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REGULAR PAPER

Functional patterns and species diversity of epiphytic vascular spore-producing plants in riparian forests with different vegetation structure from southern Brazil

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Background and aims – Functional patterns and the environmental influence over species traits are important tools for the conservation of riparian forests. Richness, diversity and functional structure of the epiphytic vascular spore-producing plant community (ferns and lycophytes) were studied and compared at the superior (site 1), middle (site 2) and inferior (site 3) parts of Sinos River, which is one of the most important and impacted rivers in southern Brazil. We tested the hypotheses that functional patterns of epiphytic vascular spore-producing plant assemblages differ among sites; that richness, canopy openness, density, and tree basal area influence the epiphytic functional structure and that functional traits that favor species tolerance to water deficit will be more abundant in areas with simplified surrounding vegetation structure.
Methods – All ferns and lycophyte species were recorded on 120 phorophytes (forty at each site). In order to compare environmental differences among sites we used the vegetation parameters taken at each sampling unit. For the functional analyses we used traits related to the ecological category, life form, leaf dimorphism, leaf division, position of leaves, presence and amount of leaf trichomes or scales and the presence of succulent rhizome.
Key results – A total of 32 epiphytic species of vascular spore-producing plants were surveyed. The majority of species recorded were holoepiphytes, had a creeping rhizome, and monomorphic, divided and erect leaves. Functional diversity, species diversity and functional redundancy were higher at site 1. The two other sites were statistically equivalent regarding these parameters. At site 1, phorophytes had the highest species richness and the vegetation as a whole showed a higher density and total basal area.
Conclusions – We observed that functional structure and richness of epiphytic vascular spore-producing plants change according to the forest stand structure, highlighting the importance of preserving the riparian forest at site 1 and the need for restoration measures at sites 2 and 3.

Key words – Functional diversity, functional traits, community ecology, disturbance gradient.

INTRODUCTION

The natural vegetation alongside a river is named riparian forest and its main function is to maintain the watercourse, local biodiversity and soil conditions (Gregory et al. 1991). In these environments, temperature is milder and humidity is higher (Rodrigues & Shepherd 2000). According to floristic surveys in riparian forests the heterogeneity in species composition and structure is the result of interacting biotic and abiotic components (Ribeiro-Filho et al. 2009).

The degradation of riparian forests caused by agriculture and population settlements drives the loss of environmental quality in watersheds (Barrella et al. 2000). The intensity of the disturbance may have a direct effect on specific diversity, because environmental variation in these ecosystems decreases habitat stability (Biswas & Mallik 2010). The spatial dimensions of the riparian forest reflect the complexity of geomorphic surfaces at the river valley. Moreover, the presence of environmental gradients across riparian forests is responsible for the formation of functionally distinct ecosystems, with a great variation in richness and vegetation composition among riverine successional stages (Gregory et al. 1991). The different irradiance patterns caused by vegetation struc-

ture and atmospheric conditions are responsible for changes in vegetation dynamics as well (Maciel et al. 2002).

Vascular spore-producing plants (ferns and lycophytes) are seedless plants, whose reproduction success depends on high humidity levels (Page 2002). Fern richness is influenced by temperature, precipitation and relative humidity, so anthropogenic changes in the physical environment have a negative effect on their diversity (Silva et al. 2011, 2014). Despite being abundant in humid environments, these plants show structural and physiological characteristics that enable them to endure water deficits and they are widely adapted to the epiphytic environment as well (Dubuisson et al. 2009). In fact, about 20% of seedless vascular plants are epiphytes (Moran 2008).

Because epiphytes are sensitive to alterations, whether anthropogenic or natural, they are considered good indicators of environmental quality (Engwald et al. 2000). The survival of these plants in the epiphytic environment is regulated by adaptations related to tolerance to hydric stress (Page 2002), such as succulent rhizomes and trichomes on the leaves (Hietz & Briones 1998). Morphological and ecophysiological characteristics are considered functional traits for their role in generating a response to environmental factors as well as their effects on the ecosystem (de Bello et al. 2010).

Then, the knowledge on how traits interact with species diversity and ecosystem disturbances is an important tool for the conservation of natural resources (Díaz et al. 2007) and can be integrated as an ecological indicator of forest changes (Koch et al. 2013). Functional analyses can also enable the understanding of environmental resilience and demonstrate how species loss influences ecosystem functions (Chazdon et al. 2007). Environmental gradients and among-species competition can select species traits, thus studies of environment-functional groups relationships allow us to better understand habitat changes (Kluge & Kessler 2007, Pillar et al. 2009).

There is an influence of the river on the epiphytic community structure in both flat lowlands and steep mountain slopes (Kersten et al. 2009). However, the knowledge on how the functional structure is acting on these plants across an environmental gradient is still missing. This study aimed to ascertain and compare the functional structure of the epiphytic vascular spore-producing plants communities of the riparian forest along Sinos River, which is one of the most important and impacted rivers in the State of Rio Grande do Sul, southern Brazil. We tested the hypotheses: (1) that species richness, diversity and functional structure of epiphytic ferns assemblages differ among sites; (2) that vascular spore-producing plants richness, canopy openness and density, and tree basal area influence the functional structure of ferns and lycophytes assemblages in riparian forests; and (3) that functional traits that favor species tolerance to water deficit will be more abundant in areas with simplified surrounding vegetation structure.

MATERIALS AND METHODS

Study sites

The study was carried out in the Sinos River Basin (SRB), located in northeast Rio Grande do Sul, southern Brazil. The regional climate is Cfa according to Köppen-Geiger classification, meaning mesothermic humid with no dry period (Peel 2007).

We selected three riparian forest patches, one in each part of Sinos River: Site 1 is located in Caraá, (29°42′25.0″S 50°17′27.8″W, 560 m a.s.l.), close to the source of the river. Mean temperature is 18.9°C and the annual rainfall is

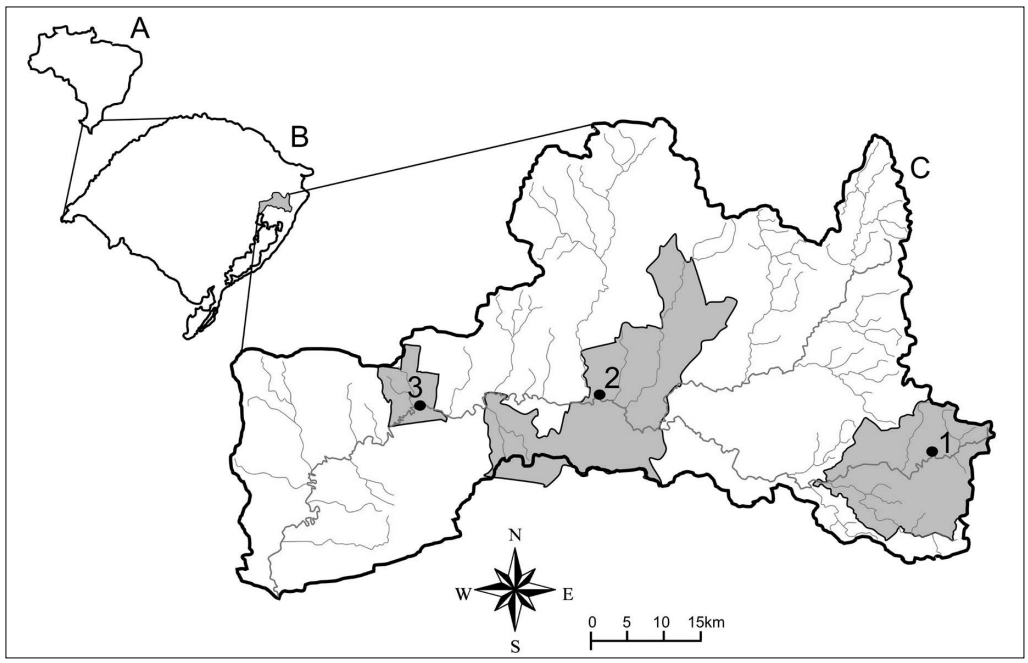

Figure 1 – Location of Sinos River Basin in Brazil (A) and in Rio Grande do Sul State (B). Study areas on the superior part of the river (1: Caraá), middle (2: Taquara) and on the inferior part (3: Campo Bom).

2540 mm. This riparian forest patch is more than 50 m wide and it is situated in a slope of rugged terrain. The region is a rural area in an advanced regeneration stage (CONAMA 2012). Site 1 has several conditions that sustain a higher richness of vascular epiphytes, as vegetation, climate and air quality, as shown by a previous study (Rocha-Uriartt et al. 2015). Site 2 is situated in Taquara (29°40′46.8″S 50°45′57.0″W, 57 m a.s.l.), at the middle part of Sinos River. Mean annual temperature is 20.9°C and the annual rainfall is 1367 mm. This riparian forest patch has a width of less than 30 m and it is inserted in a suburban matrix, with farming and cattle raising practices. Its regeneration stage is intermediate (CONAMA 2012) and it is located 37.4 km far from site 1. Site 3 is located in Campo Bom (29°40′54″S 51°3′35″W, 29 m a.s.l.), at the inferior part of the river. Its mean annual temperature is 19.6°C and the annual rainfall is 1817 mm. This patch is also less than 30 m wide; however it is placed in an urban/industrial area. It is at an intermediate regeneration stage (CONAMA 2012) and the distance between sites 2 and 3 is of 26.8 km (fig. 1).

Data collection

In each patch we traced a 200 meters-long transect parallel and up to 10 m far from the river, with sampling sites placed at every 20 m along that line. In each sampling site we selected four phorophytes (Cottam & Curtis 1956) with a diameter at breast height (dbh) of ≥ 10 cm. A total of forty trees were sampled per site, distributed in ten sampling units. In a radius of 5 m from each phorophyte we surveyed all trees with a dbh larger than 5 cm to estimate height, density and basal area of the surrounding trees. Hemispheric photographs were taken during the winter and summer of 2013 in each sampling site using a Sony H5 camera and Raynox Digital fisheye lenses (DCR-CF 85 Pro). Pictures were taken with tripods, 1.5 m above the ground, facing north as recommended by Garcia et al. (2007). For obtaining canopy openness we analysed the images on the software GAP light Analyzer 2.0 (Frazer et al. 1999), calibrated for the geographic coordinates and altitude at each site.

We recorded all vascular spore-producing species in the 120 phorophytes (forty at each site). We surveyed epiphytes with the help of binoculars (BUSHNELL® - 96m AT 1000M) and by climbing the phorophytes when needed. Epiphytic species identification was made through specialized bibliography, herbarium consultations and with the help of specialists, when necessary. Scientific names were checked in The International Plant Names Index (IPNI 2014) and The Brazilian Flora Species List (Rio de Janeiro Botanical Garden 2016). We used the classification system proposed by Smith et al. (2006). Representative fertile specimens were deposited at PACA (herbarium acronyms according to Thiers continuously updated).

Species were classified regarding their phorophyte according to Benzing (1990). We assigned each species cover notes according to their specific abundance (Kersten & Waechter 2011). In order to compare environmental differences among sites we used the vegetation parameters taken at each sampling unit: species richness and total cover notes of vascular spore-producing plants, degree of canopy openness, tree height, and density and basal area of the trees. Estimates of species richness were calculated using the nonparametric estimator *Jackknife* 1 through the software EstimateS 9.1.0 (Colwell 2013).

Functional traits

We categorized the functional traits through in situ and herbarium observations as well as specialized bibliography. Traits were selected according to Cornelissen et al. (2003) and Pérez-Harguindeguy et al. (2013) and classified as: ecological category (type of epiphyte: holoepiphyte or hemiepiphyte), life form (rosette plants or creeping rhizome), leaf dimorphism (monomorphic or dimorphic), leaf division (entire or divided), position of leaves (erect or pending), presence and amount of leaf trichomes or scales and presence of succulent rhizome. In total, nine traits were used in the functional analyses. Traits related to life form, position and leaf division are associated to light capture. Leaf dimorphism is related to reproductive functions and the presence of trichomes, scales and succulent rhizome are mechanisms that are linked to water and nutrient uptake.

Data analyses

For the data analyses we assembled three matrices: matrix W – describing sample units by species presence/absence; matrix B – describing species by their functional traits and matrix E – describing sample units by the environmental variables (canopy openness, total basal area and density of tree individuals in the sampling unit). Functional analyses followed Pillar et al. (2009) using the software SYNCSA (Pillar 2013). These analyses generated a matrix of sample units per traits weighted by species at the respective sample units (matrix T), as well as measures of Rao functional diversity (Rao 1982), species diversity (Sipman) and functional redundancy (difference between specific and functional diversities). For a better visualization of functional patterns, we subjected the matrix T to a Canonical Correspondence Analysis (CCA) using the software CANOCO (ter Braak 1986, ter Braak & Šmilauer 2002) after an automatic selection of the environmental variables that better explained the data variation.

Mean trait values were compared through Shapiro-Wilk and Levene tests in order to characterize the functional traits pattern of each site. Species diversity, functional diversity and functional redundancy results, as well as the height of phorophytes and dbh were compared through Kruskal-Wallis, followed by the Dunn's test. Data comparison on the vegetation structure of each site was made through Analysis of Variance (ANOVA), followed by Tukey test for tree height and canopy openness, and through Kruskal-Wallis followed by Dunn's test for tree basal area, species richness of vascular spore-producing plants, cover note and density of tree individuals. Data from matrix T were compared by using Kruskal-Wallis test, followed by Dunn's test. We used a 5% probability on the software Statistica 10.0.

RESULTS

A total of 31 species of ferns and one of lycophytes was recorded. Species richness was higher at site 1 (n = 29), followed by sites 2 and 3 (n = 6 and 8, respectively). The rarefaction curve in sites 1, 2 and 3 tended to reach an asymptote, yielding a total estimate of 37, 7 and 10 species, respectively, for each site (fig. 2).

The average height of the phorophytes in site 1 (7.1 ± 3.6 m) was significantly higher (H = 10.96; $P < 0.01$) than heights recorded in site 2 (5.9 ± 2.3 m) and 3 (5.8 ± 2.0 m). On average, dbh of the phorophytes in site 1 (17.2 ± 37.1 cm) and 2 (14.7 ± 11.4 cm) was statistically higher (H = 12.07; $P < 0.01$) than that observed in site 3 (12.2 ± 9.8 cm). The highest phorophyte (31 m) was recorded in site 1, with 130 cm of dbh.

Only three species from the Polypodiaceae family occurred in all the three sites. The majority of species recorded in the three sites were holoepiphytes, had a creeping rhizome, and monomorphic, divided and erect leaves (table 1). Functional diversity, species diversity and functional redundancy were higher at site 1. The two other sites were statistically equivalent regarding these parameters (table 2).

The total inertia (variation) of the CCA was 0.46, with eigenvalues of 0.14 for axis 1 and 0.04 for axis 2. The CCA evidenced a clear distinction between site 1 (right side of the diagram) and the other two sites regarding species trait means and the environmental variables. Greater mean values of rosette plants were related to site 1 and species with creeping rhizome were more related to site 3 (fig. 3). The statistic comparisons of sites based on functional traits composition of vascular spore-producing plants demonstrated a significant increase of rosette plants in site 1, and of plants with creeping rhizome in sites 2 and 3. Plants with dimorphic leaves were statistically more frequent in site 2 when compared to sites 1 and 3 (table 3). Also at site 1, phorophytes had the highest species richness and the vegetation as a whole showed a higher density and total basal area. Mean canopy openness was the highest at site 2 (fig. 4).

DISCUSSION

Species richness, diversity and functional structure of vascular spore-producing plants indeed differed among sites, but only when comparing the site 1 (where all parameters were higher) with the other two sites, which also had different forest structure. Moreover, forest structure influenced functional trait composition of ferns and lycophytes in riparian forests.

High functional diversity comes from high species diversity (Hooper & Vitousek 1997) as found at site 1, bringing up the importance of the headwaters to ecosystem functions in the SRB. The sites with the lowest functional diversity (2 and 3) are located in areas in which the riparian forest is less than 30 meters wide and at an intermediate regeneration stage. Moreover, the areas with greatest human impact had lower species and functional diversity. The vegetation on site 1 is oldest and more conserved, and this might be also optimizing diversity in site 1, once epiphyte colonization is favored on larger, older phorophytes (Flores-Palacios & García-Franco 2006). Other parameters, as precipitation and altitude, may also be responsible for higher species richness on site 1. Rocha-Uriartt et al. (2015) evaluated the environmental quality of sites 1, 2 and 3 from an integrated approach based on botanical, meteorological and genetic parameters.

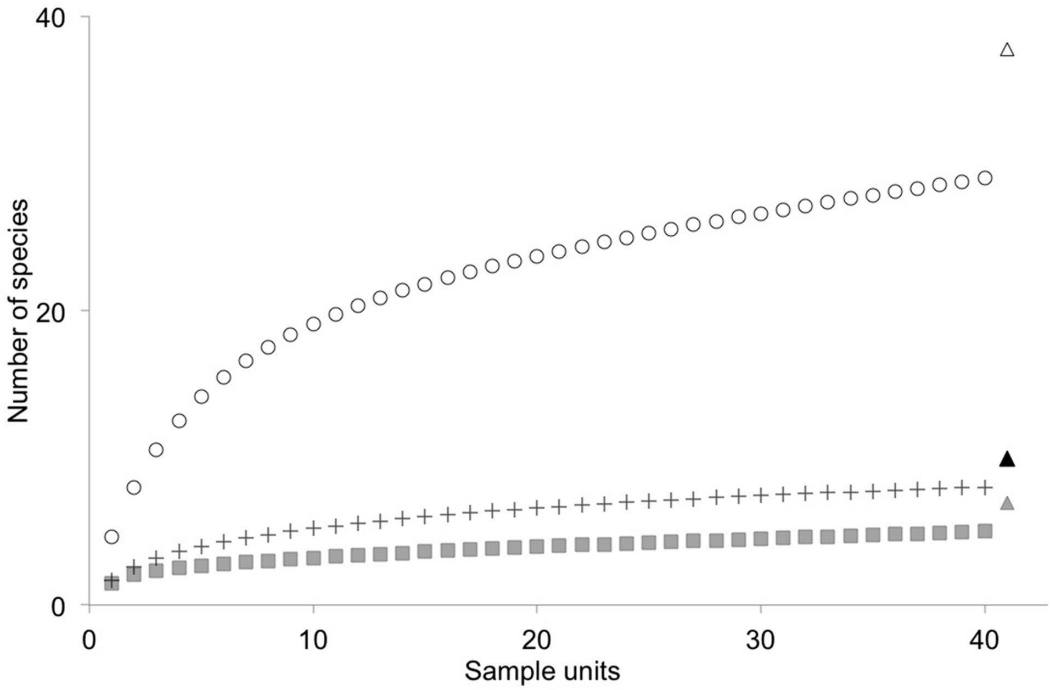

Figure 2 – Rarefaction curves and species richness estimator (*Jackknife* 1: triangles; site 1: white; site 2: black; site 3: gray) for sites 1 (○), 2 (+) and 3 (■).

Table 1 – Floristic survey and functional traits of ferns and lycophyte epiphytic species occurring in the sites of Caraá (1), Taquara (2) and Campo Bom (3).
Classification (CL): holoepiphyte (HO) or hemiepiphyte (HE); Ecological category (EC): characteristic holoepihyte (CH), accidental holoepihyte (AH), facultative holoepihyte (FH) or secondary hemiephiphyte (SH); form of life (FL): creeping rhizome (RE) or rosette plants (RO); leaf: monomorphic (MO) or dimorphic (DM), entire (EN) or divided (DV), pending (PN) or erect (ST); leaf cover by scales (SC) and trichomes (TR): sparse (SP) or dense (DE); presence (PR) of succulent rhizome (RS).

Family/species	Sites			CL	EC	FL	Leaf			SC	TR	RS
	1	2	3									
ASPLENIACEAE												
Asplenium claussenii Hieron.	X			HO	AH	RO	MO	DV	ST	SP	-	-
Asplenium gastonis Fée	X			HO	CH	RO	DM	DV	PN	-	-	-
Asplenium oligophyllum Kaulf.	X			HO	CH	RO	MO	DV	PN	SP	-	-
Asplenium scandicinum Kaulf.	X			HO	CH	RO	MO	DV	PN	-	-	-
Hymenasplenium triquetrum (N. Murak. & R.C.Moran) L. Regalado & Prada	X			HO	AH	RE	MO	DV	ST	SP	-	-
BLECHNACEAE												
Blechnum acutum (Desv.) Mett	X			HE	SH	RE	DM	DV	PN	-	-	-
Blechnum cordatum (Desv.) Hieron.	X			HO	AH	RO	DM	DV	ST	SP	-	-
DRYOPTERIDACEAE												
Elaphoglossum sellowianum (Klotzsch ex Kuhn) T.Moore	X			HO	CH	RE	DM	EN	ST	SP	-	-
Elaphoglossum vagans (Mett.) Hieron.	X			HO	CH	RE	DM	EN	ST	-	-	-
Lastreopsis amplissima (C.Presl) Tindale	X			HO	AH	RE	MO	DV	ST	SP	SP	-
Mickelia scandens (Raddi) R.C.Moran *et al*.	X			HE	SH	RE	DM	DV	PN	-	-	PR
Rumohra adiantiformis (G.Forst.) Ching	X		X	HO	AH	RE	MO	DV	ST	SP	SP	-
HYMENOPHYLLACEAE												
Vandenboschia radicans (Sw.) Copel.	X			HE	SH	RE	MO	DV	PN	-	-	PR
LYCOPODIACEAE												
Phlegmariurus heterocarpon (Fée) Holub	X			HO	CH	RO	MO	EN	PN	-	-	-
POLYPODIACEAE												
Campyloneurum austrobrasilianum (Alston) de la Sota	X		X	HO	CH	RE	MO	EN	PN	-	-	-
Campyloneurum nitidum (Kaulf.) C.Presl	X		X	HO	CH	RE	MO	EN	ST	-	-	PR
Microgramma squamulosa (Kaulf.) de la Sota	X	X	X	HO	CH	RE	DM	EN	ST	SP	SP	PR
Microgramma vacciniifolia (Langsd. & Fisch.) Copel.	X	X	X	HO	CH	RE	DM	EN	ST	SP	SP	PR
Niphidium crassifolium (L.) Lellinger	X	X		HO	FH	RE	MO	EN	ST	-	-	PR
Pecluma paradiseae (Langsd. & Fisch.) M.G.Price	X			HO	AH	RE	MO	DV	ST	-	SP	-
Pecluma pectinatiformis (Lindm.) M.G.Price	X			HO	FH	RE	MO	DV	PN	-	SP	-
Pecluma recurvata (Kaulf.) M.G.Price	X			HO	CH	RE	MO	DV	PN	-	SP	-
Pleopeltis astrolepis (Liebm.) E.Fourn.	X			HO	CH	RE	MO	EN	ST	-	-	-
Pleopeltis hirsutissima (Raddi) de la Sota	X	X	X	HO	CH	RE	MO	DV	ST	DE	DE	-
Pleopeltis macrocarpa (Bory ex Willd.) Kaulf.	X			HO	CH	RE	MO	DV	ST	SP	SP	-
Pleopeltis pleopeltidis (Fée) de la Sota	X			HO	CH	RE	MO	DV	ST	SP	-	-
Pleopeltis pleopeltifolia (Raddi) Alston		X	X	HO	CH	RE	MO	DV	ST	SP	SP	-
Pleopeltis minima (Bory) J.Prado & R.Y.Hirai		X		HO	CH	RE	MO	DV	ST	SP	DE	-
Serpocaulon catharianae (Langsd. & Fisch.) A.R.Sm.	X			HO	CH	RE	MO	DV	ST	SP	-	PR
Serpocaulon latipes (Langsd. & Fisch.) A.R.Sm.	X			HO	CH	RE	MO	DV	ST	-	-	PR
PTERIDACEAE												
Vittaria lineata (L.) Sm.	X			HO	CH	RE	MO	EN	PN	-	-	-
THELYPTERIDACEAE												
Thelypteris hispidula (Decne.) C.F.Reed			X	HO	AH	RO	MO	DV	ST	-	SP	-

Table 2 – **Mean values ± standard deviations for species diversity, functional diversity and functional redundancy in the sites of Caraá (1), Taquara (2) and Campo Bom (3)**.
H: Kruskal-Wallis's test; *P*: probability. Different letters in the same column indicate statiscally significant different values at 5%, tested through the Dunn's test.

Sites	Species Diversity	Functional Diversity	Functional Redundancy
1	0.9 ± 0.1^{a}	0.5 ± 0.1^{a}	0.4 ± 0.1^{a}
2	0.6 ± 0.2^{b}	0.3 ± 0.1^{b}	0.2 ± 0.1^{b}
3	0.6 ± 0.2^{b}	0.3 ± 0.1^{b}	0.3 ± 0.1^{b}
H	14.93	12.74	12.12
P	< 0.01	< 0.01	< 0.01

Table 3 – **Mean values and standard deviations (SD) of plant traits studied at the sites of Caraá (1), Taquara (2) and Campo Bom (3)**.
H: Kruskal-Wallis's test; *P*: probability. Different letters in the same traits indicate statistically significant different values at 5%, tested through the Dunn's test.

Trait	Site	Mean	SD	H	*P*
Holoepiphyte	1	0.17	0.01	14.27	0.07
	2	0.19	0.00		
	3	0.19	0.00		
Rosette plants	1	0.27^{a}	0.17	20.46	< 0.01
	2	0.00^{b}	0.00		
	3	0.00^{b}	0.00		
Creeping rhizome	1	0.15^{b}	0.02	27.5	< 0.01
	2	0.10^{a}	0.00		
	3	0.20^{a}	0.00		
Dimorphic leaves	1	0.21^{a}	0.08	13.2	< 0.01
	2	0.01^{b}	0.04		
	3	0.10^{ab}	0.21		
Divided leaves	1	0.18	0.05	3.98	0.14
	2	0.19	0.09		
	3	0.13	0.07		
Erect leaves	1	0.16	0.03	1.71	0.43
	2	0.19	0.05		
	3	0.18	0.05		
Pending leaves	1	0.16	0.07	0.82	0.67
	2	0.16	0.09		
	3	0.18	0.08		
Scales	1	0.17	0.04	1.14	0.57
	2	0.19	0.08		
	3	0.15	0.08		
Trichomes	1	0.13	0.07	4.5	0.11
	2	0.21	0.09		
	3	0.14	0.09		
Succulent rhizome	1	0.10	0.08	0.66	0.72
	2	0.11	0.15		
	3	0.17	0.16		

The authors verified that in the riparian forests at site 1 the precipitation was more intense and the air quality was better. Furthermore, these forests also had higher trees, which are able to support a greater epiphytic richness.

Besides showing lower values of species and functional diversity, sites 2 and 3 had also lower values of functional redundancy, which can result in lower stability for these communities, since there would be fewer species that might substitute the ones that were extinct, for example. Furthermore, some ecosystem functions or processes may be affected in the absence of some species (Yachi & Loreau 1999).

Considering the estimated total species richness, around 78%, 85% and 80% of the total species of sites 1, 2 and 3, were recorded respectively. Richness estimates provides the anticipation of minimum numbers expected (Colwell et al. 2004) and makes the data obtained comparable with other floristic inventories that adopted the same analytical approach (Gotelli & Colwell 2001).

The three species that were common to all sites (*Pleopeltis hirsutissima*, *Microgramma squamulosa* and *M. vacciniifolia*) belong to Polypodiaceae, which is one of the most frequent families in the epiphytic environment due to their vegetative adaptations (Johansson 1974, Gentry & Dodson 1987, Rocha et al. 2013). These species have traits that allow a better settlement in the phorophyte, hence their wider occurrence. They also have leaves covered by scales and trichomes, which reduce the effects of excessive radiation and, along with the succulent rhizome, are an important mechanism against desiccation (Körner 2003).

As hypothesized, functional traits that favor species tolerance to water deficit were more abundant in areas with simplified surrounding vegetation structure. At least 50% of the species in each site showed leaves covered by trichomes and/or scales. *Pleopeltis minima* is a species capable of water regulation through poikilohydry (Benzing 1990, as *Polypodium polypodioides*) and was exclusive to site 2, where the highest canopy openness was recorded. Plants submitted to arid environments have a thicker cover of trichomes and the presence of scales, which is mostly observed on the exposed parts of the lamina (Kluge & Kessler 2007). As an adaptation to the arid environment, where water supply is intermittent, epiphytes display xeromorphic characters (Benzing 1989), i.e. reduced size, whole leaves and creeping rhizome (Hietz 2010).

Site 1, the most humid and with the most closed canopy, had the highest frequency of rosette plants. This leaf disposition allows plants to retain more rainwater and leaf litter, thus creating a nutrient cycle of their own (Sharpe & Mehltreter

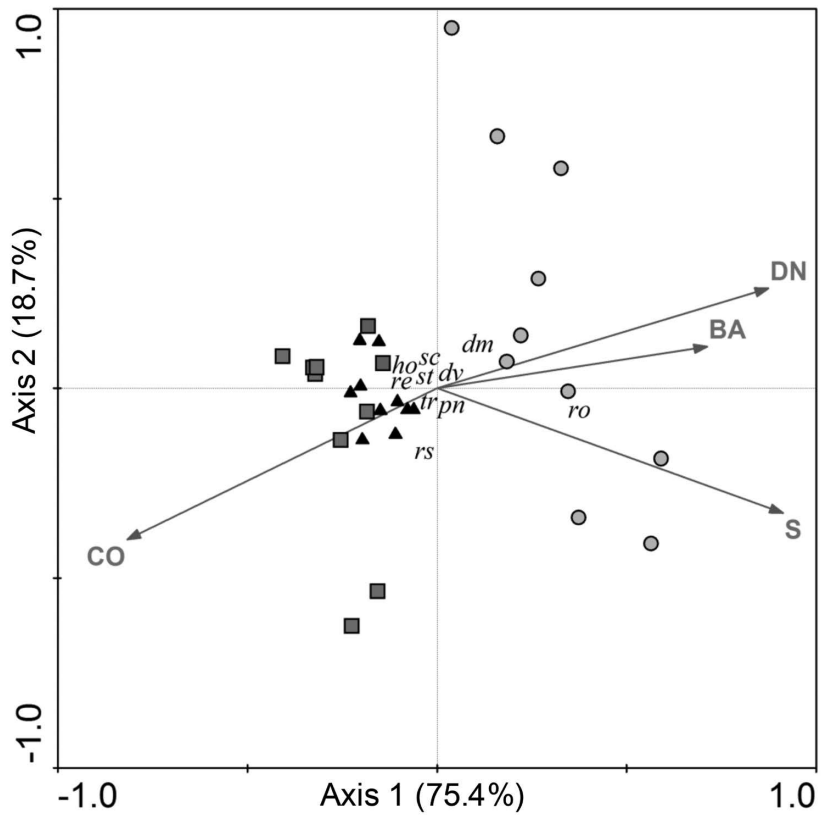

Figure 3 – Diagram of the Canonical Correspondence Analysis (CCA) of functional traits (*ho*: holoepiphytes; *sc*: leaf cover by scales; *tr*: leaf cover by trichomes; *st*: erect leaf; *dv*: divided leaf; *dm*: dimorphic leaf; *pn*: pending leaf; *re*: creeping rhizome; *ro*: rosette plants; *rs*: succulent rhizome) and environmental variables (S: species richness; CO: canopy openness; BA: total basal area; DN: density of tree individuals in the sampling unit) in sites of Caraá (●), Taquara (■) and Campo Bom (▲). Length of the red arrows indicated the relative importance of the factor explaining variation in the vascular spore-producing plants communities.

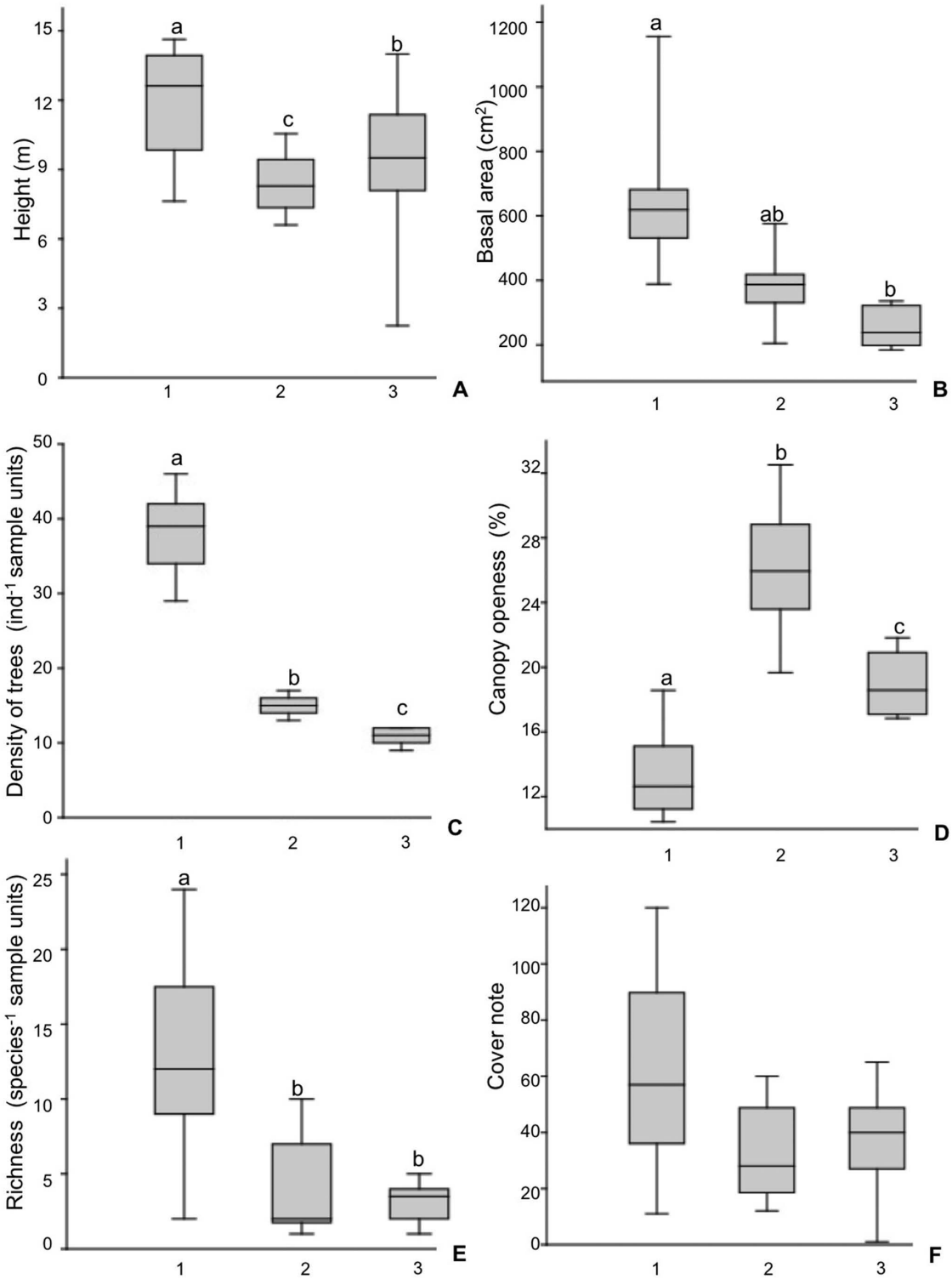

Figure 4 – Arboreal vegetation structure of Caraá (1), Taquara (2) and Campo Bom (3) sites. H: Kruskal-Wallis's test; F: Levene's test; *P*: probability. Different letters in the same graphic indicate statistically significant different values at 5%, tested through the Dunn's or Tukey's tests. A, height (F = 12.07; $P < 0.01$); B, basal area (H = 9.9; $P = 0.007$); C, density (H = 25.97; $P < 0.01$); D, canopy openness (F = 45.61; $P < 0.001$); E, species richness (H = 13.68; $P = 0.001$); F, cover note (H = 4.59; $P = 0.10$).

2010). Sunlight absorption and substrate use are more efficient in this type of plant (Senna & Waechter 1997).

The presence of plants with morphologically different fertile and sterile leaves is a common trait in epiphytic ferns, observed in 25% of the species recorded here, as in *Microgramma*, *Blechnum* and *Elaphoglossum*. The reduction of the fertile leaf can be related to their function as well as lifetime (Kluge & Kessler 2007, Rocha et al. 2013, Mehltreter 2008). As a functional adaptation, the display of fertile leaves enables the wind passage, which is the dispersal agent of spores (Kramer et al. 1995). In this study, the presence of dimorphic ferns was more related to greater canopy openness (site 2).

Characteristics of the tree stratum of the studied riparian forests were more favorable to vascular spore-producing plants at site 1. Canopy openness, basal area and tree density, as well as epiphyte richness seem to be the most important factors characterizing each community, as evidenced on the canonical ordination diagram. Species richness, density and basal area were all directly related and the highest values were observed at site 1, which also had the most rosette plants. The relationship between epiphyte traits and vegetation parameters, and the presence of these traits itself, can be considered indicators of the state of the riparian forest conservation. However, studies on the interaction of vascular spore-producing plants and the phorophytes should be deepened. The epiphyte assemblages on a given tree are not simply a random sample of the local species pool (Laube & Zotz 2006). The age, size and species of the studied phorophytes have a significant effect on the epiphytic communities (e.g. Flores-Palacios & García-Franco 2006, Vergara-Torres et al. 2010, Zotz &Vollrath 2003).

In a fragment of 60 ha which was 2.5 km far from site 3, Quevedo et al. (2014) recorded fourteen species of epiphytic ferns in only eight phorophytes. This last study indicates that the sites in the middle and the lower parts of Sinos river (sites 2 and 3) are capable of showing higher species diversity and consequently higher functional diversity. In spite of this potential, we did not find an increase on richness in these sites, probably due to changes on forest structure and to the influence of the urban and industrial matrixes.

By using functional traits of vascular spore-producing plants, we were able to describe epiphytic assemblages of the riparian forest surrounding Sinos River. The most preserved part of the river showed the highest functional structure of epiphytic ferns and lycophytes assemblages, and we also observed differences in richness, species and functional diversity among sites, especially when comparing site 1 to the other two sites. Our results highlight the influence of the environment on the functional structure of the vegetation, as well as the need for conservation efforts to restore the stability of vascular spore-producing plants in the riparian forest at sites 2 and 3, e.g. elevating richness and diversity. Taking into account the fact that disturbances alter this stability (Biswas & Mallik 2010), the forest around the headwaters is still in good condition, with high species and functional diversity. Therefore, preserving the superior part of Sinos River is of paramount importance.

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