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Assessment of a subtropical riparian forest focusing on botanical, meteorological, ecological characterization and chemical analysis of rainwater

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ABSTRACT

Riparian forests are heterogeneous environments, in which epiphytes find ideal conditions to develop. These plants absorb the necessary nutrients for survival from the atmosphere, and their occurrence and distribution can be influenced by the quality and quantity of precipitation. The objective of this research was to perform an integrated analysis of botanical, meteorological and chemical precipitation parameters so as to compare them in fragments of the riparian forest in the lower (São Leopoldo-SL) and upper (Caraá-CA) stretches of the Rio dos Sinos Hydrographic Basin (RSHB), RS, Brazil. Rainwater was chemically analyzed, the community structure of epiphytic ferns was surveyed and the ecological characterization was evaluated through the Rapid Habitat Assessment Protocol (RHAP). The results showed that the chemical composition of rainwater is influenced by the environment of each area. In the upper stretch (CA), for instance, the main contribution is that of marine ions, while in the lower stretch (SL), the most impacting aspects are urbanization and industrialization. Similarly, the results depict a reduction of richness and a simplification of the community structure of epiphytic ferns and their environmental quality according to the RHAP categories, towards the base level of the RSHB. The integrated analysis, in which different methods were applied, proved to be an efficient tool to evaluate environmental quality. This analysis considers that a greater number of biotic and abiotic variables may be applied in different scenarios.

Keywords: ecological characterization, environmental analysis, epiphytic ferns, rainwater.

Análise integrada de mata ciliar subtropical focando parâmetros botânicos, meteorológicos e químicos da precipitação

RESUMO

Matas ciliares são ambientes heterogêneos, no qual, epífitos encontram condições ideais para se desenvolverem. Essas plantas, retiram da atmosfera os nutrientes necessários à sobrevivência, podendo ter sua ocorrência e distribuição influenciada pela qualidade e quantidade das precipitações. O objetivo foi realizar uma análise integrada de parâmetros

botânicos, meteorológicos e químicos da precipitação, a fim de compará-los em fragmentos de mata ciliar, nos trechos inferior (São Leopoldo-SL) e superior (Caraá-CA) da Bacia Hidrográfica do Rio dos Sinos (BHRS), RS Brasil. Para tal, foram realizadas análises químicas da água de chuva, analisada a estrutura comunitária das samambaias epifíticas e, avaliada a caracterização ecológica, através do Protocolo de Avaliação Rápida de Hábitats (PARH). Os resultados demonstraram que a composição química da água de chuva é influenciada pelo entorno de cada local estudado, sendo que do terço superior (CA), a maior contribuição é de íons de origem marinha, enquanto que, no trecho inferior (SL), a mesma é oriunda da urbanização e industrialização. Da mesma forma, ficou evidenciada a redução da riqueza e simplificação da estrutura comunitária de samambaias epifíticas e de sua qualidade ambiental de acordo com as categorias do PARH, em direção à foz da BHRS. A análise integrada aplicando diferentes métodos foi uma ferramenta eficiente para avaliar a sua qualidade ambiental, pois permite integrar um maior número de variáveis bióticas e abióticas, podendo ser aplicada em diferentes cenários.

Palavras-chave: água de chuva, análise ambiental, caracterização ecológica, samambaias epifíticas.

1. INTRODUCTION

Riparian forests are formations found along waterways (Mueller, 1996), characterized by high-environmental heterogeneity due to the physical and biological interactions in these environments (Rodrigues and Nave, 2000). One of its main functions is to protect the lotic environment and local biodiversity (Gregory et al., 1992). Despite being extremely important and being protected by specific legislation (Brasil, 2012), these environments suffer from fragmentation and edge effects, which end up increasing erosion; consequently, losing a biologically active soil layer, suffering silting and flooding, and to an invaluable loss of biodiversity (Joly et al., 2000).

Rainfall is one of the main processes for the removal of pollutants and chemical compounds from the atmosphere. The natural process of wet deposition results from the combination of chemical compounds and particles, which are removed by droplets or cloud droplets incorporated during precipitation (Seinfeld and Pandis, 2006; Souza et al. 2006; Herrera et al., 2009; Migliavacca et al., 2012). Therefore, rainwater reflects characteristics of the content of soluble gases and the particles of the atmosphere itself (Xiao et al., 2013; Wu et al., 2016).

Epiphytism is a harmonic interaction between two species, in which the epiphyte uses the host plant only as a carrier, removing the nutrients that are necessary for survival (Benzing, 1990). Epiphytes are good indicators of the environmental quality and their monitoring allows researchers to evaluate the effects of forest disturbance, since epiphytic richness has an inverse relation to environmental degradation (Engwald et al., 2000; Barthlott et al., 2001; Rocha-Uriartt et al., 2015). Ferns, which add to 29% of the species, constitute the second group of vascular plants in terms of epiphytic diversity (Kress, 1986). Thus, they absorb humidity from the air (Benzing, 1990), and may have their occurrence and distribution influenced by the quality and quantity of precipitations.

The Rio dos Sinos Hydrographic Basin (RSHB) is located in the lower northeast of the state of Rio Grande do Sul, southern Brazil. It covers an area of 3,820 km², in which 32 municipalities are distributed, with a population of approximately 1,343.558 inhabitants. Of this total, 94% are residents of urban areas, while only 6% reside in rural areas (IBGE, 2015). Its main watercourse is Rio dos Sinos, with its source in the municipality of Caraá, which has rural surroundings and it is less impacted. Rio dos Sinos is divided into upper, middle and lower stretches, transcending an urban-industrial matrix at its mouth, near the Jacuí delta

(PROSINOS, 2014). Kieling-Rubio et al. (2015) and Rocha-Uriartt et al. (2016) surveyed the environmental scenario of this basin, integrating botanical, meteorological and air genotoxicity parameters, based on which they demonstrated the existence of a decreasing gradient of environmental quality from the source to the mouth of Rio dos Sinos.

The objectives of the present study were: I) to evaluate the chemical composition of rainwater in a fragment of riparian forest of the lower stretch of Rio dos Sinos – one of the most important and impacted rivers of Rio Grande do Sul, Brazil; II) to determine the richness, composition and community structure of the epiphytic ferns in the same area; III) to perform ecological characterization in the same environment and IV) to compare the data obtained in I, II and III with the results obtained in the upper stretch of the river.

2. MATERIALS AND METHODS

2.1. Study area

The present study was carried out in a riparian forest fragment, in the lower stretch of the Rio dos Sinos, Rio Grande do Sul, Brazil. The Imperatriz Leopoldina Park (29°45'651'' S 051°07'928'' O, alt. 26 m), where the study area is located, is a Permanent Preservation Area (PPA) of 174 hectares inserted in the municipality of São Leopoldo and is one of the last remnant areas of urban vegetation. The vegetation in the area is altered by antropic action and irregular deposits of residues and, it is frequently inundated during periods of flood of Rio dos Sinos (São Leopoldo, 2016).

The lower stretch of the RSHB is considered a floodplain, with typical vegetation of plains. It presents smooth slopes, typical of lowland rivers, with the formation of meanders and zones of sedimentation. It is also the most anthropogenic stretch of the basin, with a great concentration of population and industries, and with frequent occurrence of erosion processes, deforestation, soil and water pollution (FEPAM, 2016).

The climate of the region is classified as Cfa, humid subtropical (C), with no dry season (f), and with average annual temperature of the hottest month exceeding 22°C (a), according to Köppen (Peel et al., 2007).

2.2. Rainwater

During the year (Sep/2013 to Aug/2014) rainwater was monitored in the study area and in the region of the source of the Rio dos Sinos. A rainwater collector was installed externally to the rainforest fragment of the Imperatriz Leopoldina Park, and the monthly precipitation data were obtained from meteorological bulletins provided by the automatic meteorological station - Cristo Rei Station (29°46'54.72" S; 51°09'11.93" O 33 m altitude). For comparison purposes, in the municipality of Caraá, near the source of the Rio dos Sinos, a mobile weather station (Davis Vantage PRO 2 VP USB NS) and another rainwater collector (29°44'15.88'' S; 50°21'34.52'' O 375 m altitude) were installed.

Rainwater samples were collected every 15 days, according to the methodology proposed by Migliavacca et al. (2005a). The collectors were always open, both in rainy and dry periods, to sample the atmospheric components of wet (rainfall) and dry deposition (dispersed gases and suspended particles) (Campos et al., 1998). The collectors consisted of a 21.5 cm diameter polyethylene funnel, 2 m away from the ground and covered with nylon mesh to prevent the entry of leaves and insects. The funnel was coupled to a 5 L collection vial and affixed to a metal rod.

After collection, the samples were sent to the laboratory of the Analytical Center of Feevale University for the chemical analyzes. In the unfiltered samples, pH was checked by using a digital pHmeter (Digimed DM-20, precision ± 0.01) and conductivity was surveyed by using a conductivity meter (Quimis Q795M2, precision ± 0.01), both previously calibrated. For

alkalinity, the analysis was performed according to APHA (2012). Subsequently, two aliquots, approximately 100 mL, were filtered through a cellulose ester membrane (0.22 μm pore and 47 mm diameter). In order to determinate major ions, the samples were preserved with chloroform and for the determination of metals, preserved with Supra Pure HNO_3 (MERCK) up to pH <2. Subsequently, these samples were stored at 4ºC, up to a maximum of 30 days, for chemical analysis.

The major ions were determined by ion chromatography (Dionex ICS 5000 with electrical conductivity detector). The Dionex IonPac ™ AS9-HC and CS12A columns were used for analyzing the anions (Cl^-, NO_3^- and SO_4^{2-}) and cations (Na^+, Ca^{2+}, Mg^{2+}, K^+ and NH_4^+), respectively. The limits of detection were: 0.01 mg L^{-1} for Cl^-; 0.05 mg L^{-1} for NO_3^-, SO_4^{2-}, Na^+, NH_4^+, K^+ and Ca^{2+} and Mg^{2+}.

The analysis of metals (Al, Pb, Cd, Cu, Cr, Fe, Mn) was performed by using the Atomic Flame Absorption Spectrometry method (SpectrAA 110, VARIAN). All of the calibration solutions were prepared by dilutions in ultrapure water of Titrisol (Merck) standards of each metal. Detection limits were 0.0005 μg L^{-1} for Al; 0.12 μg L^{-1} for Cd; 0.80 μg L^{-1} for Pb; 0.10 μg L^{-1} for Cu; 0.11 μg L^{-1} for Cr; 5.7 μg L^{-1} for Fe; 0.15 μg L^{-1} for Ni and 5.8 μg L^{-1} to Zn.

The data of the accumulated precipitation and chemical composition of rainwater were submitted to the Shapiro-Wilk normality test. The pH, Na^+ and Ca^{2+} and accumulated precipitation met the normality assumption. The t-test was used for comparison purposes. Further data did not meet normality, being compared by the Mann-Whitney test. These analyzes were conducted using PAST software.

The Enrichment Factor (EF) can be used to estimate the main sources of chemical components present in rainwater (Song and Gao, 2009). In the present study, two EF were used to estimate anthropic, marine and terrestrial crust sources. The Enrichment Factor for marine origin (EFm) (Equation 1) was used as the reference ion Na^+ and the marine ratio (Xi/Na^+) according to Akkoyunlu and Tayan (2003). For the Earth's Crust Enrichment Factor (EFc) (Equation 2) Al and the ratio (Xi/Al) were used as the reference ion, according to Taylor and McLennan (1995). The EF were calculated according to the equations below, where X is the concentration of the reference ion and Xi is the concentration of the ions of interest:

$$EFm = \frac{\left(X/_{Na^+}\right)sample}{\left(X/_{Na^+}\right)marine} \quad (1)$$

$$EFc = \frac{\left(X/_{Al}\right)sample}{\left(X/_{Al}\right)marine} \quad (2)$$

EF was interpreted using a scale according to Poissant et al. (1994) in which EF from 1 to 10 indicate marine or terrestrial crust contribution, consequently a low EF; EF> 10 to 500 moderate enrichment and over 500, extreme enrichments.

2.3. Floristic inventory and community structure

Throughout the riparian vegetation, a continuous transect of 800 meters, parallel to the course of the river was traced. An arboreal individual was selected at every 20 m, totaling 40 sample units in the fragment. These were divided into five ecological zones based on height (1 base, 2 low shaft, 3 high shaft, 4 inner cup, and 5 external cup).

For the inventory of the epiphytic ferns, monthly visits were carried out for one year. Representative and fertile specimens were collected and herborized according to Windisch (1992). The classification of epiphytic ferns followed the system proposed by Schuettpelz et al. (2016) and the validity of scientific names was verified in the List of Species of the Brazilian

Flora (Prado and Sylvestre, 2016). Sample specimens were deposited in the *Herbarium* Anchieta (PACA), from the Anchietano Institute of Research (UNISINOS).

For the community structure, coverage notes (1, 3, 5, 7 and 10) were given for each species according to size and abundance in the area of occurrence (Kersten and Waechter 2011). The epiphytic importance value (IVs) was obtained from the arithmetic mean of the sum of the relative frequencies in the phorophytes, in the zones and the relative coverage.

The floristic composition and the community structure of the present study were compared to the inventory performed by Becker et al. (2014), in a riparian forest, in the source of the Rio dos Sinos, in the municipality of Caraá, upper stretch of the basin.

2.4. Rapid Habitat Assessment Protocol

The rapid habitat assessment protocol (RHAP) was applied in the study area. The protocol was adapted from the Environmental Protection Agency (USEPA, 1987), Barbour et al. (1999) and Callisto et al. (2002). Sixteen parameters were analyzed based on visual observations: 1. Type of occupation of the margins; 2. Erosion on the banks and silting of the river; 3. Anthropogenic alterations; 4. Vegetation cover on the river channel; 5. Water odor and sediment; 6. Water and sediment oils; 7. Water transparency; 8. Type of background (composition); 9. Type of bed (diversification); 10. Extension and frequency of rapids; 11. Type of substrate; 12. Sedimentary deposits; 13. Changes in the river channel; 14. Water flow characteristics; 15. Stability of the margins; 16. Extension of riparian forest. After applying the protocol, the sum of points of each parameter was performed, which were converted into the scale proposed by Callisto et al. (2002) in which the obtained values represent: from 0 to 40 points - impacted stretch; from 41 to 60 points - altered stretch; from 61 to 100 points - natural stretch.

The rapid habitat assessment protocol (RHAP) of the present study was compared to the study by Rocha-Uriartt et al. (2015), which was undertaken also along the riparian forest of Rio dos Sinos.

3. RESULTS AND DISCUSSION

3.1. Rainwater

The accumulated precipitation was 1842.2 mm e 2548.2 mm in São Leopoldo and in Caraá, respectively, and there was no significant difference during the evaluated period (t=1.81, $p>0.05$) (Table 1). However, Rocha-Uriartt et al. (2015) showed that, when the precipitation is monitored over a longer period, precipitation tends to be significantly higher in the Rio dos Sinos source region than in the lower stretch of the basin.

The cumulative monthly precipitation was equivalent in the month of Sep/2014 in the two areas (124.6 mm and 122.7 mm, respectively). The minimum precipitation in São Leopoldo occurred in March 2014 (95.5 mm) and Caraá in October 2013 (94.0 mm). During February 2014, the highest precipitation was recorded in São Leopoldo (253.3 mm), and in Caraá this occurred in June 2014 (420.4 mm) (Figure 1). Rocha-Uriartt et al. (2015) recorded, in Caraá, twice the maximum value of accumulated monthly precipitation in relation to the lower stretch (Caraá: 698.8 mm and Campo Bom: 370.3 mm).

Table 1. Average ± standard deviation of physical-chemical parameters and precipitation enrichment factor in Caraá and São Leopoldo.

Parameter	Unit	Caraá				São Leopoldo				p value	
		Min	Average ± SD	Max	EF	Min	Average ± SD	Max	EF		
										t-test	
Precipitation	(mm)	94.00	2548.2 ± 97.36	420.40	--	95.50	1842.2 ± 56.20	253.5	--	1.81	0.08
pH		5.25	6.14 ± 0.48	6.77	--	5.29	6.24 ± 0.51	7.13	--	-0.50	0.62
Na^+	(μeq L^{-1})	2.83	43.76 ± 21.14	74.62	--	5.49	22.60 ± 18.46	72.28	--	2.45	0.02
Ca^{2+}	(μg L^{-1})	2.99	49.78 ± 26.77	100.55	32*	2.49	38.57 ± 36.50	117.68	47*	0.84	0.40
										Mann-Whitney	
Conductivity	(μS cm^{-1})	6.41	19.23 ± 17.15	71.35	--	6.16	12.71 ± 7.52	33.15	--	42.0	0.14
$N\text{-}NH_4^+$	(μeq L^{-1})	4.44	30.44 ± 25.63	75.50	--	2.81	53.51 ± 66.90	166.96	--	23.0	0.85
$N\text{-}NO_3^-$	(μeq L^{-1})	0.69	11.80 ± 7.18	28.33	--	0.80	7.10 ± 11.50	33.51	--	34.0	0.06
Cl^-	(μeq L^{-1})	6.68	74.50 ± 49.34	177.09	2*	9.99	32.70 ± 28.15	91.93	2*	21.0	0.06
SO_4^{2-}	(μeq L^{-1})	6.26	45.84 ± 29.91	91.25	10*	3.63	20.58 ± 27.20	97.35	7*	24.0	0.03
K^+	(μeq L^{-1})	2.14	38.16 ± 34.54	135.66	56*	1.26	11.01 ± 11.04	36.55	24*	21.0	<0.01
Mg^{2+}	(μeq L^{-1})	44.90	60.18 ± 16.12	87.22	5*	2.05	9.03 ± 5.70	20.8	2*	0.0	<0.01
Pb	(μg L^{-1})	0.24	0.64 ± 0.49	2.12	1**	0.27	0.75± 0.70	1.76	1**	21.0	0.71
Al	(μg L^{-1})	2.04	12.30 ± 11.40	30.00	15**	1.12	12.76 ± 17.30	50.61	13**	50.0	0.75
Cd	(μg L^{-1})	0.002	0.04 ± 0.05	0.11	3229**	0.11	0.28 ± 0.24	0.45	14838**	2.0	0.09
Cu	(μg L^{-1})	0.05	1.13 ± 1.31	4.19	552**	0.10	1.64 ± 2.60	8.63	4899**	56.0	0.79
Cr Total	(μg L^{-1})	0.02	0.04 ± 0.01	0.06	17**	0.02	0.50 ± 0.50	1.09	82**	1.50	<0.01
Fe	(μg L^{-1})	0.02	12.95 ± 10.60	31.10	4**	3.63	24.54 ± 31.54	106.1	13**	57.0	0.60
Mn	(μg L^{-1})	0.06	6.16 ± 8.70	32.19	142**	0.007	2.16± 2.55	7.67	144**	38.0	0.09

Legend: EF: Enrichment Factor;* marine EF; ** crust EF; p value: significance level of 5%.

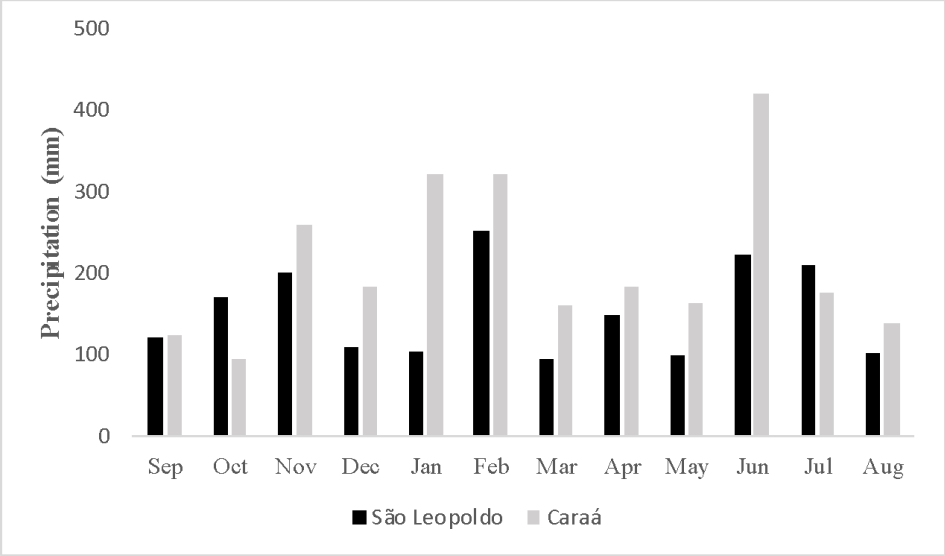

Figure 1. Monthly accumulated precipitation in a 12-month period at São Leopoldo and Caraá.

In the analysis of rainwater, the ions SO_4^{2-}, Na^+, K^+ and Mg^{2+} showed significantly higher average concentrations in Caraá than the concentrations recorded in São Leopoldo. Only Cr T had a significantly higher concentration in São Leopoldo than in Caraá (Table 1). The values of conductivity, pH and other ions and metals did not present significant differences between the study sites.

Only in 18% of the events (4) the pH was lower than 5.6, which characterizes acid rain. Thus, for the studied sites, a slightly alkaline pH can be considered when compared to the rainfall reference value (Seinfeld and Pandis, 2006). The presence of alkaline compounds in rainwater, such as NH_3 and carbonates, aid in its neutralization process. Alkaline pH values were also recorded in the Guaíba Hydrographic Basin (Migliavacca et al., 2005b) in 16% of samples, and in the Metropolitan Region of Porto Alegre in 22% of samples (Migliavacca et al., 2012), both located near the Rio dos Sinos basin.

The marine enrichment factor (EFm) for the analyzed elements followed the sequence $K^+ > Ca^{2+} > SO_4^{2-} > Mg^{2+} > Cl^-$ in Caará and $Ca^{2+} > K^+ > SO_4^{2-} > Mg^{2+} > Cl^-$ in São Leopoldo (Table1). The presence of sulfate (SO_4^{2-}) in the atmosphere comes from natural sources such as the oxidation of dimethyl sulphide (CH_3SCH_3) emitted by ocean waters (Oliveira Junior et al., 2015). The EFm for this chemical compounds was low, reinforcing the indication of the presence of marine ions in rainwater samples (Oliveira Junior et al., 2015), especially in Caraá, where it was significantly larger. This occurs, therefore, in the source of Rio dos Sinos, which is located approximately 32 km in a straight line from the Atlantic Ocean, confirming the influence of rainwater in these ions. In addition, Na^+ e Cl^- (EFm=4 low), which are ions derived from marine aerosols (Migliavacca et al., 2005a; 2005b) were also detected in high concentrations in Caraá. In fact, Na^+ was significantly higher at the site.

Incorporation of Mg^{2+} e K^+ (low and moderate EFm, respectively) comes from soil dust, by the dissolution of minerals, silicates or by arable soils that have traces of fertilizers. These can then release particulate material into the atmosphere during precipitation (Sardinha et al., 2013). These ions were significantly higher in Caraá, which is an essentially a rural municipality, and could have been incorporated to the rain of the region (Table 1).

The enrichment factor for Ca^{2+} enrichment may be related to the dissolution of $CaCO_3$ present in suspended soil dust, due to the intense vehicular traffic (Migliavacca et al., 2012), mainly in São Leopoldo, where a moderate EFm (47) was verified. This result reinforces the possible anthropic origin for this ion in rainwater samples. The Imperatriz Leopoldina Park is

directly influenced by vehicular sources coming from the highway BR-116, Imperatriz Leopoldina and Mauá avenues, and from the downtown area of the municipality, corroborating with the high concentration of these metals in the rainwater (Blume et al., 2014; Costa et al., 2016).

The concentrations of NO_3^- and NO_2^- are derived from agricultural sources, from phosphate fertilizers, in which the NH_4^+ ion can be converted to NH_3 by chemical reactions in the atmosphere and potentiate the process of rainwater neutralization (Migliavacca et al., 2012). The presence of these ions comes from subsistence agriculture and monocultures of rice in the upper and lower stretches of the RSHB, respectively. (Roy et al., 2016).

The crust Enrichment Factor (EFc) values (Table 1) ranged from 1 to 9034, with an EFc of less than 10 for Pb and Fe (only in Caraá), indicating a low enrichment of rainwater samples from the terrestrial crust. The presence of Pb in rainwater does not come from the Earth's crust and its origin may be related to the enrichment of particles originating from anthropic sources, such as coal combustion, founding and vehicular emissions (Migliavacca, et al., 2012, Wu et al., 2016, Herrera et al., 2009). As to the other metals, Cr> Cu> Cd, a strong (Cr) to extreme (Cu and Cd) enrichment is observed.

The Cu and Cd elements are derived from vehicular emissions because they are present in practically all types of brake linings and are used for tire manufacturing (Manahan, 2005; Alleman et al., 2010; Moreira, 2010; Loyola et al., 2012; Alves et al., 2015). The extreme EFc values for both study areas, especially in the lower stretch of the RSHB, show that the contribution of vehicular traffic dust is incorporated into precipitation, especially in São Leopoldo. This is confirmed by the higher vehicular fleet in this municipality (74.412 vehicles) than in Caraá (1.531 vehicles) (IBGE, 2017). Costa et al. (2016), who counted vehicles in an area near Imperatriz Leopoldina Park in São Leopoldo, indicated that the circulation of vehicles over an hour is from 1420 to 2349. In São Leopoldo, the significantly higher concentration of total chromium (Cr T) is related to the great industrialization of the lower stretch of the RSHB, derived from steel and metallurgical processes, and especially from leather tanning (Alves et al., 2015) in the studied region.

3.2. Floristic Inventory and community structure

Seven species were inventoried. They belong to five genera and two families, being Polypodiaceae with six species and Dryopteridaceae with only one species (Table 2). The analysis of distribution of epiphytic ferns along the RSHB shows a simplification in the richness and a change in the floristic composition of the area. Studies that applied the same methodology demonstrate the same results. For instance, Becker et al. (2014) recorded 30 species near the source of the Rio dos Sinos in Caraá, out of which only three were shared with the present study. Barbosa et al. (2015), in a study carried out in an urban park in the lower stretch of the basin, recorded only nine species of epiphytic ferns, four of which were shared with this study. This fact may be associated to vegetation and environment characteristics, since epiphytes, especially ferns, need a healthy environment to develop (Johansson, 1974) and Rocha-Uriartt et al. (2015) showed that there is a decreasing gradient in vegetation degradation from the source towards the mouth of the river in the RSHB.

The community structure of the present study did not present an equitable distribution, since the three most important species of the community (*Microgramma vaccinifolia*, *Pleopeltis pleopeltifolia* and *M. squamulosa*) contribute with more than 95% of IVs. The other species (four) registered less than 5% of IVs, but their contribution in the wealth was more than 57%. The opposite happens if we compare the community structure near the source of Rio dos Sinos, analyzed by Becker et al. (2014). In that case, the epiphytic fern community presented a more equitable distribution with about 76.66% more wealth.

The morphological characteristics, such as succulent rhizome, presence of trichomes and scales, are considered functional attributes (Rocha-Uriartt et al., 2016) and adaptive strategies of the epiphytic ferns against water stress (Benzing, 1989). In this study, these characteristics were also found in the inventoried specimens of Polypodiaceae, relating their occurrence to a drier environment, such as the lower stretch of the RSHB.

Polypodiaceae is also the most diverse within the epiphytic environment (Dubuisson et al., 2009), and is commonly found in urban and impacted environments (Sehnem, 1970; Becker et al., 2015). In these environments, plants have adaptive strategies that favor their development. For example, species of the genus *Microgramma* present a long-crawling rhizome that allows the occupation of extensive areas in the forophytes (Waechter 1998; Kersten and Silva, 2001). Specifically, *M. vaccinifolia* could have taken the highest IVs due to its aleopathic potential (Peres et al. 2009) and this species is cyanogenic, what can be reducing the predation (Santos et al., 2005) and increase its population. *Microgramma squamulosa* has a high sclerophylly index (Rocha et al., 2013), stomatal density and higher thickness of hypoderm in more polluted environments (Rocha et al., 2014), and these adaptations are important under water stress (Fahn and Cutler, 1992). *Pleopeltis pleopeltifolia*, on the other hand, reduces its exposed leaf surface, thus lessening the damage caused by the solar incidence and the lack of humidity in the environment, a strategy known as poikilohydry (Benzing, 1990), in which it can live with only 25% of its water content over long periods (Moran, 2012). These adaptations are fundamental for their survival in anthropic areas with less water availability.

Table 2. Phytosociological structure of species of epiphytic ferns inventoried in present study (São Leopoldo), in descending order of Specific Importance Value (IVs).

Family	Species	nf	nz	FRf %	FRz %	NCr %	IVs %
Polypodiaceae	*Microgramma vaccinifolia* (Langsd. & Fisch.) Copel.	35	118	53.8	58.1	60.3	57.4
Polypodiaceae	*Pleopeltis pleopeltifolia* (Raddi) Alston	20	61	30.8	30.0	26.0	29.0
Polypodiaceae	*Microgramma squamulosa* (Kaulf.) de la Sota	6	19	9.2	9.4	12.6	10.4
Polypodiaceae	*Pecluma sicca* (Lindm.) M.G.Price	1	2	1.5	1.0	0.2	0.9
Polypodiaceae	*Serpocaulon catharinae* (Langsd. & Fisch.) A.R.Sm.	1	1	1.5	0.5	0.4	0.8
Polypodiaceae	*Pleopeltis hirsutissima* (Raddi) de la Sota	1	1	1.5	0.5	0.4	0.8
Dryopteridaeae	*Rumhora adiantiformis* (G.Forst.) Ching	1	1	1.5	0.5	0.1	0.7

Legend: Nf and nz: number of forophytes and species occurrence zones, respectively; FRf: relative frequency in the forophytes; FRz: relative frequency in zones; NCr: relative coverage note; IVs: importance value.

3.3. Rapid Habitat Assessment Protocol (RHAP)

The result of the RHAP in the surveyed area totalled 33 points, thus classifying the stretch as impacted. The parameter "1-Occupancy type" had a maximum score. Being a Permanent Preservation Area (PPA), this riparian forest, although altered due to recreational trails, has original vegetation and few signs of suppression. At the opposite extreme, parameters 4 and 11 (vegetal cover over the river and type of substrate) scored zero. The absence of vegetation cover in the Rio dos Sinos gutter occurs due to the widening of the river, which also causes erosion in its banks. This reflects the deposition of mud on the river bed, demonstrated by the analysis of the RHAP.

The evaluation of the habitat quality is considered fundamental for the ecological integrity analysis, and the final scores reflect the level of conservation of the area (Barbour et al., 1999; Callisto et al., 2002). The result of the RHAP in the present study, obtained the same (impacted) framework from another stretch. Rocha-Uriartt et al. (2015) also analyzed the lower stretch of the RSHB. This location is at a distance of 12 km from the Imperatriz Leopoldina Park, showing that both are under the same environmental pressures and have the same characteristics of vegetation. A significant contribution to this result is caused by the population density and the consequent urban impact, mainly regarding the type of occupation of the margins and the

devastation of the riparian forests (Barrella et al., 2000; Rodrigues and Gandolfi, 2000), which leads to the loss of environmental quality along the area.

Towards the mouth the river basin, the caracteristics of the vegetation follows the change of landscape. This is valid from the headwaters of formative streams to the main river, with heterogeneous environmental conditions towards the floodplain with more homogeneous characteristics (Barrella et al., 2000). Throughout the RSHB, this change in landscape is observed, evidenced by the RHAP score (Table 3), a significant reduction of epiphytic fern richness, and the concentration of IVs in a few species. In addition, the influence of lower altitude and significantly lower precipitation in the lower stretch of the RSHB (Rocha-Uriartt et al., 2015), prove to be natural causes and characteristics that become more homogeneous toward the mouth of the Rio dos Sinos.

Table 3. Score applied to RHAP parameters at Imperatriz Leopoldina Park compared to another study.

Comparative Studies				
	Rocha-Uriartt et al. (2015)			Present Study
Assessed Parameter	Upper Stretch (Caraá)	Middle Stretch (Taquara)	Lower Stretch (Campo Bom)	Lower stretch (São Leopoldo)
1	4	2	0	4
2	4	2	2	2
3	4	2	2	2
4	4	0	0	0
5	4	2	2	2
6	4	2	2	2
7	4	2	2	2
8	4	2	2	2
9	5	3	3	2
10	5	2	2	2
11	5	2	2	0
12	5	3	2	3
13	5	2	2	3
14	5	2	2	2
15	5	2	0	3
16	5	2	2	2
Score Assessment	72 Natural Stretch	32 Impacted Stretch	27 Impacted Stretch	33 Impacted Stretch

Legend: Parameters 1 - 8: maximum score (4: natural situation), intermediate (2: slight alteration) and minimum score: (0: severe alteration); Parameters 9 - 16: maximum score (4: natural situation), intermediate (3: slight alteration, 2: median alteration) and minimum score (0: severe change).

4. FINAL CONSIDERATIONS

This study showed that the chemical composition of rainwater is influenced by the environment of each area studied. In the upper stretch (Caraá), the greatest contribution is of marine origin, while in the lower stretch (São Leopoldo) it is basically derived from urbanization and industrialization.

In the riparian forest of Imperatriz Leopoldina Park, a reduction of the wealth and a simplification of the community structure of epiphytic ferns is evidenced, compared to the region of the source of the Rio dos Sinos. Likewise, the riparian forest of the area has lost its

natural characteristics, and its environmental quality diminished according to the categories of RHAP and receives rainwater with a predominantly non-natural chemical composition.

The analysis of the riparian forest of the park applying different methods was an efficient tool to evaluate its environmental quality as it allowed the integration of a greater number of biotic and abiotic variables. The proposed integrated analysis can be applied to other scenarios as well.

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