformis</i> (G. Forst.) Ching	HA	8	11	1.8	1.4	1	1.4
Aspleniaceae	<i>Asplenium scandicinium</i> Kaulf.	HC	8	10	1.8	1.3	1	1.3
Hymenophyllaceae	<i>Vandenboschia radicans</i> (Sw.) Copel.	HS	6	10	1.3	1.3	1.3	1.3
Blechnaceae	<i>Blechnum acutum</i> (Desv.) Mett	HS	8	8	1.8	1	1	1.3
Bromeliaceae	<i>Vriesea gigantea</i> Gaudich. NT	HC	4	7	0.9	0.9	1.8	1.2
Polypodiaceae	<i>Pecluma pectinatiformis</i> (Lindm.) M.G.Price	HC	5	9	1.1	1.2	0.8	1
Begoniaceae	<i>Begonia fruticosa</i> (Klotzsch) A.DC	HF	6	7	1.3	0.9	0.8	1
Polypodiaceae	<i>Pleopeltis astrolepis</i> (Liebm.) E.Fourn.	HC	6	8	1.3	1	0.5	1
Bromeliaceae	<i>Vriesea rodigasiana</i> E.Morren	HC	4	5	0.9	0.7	1.1	0.9
Bromeliaceae	<i>Vriesea platynema</i> Gaudich. NT	HC	3	5	0.7	0.7	1.3	0.9
Polypodiaceae	<i>Pecluma recurvata</i> (Kaulf.) M.G. Price	HC	5	7	1.1	0.9	0.6	0.9
Cactaceae	<i>Rhipsalis cereuscula</i> Haw.	HC	3	6	0.7	0.8	1.1	0.8
Bromeliaceae	<i>Nidularium</i> <i>amazonicum</i> (Baker) Linden & E.Morren ex Lindm	HF	4	5	0.9	0.7	0.7	0.7
Orchidaceae	<i>Gomesa crispa</i> (Lindl.) Klotzsch ex Rchb. f	HC	5	6	1.1	0.8	0.3	0.7
Bromeliaceae	<i>Tillandsia usneoides</i> (L.) L.	HC	4	6	0.9	0.8	0.5	0.7
Orchidaceae	<i>Stelis fraterna</i> Lindl.	HC	4	6	0.9	0.8	0.4	0.7
Bromeliaceae	<i>Vriesea vagans</i> (L.B.Sm.) L.B.Sm.	HC	4	4	0.9	0.5	0.6	0.7
Bromeliaceae	<i>Tillandsia gardneri</i> Lindl.	HC	4	6	0.9	0.8	0.3	0.7
Orchidaceae	<i>Isochilus linearis</i> (Jacq.) R.Br.	HC	3	4	0.7	0.5	0.7	0.6
Orchidaceae	<i>Zygopetalum maxillare</i> Lodd. DD	HC	2	5	0.4	0.7	0.7	0.6
Lycopodiaceae	<i>Huperzia heterocarpon</i> (Fée) Holub	HC	3	3	0.7	0.4	0.7	0.6
Orchidaceae	<i>Prosthechea bulbosa</i> (Vell.) W.E.Higgins	HC	3	4	0.7	0.5	0.4	0.5
Orchidaceae	<i>Pabstiella mirabilis</i> (Schltr.) Brieger & Senghas	HC	3	4	0.7	0.5	0.3	0.5

Orchidaceae	<i>Promenaea xanthina</i> (Lindl.) Lindl.;	HC	3	3	0.7	0.4	0.3	0.4
Orchidaceae	<i>Christensonella vernicosa</i> (Barb.Rodr.) Szlach. et al.	HC	3	3	0.7	0.4	0.2	0.4
Piperaceae	<i>Peperomia catharinae</i> Miq.	HC	3	3	0.7	0.4	0.2	0.4
Araceae	<i>Philodendron appendiculatum</i> Nadruz & S.J. Mayo	HS	3	3	0.7	0.4	0.2	0.4
Aspleniaceae	<i>Asplenium oligophyllum</i> Kaulf.	HC	2	3	0.4	0.4	0.4	0.4
Dryopteridaceae	<i>Lastreopsis amplissima</i> (C.Presl) Tindale	HA	2	3	0.4	0.4	0.4	0.4
Orchidaceae	<i>Brasiliidium concolor</i> (Hook.) F.Barros & V.T.Rodrigues	HC	2	3	0.4	0.4	0.3	0.4
Orchidaceae	<i>Dryadella zebrina</i> (Porsch) Luer	HC	1	3	0.2	0.4	0.3	0.3
Aspleniaceae	<i>Asplenium claussenii</i> Hieron.	HA	2	2	0.4	0.3	0.1	0.3
Cactaceae	<i>Hattoria rosea</i> (Lagerh.) Barthlott *	HC	2	2	0.4	0.3	0.1	0.3
Aspleniaceae	<i>Hymenasplenium triquetrum</i> (N. Murak. & R.C. Moran) L. Regalado & Prada	HA	2	2	0.4	0.3	0.1	0.3
Orchidaceae	<i>Lankesterella ceracifolia</i> (Barb. Rodr.) Ames	HC	2	2	0.4	0.3	0.1	0.3
Cactaceae	<i>Lepismium lumbricoides</i> (Lem.) Barthlott	HC	1	2	0.2	0.3	0.2	0.2
Polypodiaceae	<i>Pleopeltis macrocarpa</i> (Bory ex Willd.) Kaulf.	HC	1	2	0.2	0.3	0.1	0.2
Orchidaceae	<i>Stelis pauciflora</i> Lindl.	HC	1	1	0.2	0.1	0.2	0.2
Bromeliaceae	<i>Tillandsia recurvata</i> (L.) L.	HC	1	1	0.2	0.1	0.2	0.2
Orchidaceae	<i>Acianthera glanduligera</i> (Lindl.) Luer	HC	1	1	0.2	0.1	0.1	0.1
Orchidaceae	<i>Acianthera hygrophila</i> (Barb.Rodr.) Pridgeon & M.W.Chase	HC	1	1	0.2	0.1	0.1	0.1
Orchidaceae	<i>Acianthera sonderana</i> (Rchb.f.) Pridgeon & M.W.Chase	HC	1	1	0.2	0.1	0.1	0.1
Blechnaceae	<i>Blechnum cordatum</i> (Desv.) Hieron.	HA	1	1	0.2	0.1	0.1	0.1
Dryopteridaceae	<i>Elaphoglossum sellowianum</i> (Klotzsch ex Kuhn) T. Moore	HC	1	1	0.2	0.1	0.1	0.1
Dryopteridaceae	<i>Elaphoglossum vagans</i> (Mett.) Hieron.	HC	1	1	0.2	0.1	0.1	0.1
Polypodiaceae	<i>Microgramma vacciniifolia</i> (Langsd. & Fisch.) Copel.	HC	1	1	0.2	0.1	0.1	0.1
Polypodiaceae	<i>Pecluma paradiseae</i> (Langsd. & Fisch.) M.G.Price	HF	1	1	0.2	0.1	0.1	0.1
Polypodiaceae	<i>Serpocaulon latipes</i> (Langsd. & Fisch.) A.R.Sm.	HC	1	1	0.2	0.1	0.1	0.1
Commelinaceae	<i>Tradescantia fluminensis</i> Vell.	HA	1	1	0.2	0.1	0.1	0.1
Pteridaceae	<i>Vittaria lineata</i> (L.) Sm.	HC	1	1	0.2	0.1	0.1	0.1

HA: accidental holoeiphyte; HC: characteristic holoeiphyte; HF: facultative holoeiphyte; HS: secondary hemiepiphyte; Plants included in the Final List of Endangered Species of Flora of Rio Grande do Sul (SEMA, 2015) in vulnerable (VU) and endangered (EN) categories; *taxon with restricted distribution and e insufficient data for classification on the Official List of Species of Endangered Flora of Brazil (MARTINELLI and

MORAES, 2013); np e nz: number of phorophytes and zones of occurrence of the species, respectively; Rp: relative frequency in phorophytes; Rz: relative frequency in zones; rN: relative coverage note.

Table 2: Ecological category (EC), degree of threat and phytosociological structure of species of vascular epiphytes inventoried in Taquara, in descending order of specific Importance Value (VI).

* see legend Table 1.

Family	Species	EC	np	nz	Rp%	Rz%	rN%	VI%
Polypodiaceae	<i>Pleopeltis pleopeltifolia</i> (Raddi) Alston	HC	33	86	17	22.9	27.2	22.4
Polypodiaceae	<i>Microgramma squamulosa</i> (Kaulf.) de la Sota	HC	22	64	11	17.1	18.2	15.6
Bromeliaceae	<i>Tillandsia usneoides</i> (L.) L.	HC	21	45	11	12	13.9	12.3
Bromeliaceae	<i>Tillandsia aeranthos</i> (Loisel.) L.B. Sm.	HC	20	34	10	9.1	7.0	8.8
Orchidaceae	<i>Lophiaris pumila</i> (Lindl.) Braem	HC	16	26	8.3	6.9	5.8	7.0
Bromeliaceae	<i>Tillandsia geminiflora</i> Brongn.	HC	17	26	8.8	6.9	4.5	6.7
Orchidaceae	<i>Campylocentrum brachycarpum</i> Cogn	HC	16	23	8.3	6.1	4.3	6.2
Cactaceae	<i>Rhipsalis cereuscula</i> Haw.	HC	15	18	7.8	4.8	3.2	5.3
Bromeliaceae	<i>Tillandsia recurvata</i> (L.) L.	HC	7	17	3.6	4.5	4	4.1
Polypodiaceae	<i>Pleopeltis minima</i> (Bory) J. Prado & R.Y. Hirai	HC	6	13	3.1	3.5	5.3	4
Polypodiaceae	<i>Microgramma vacciniifolia</i> (Langsd. & Fisch.) Copel.	HC	4	7	2.1	1.9	1.8	1.9
Cactaceae	<i>Lepismium lumbricoides</i> (Lem.) Barthlott	HC	3	3	1.6	0.8	1.1	1.2
Bromeliaceae	<i>Vriesea gigantea</i> Gaudich.	HC	2	2	1	0.5	1.3	0.9
Bromeliaceae	<i>Vriesea friburgensis</i> Mez	HC	2	2	1	0.5	0.6	0.7
Orchidaceae	<i>Cattleya intermedia</i> Graham ^{VU*}	HC	2	2	1	0.5	0.3	0.6
Bromeliaceae	<i>Tillandsia stricta</i> Sol. Ex Sims	HC	2	2	1	0.5	0.3	0.6
Polypodiaceae	<i>Niphidium crassifolium</i> (L.) Lellinger	HC	1	1	0.5	0.3	0.5	0.4
Orchidaceae	<i>Gomesa</i> sp. R.Br.	HC	1	1	0.5	0.3	0.2	0.3
Orchidaceae	<i>Coppensia flexuosa</i> (Lodd.) Campacci	HC	1	1	0.5	0.3	0.2	0.3
Polypodiaceae	<i>Pleopeltis hirsutissima</i> (Raddi) de la Sota	HC	1	1	0.5	0.3	0.2	0.3
Cactaceae	<i>Rhipsalis teres</i> (Vell.) Steud.	HC	1	1	0.5	0.3	0.2	0.3

Table 3: Ecological category (EC), degree of threat and phytosociological structure of species of vascular epiphytes inventoried in Campo Bom, in descending order of specific Importance Value (VI).

* see legend Table 1.

Family	Species	EC	np	nz	Rp%	Rz%	rN%	VI%
Cactaceae	<i>Rhipsalis teres</i> (Vell.) Steud.	HC	35	86	24.1	30	36.4	30.4
Polypodiaceae	<i>Microgramma squamulosa</i> (Kaulf.) de la Sota	HC	27	68	18.6	24	29.7	24.2
Polypodiaceae	<i>Pleopeltis pleopeltifolia</i> (Raddi) Alston	HC	19	35	13.1	12	10	11.8
Polypodiaceae	<i>Microgramma vacciniifolia</i> (Langsd. & Fisch.) Copel.	HC	11	27	7.6	9.6	11.3	9.5
Bromeliaceae	<i>Tillandsia aeranthos</i> (Loisel.) L.B. Sm.	HC	14	16	9.7	5.7	3.2	6.2
Bromeliaceae	<i>Vriesea friburgensis</i> Mez	HC	4	5	2.8	1.8	1.6	2
Cactaceae	<i>Lepismium cruciforme</i> (Vell.) Miq.	HC	4	5	2.8	1.8	1.3	1.9
Polypodiaceae	<i>Campyloneurum austrobrasiliense</i> (Alston) de la Sota	HC	4	5	2.8	1.8	0.7	1.8
Bromeliaceae	<i>Tillandsia gardneri</i> Lindl	HC	4	5	2.8	1.8	0.7	1.8
Bromeliaceae	<i>Tillandsia geminiflora</i> Brongn.	HC	3	6	2.1	2.1	0.9	1.7

Polypodiaceae	<i>Pleopeltis hirsutissima</i> (Raddi) de la Sota	HC	3	4	2.1	1.4	0.9	1.5
Cactaceae	<i>Lepismium warmingianum</i> (K. Schum.) Barthlott	HC	3	3	2.1	1.1	0.4	1.2
Orchidaceae	<i>Lophiaris pumila</i> (Lindl.) Braem	HC	3	3	2.1	1.1	0.4	1.2
Orchidaceae	<i>Coppensia flexuosa</i> (Lodd.) Campacci	HC	2	3	1.4	1.1	0.7	1.1
Bromeliaceae	<i>Tillandsia recurvata</i> (L.) L.	HC	2	3	1.4	1.1	0.4	1
Thelypteridaceae	<i>Thelypteris hispidula</i> (Decne.) C.F. Reed	HA	2	3	1.4	1.1	0.4	1
Bromeliaceae	<i>Tillandsia usneoides</i> (L.) L.	HC	2	2	1.4	0.7	0.3	0.8
Dryopteridaceae	<i>Rumohra adiantiformis</i> (G. Forst.) Ching	HA	1	1	0.7	0.4	0.4	0.5
Polypodiaceae	<i>Campyloneurum nitidum</i> (Kaulf.) C. Presl	HC	1	1	0.7	0.4	0.1	0.4
Cactaceae	<i>Lepismium houlettianum</i> (Lem.) Barthlott	HC	1	1	0.7	0.4	0.1	0.4

The *Tillandsia* genus was represented by five species in each of the three fragments, and it was the richest in Taquara and Campo Bom. In Caraá, *Vriesea* (six species) was the richest genus. The species common to the three fragments were *Tillandsia aeranthos*, *Tillandsia geminiflora*, *Tillandsia recurvata*, *Tillandsia usneoides*, *Microgramma squamulosa*, *Microgramma vacciniifolia*, *Pleopeltis hirsutissima* and *Pleopeltis pleopeltifolia*. The highest number of exclusive species was found in Caraá (58 species), followed by Taquara (five species) and Campo Bom (three species). Among the Caraá exclusive species, only *Asplenium clausenii*, *Blechnum cordatum*, *Lastreopsis amplissima* and *Tradescantia fluminensis* were classified as accidental holoepiphytes (Tables 1, 2 and 3).

Similarity

In the analysis of floristic similarity, all fragments of the Sinos River Basin, except Caraá (A), were concentrated on the same group (B). The subgroup Ba contained the remaining secondary forest in Caraá and Novo Hamburgo (Ca) and the

remaining riparian forest of Sinos River in Taquara and Campo Bom (Cb). The fragment of Gallery Forest outside the basin formed an independent subgroup (Bb) (Figure 3).

Figure 3: Floristic similarity dendrogram among Caraá (CA_{DRF}), Taquara (TA_{SDF}) and Campo Bom (CB_{SDF}), with other studies in the Basin Sinos River (CN_{DRF}: Caraá; NH_{SDF}: Novo Hamburgo - Barbosa et al., 2015) and in Forest Gallery (FG_{GAF} - Giongo e Waechter, 2004); DRF: Dense Rain Forest; SDF: Seasonal Semideciduous Forest).

Community structure

In all fragments, the species with the highest VI were observed in over 80% of phorophytes. In Caraá, *Vriesea incurvata* (11.5%) had the highest VI, followed by *Aechmea*

calyculata (6.0%) and *Niphidium crassifolium* (5.5%). *Pleopeltis pleopeltifolia* (22.4%), *Microgramma squamulosa* (15.6%) and *Tillandsia usneoides* (12.3%) were the species with the highest VI in Taquara. In Campo Bom, the highest VI was observed for *Rhipsalis teres* (30.3%), *Microgramma squamulosa* (24.2%) and *Pleopeltis pleopeltifolia* (11.8%) (Tables 1, 2 and 3).

Discussion

The decreasing gradient of total epiphytic richness observed in the Sinos River riparian forest from the watersheds towards the lower section may be related to variations in altitude, vegetation type and rainfall. The richest fragment belongs to the areas of Dense Humid Forest, and it is located at a higher elevation, at a site where rainfall was about 30% higher than that recorded in other sites (Rocha-Uriartt et al., 2015). In southern Brazil, rain forests are richest in epiphytes than the seasonal forests (Roderjan et al., 2002; Marques et al., 2015). The greater number of species in relation to increased rainfall is a general pattern observed in tropical forests (Nieder et al., 1996-1997, Machado et al., 2016). Moreover, environments at higher altitudes tend to have greater epiphytic richness (Krömer et al., 2005; Amorim et al., 2021), as observed in Caraá, which is located about 500 m above the other two fragments.

The richness in Taquara and Campo Bom was close to that found in another study conducted in a fragment of Semideciduous Forest (25 species on 40 phorophytes) in the lower section of the Sinos River Basin (Barbosa et al., 2015). In the Gallery Forest in the central depression of Rio Grande do Sul, Giongo and Waechter (2004) recorded an intermediate richness (50 species on 60 phorophytes). In rural area of Caraá, in a fragment of 60 hectares of predominantly Dense Secondary Humid Forest with some elements of Mixed Humid Forest, Barbosa et al. (2015) found a richness around 2.5 times smaller (30 species on 40 phorophytes) than that of the riparian forest in the same municipality.

Were recorded 81%, 81% and 87% of the total species of the fragments in Caraá, Taquara and Campo Bom, respectively, considering the estimated total. The richness estimates provided an anticipation for the minimum numbers expected (Colwell et al., 2004; Pincheira-Ulbrich et al., 2016) and generated information that made the data (Gotelli and Colwell, 2001; Shimadzu, 2018) obtained in this study comparable with other floristic inventories that adopted the same analytical approach.

The prevalence of characteristic holoepiphytes was approximately 10 times higher than other categories. It was also reported in studies conducted in Dense Humid Forest (Blum et al., 2011; Barbosa et al., 2015). Mixed Rain Forest (Kersten and Silva, 2002; Furtdo and Manini, 2016), Semideciduous Seasonal Forest (Bataghin et al., 2010; 2012; Barbosa et al., 2015), as well as in Sandy Coastal Forest (Staudt et al., 2012) and Gallery Forest (Waechter and Giongo, 2004), among others. More specialized and diversified vegetative adaptations favor a more generalized distribution of characteristic holoepiphytes in the different forest formations (Staudt et al., 2012).

Except for accidental holoepiphytes, 90% of the total species in the present study were included in six families (Aspleniaceae, Bromeliaceae, Cactaceae, Orchidaceae, Piperaceae and Polypodiaceae). In Brazil, 91% of epiphytes species are usually concentrated in 10 families, among which are Bromeliaceae, Orchidaceae, Piperaceae and Polypodiaceae (Kersten, 2010). From the total of recorded species, 72% are concentrated only into the Bromeliaceae, Orchidaceae and Polypodiaceae families. These three families are considered to have the greatest epiphytic richness for different biomes (Madison, 1977; Freitas et al., 2016), and they are dominant in the Neotropics (Gentry and Dodson, 1987; Barthlott et al., 2001; Taylor et al., 2021) and in Brazil (Waechter, 1998; Kersten and Silva 2001; Borgo and Silva, 2003; Kersten, 2010). The survival of plants in the epiphytic environment is restricted to the specializations inherent to a limited number of families (Madison, 1977; Gentry and Dodson, 1987; Wagner et al., 2015).

Orchidaceae, which was the richest family in Caraá, is considered to be the most important, because it presents a large number of epiphytic species (Figure 2). However, orchids are highly susceptible to biodiversity loss and may become in critical danger or extinct due to habitat loss (Cardoso et al. 2016). The orchid species have adaptations to epiphytism (Blanco et al., 2021), such as the presence of pseudo bulbs and velamen, and physiological mechanisms that reduce excessive water loss (Zhang et al., 2018). The Atlantic Forest is a center of diversity for Orchidaceae (Ramos et al., 2021), and the Dense Humid Forest is one of its phytophysiognomies that occur in Rio Grande do Sul.

The epiphyte richness reinforces the preservation character of the Sinos River watersheds (Rocha-Uriartt et al., 2015; 2016),

considering that the number of species has an inverse relationship to vegetation degradation (Johansson, 1989) and that forests that are poor in epiphytes show a high degree of disturbance (Wolf, 2005). Exploratory extraction is responsible for the decrease of orchids in nature (Moraes et al., 2009), especially in areas close to cities (Freitas and Jasper, 2001). The riparian forest of the Sinos River source is an area with little human impact and many orchid species. On the other hand, fragments of the middle and lower sections, which are located in an urban and industrial matrix, showed a reduced number of Orchidaceae (5 and 2 species, respectively). The maintenance of these species within the natural ecosystem is relevant because orchids are great indicators of environmental quality (Dorneles and Trevelin, 2011).

Sinningia douglasii and *Isochilus linearis* are species that were recorded in the Caraá riparian forest, whose distribution is influenced by human interference. Additionally, their occurrence is restricted to preserved places, thus making them indicators of conserved environments (Bonnet et al., 2011).

Tillandsia was one of the richest genus across the three sites studied. It includes plants widely distributed in the Neotropics, where the occurrence of species is independent of altitude and vegetation type (Versieux and Wendt, 2007). The absorption of water and nutrients in species of this genus is optimized for scales and trichomes that cover the leaf blades (Vanhoutte et al., 2017). These adaptations to epiphytism enable *Tillandsia* species to occupy the drier regions of the phorophyte, such as the canopy of trees (Sudgen, 1981), thus contributing to the widespread occurrence of *Tillandsia aeranthos*, *Tillandsia geminiflora*, *Tillandsia recurvata* and *Tillandsia usneoides*, common in the fragments studied.

At the Caraá site, *Vriesea incurvata* showed a higher VI, and other tank bromeliads, other members of the *Aechmea*, *Vriesea* and *Nidularium* genus, totaled 25% of this value in the fragment's community. In the middle and lower sections of the Sinos River, the total VI of tank type bromeliads was less than 2.5% (*Vriesea friburgensis* and *Vriesea gigantea*). The occurrence of tank bromeliads largely restricted to environments with better conservation, in late stages of epiphytic succession (Bonnet et al., 2011) and, consequently, with better environmental quality. Additionally, other studies have reported the prevalent occurrence of these plants in Dense Humid Forest, also linking it to areas with higher rainfall (Neves et al., 2020). Unlike the present

study, in Caraá, Barbosa et al. (2015) have reported *Microgramma squamulosa* and *Pleopeltis pleopeltifolia* as the two most important species, thus reinforcing the secondary feature of this other forest fragment.

Pleopeltis pleopeltifolia showed a higher VI in Taquara and it was the third most important species in Campo Bom. *Microgramma squamulosa* was the species with the second highest VI at both sites and the sixth in Caraá. Also on the lower section of the Sinos River Basin, in Semideciduous Seasonal Forest, *Microgramma squamulosa* and *Pleopeltis pleopeltifolia* have presented the first and the fifth highest VI (Barbosa et al., 2015). Giongo and Waechter (2004) have recorded *Pleopeltis pleopeltifolia* and *Microgramma squamulosa* in Rio Grande do Sul Gallery Forest, ranking as the second and 10th highest VI. These two species are classified as Polypodiaceae that includes most epiphytic ferns, which have adapted to survive in drought (Dubuisson et al., 2009) and they occupy the phorophyte at a pioneer stage of epiphytic succession (Bonnet et al., 2011).

Microgramma squamulosa is considered to be one of the most common species in epiphytic environments, occurring on trees of primary and secondary forest (Sehnem, 1970; Barbosa et al., 2015). The adaptations of *Microgramma squamulosa* to epiphytism mainly involve the presence of sclerified tissue and an increase in the number of stomata and leaf size, due to variations in luminosity (Rocha et al., 2013).

Rhopsalis teres showed a higher VI in the Campo Bom riparian forest and occurred in the other study sites as well. The species is widely distributed across different vegetation formations in Rio Grande do Sul, occurring mainly in pioneer formations, such as in the peat forests and riparian forests (Bauer and Waechter, 2011). This species has presented with wide distribution along the Taquari River Basin (Brussel and Jasper, 2005), the fourth largest VI in the phytosociological inventory by Barbosa et al. (2015) and the 27th in that conducted by Giongo and Waechter (2004), in the same state. All species with the highest importance across the three sites were classified as characteristic holoeiphytes, unlike accidental holoeiphytes, which presented the lowest values (<0.9%), thus indicating restricted distribution, probably due to the absence of specific adaptations for epiphytism.

As well as for the total richness, the sites most similar to each other, in terms of composition, were Taquara and Campo Bom. Both comprise the Sinos River riparian forest, are geographically

close in location, belong to the same vegetation type and shared 12 species. The specific composition of Caraá set this fragment apart from the others, due to the presence of 58 unique species, thus indicating a high floristic heterogeneity in the region's riparian forest.

In terms of conservation, *Cattleya intermedia* (vulnerable) and *Hatiora rosea* are included in the official list of endangered flora species in Brazil. However the data for the classification of *Hatiora rosea* are considered to be insufficient (Martinelli and Moraes, 2013). Thirteen of the species surveyed, of which nine are Bromeliaceae, two are Orchidaceae, one is Cactaceae and one is Begoniaceae, were included in the Final List of Endangered Flora Species of Rio Grande do Sul, in the "endangered" and "vulnerable" categories (Tables 1, 2 and 3). From the total species identified in the Caraá riparian forest, 16% are endangered, and most of these are classified as Bromeliaceae. At this site *Hatiora rosea* was also recorded, and this is the only species native of the genus to Rio Grande do Sul (Bauer and Waechter, 2011) and it is endangered in the state, in the "vulnerable" category. *Vriesea* was the richest genus in the Caraá site, and is considered the first among the 15 most important genera in relation to the number of non-endangered species, but with conservation interest or research (Martinelli and Moraes, 2013).

Conclusion

The devastation of the Atlantic Forest has intensified in recent decades and is accountable for the simplification of forests (Ribeiro et al., 2009). The botanical parameters obtained support the idea that the riparian forest of Caraá presents a more complex community structure, with a higher degree of conservation and better environmental quality, when compared to the Taquara and Campo Bom sites. Given the scenario of fragmentation and heterogeneity of the riparian forests analyzed, improving the permeability of the matrix, thus fostering a connection between the fragments is a measure that needs to be considered in planning for biodiversity conservation in the Sinos River Basin.

Acknowledgement

The authors thank the Universidade Feevale infrastructure; to scholarships granted by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Code 001) for the first two and fourth authors and by Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS) to the third author. The last author is

supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (PQ-312908/2020-2).

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