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Original Paper

Distinct lichen community in riparian forests along an anthropogenic disturbance gradient in Southern Brazil

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Abstract
The riparian forest sustains an expressive richness and diversity of species and anthropogenic impacts in certain sites have caused changes in the structure of the communities. This study aimed to analyze the composition and structural parameters of the lichen community in riparian forests. The study was carried out in seven sites surrounded by different matrices: rural, urban and industrial. The lichens were mapped using the acetate method and the composition and phytosociological parameters were analyzed. A total of 208 species were identified. The riparian forest sites of the rural matrix differed from the others by the dominance of the morphological forms crustose and squamulose, as well as the predominance of species from humid and shaded environments. *Phyllopsora lividocarpa*, *Phyllopsora parvifolia* and *Herpothallon minimum* presented the highest importance values in the forest sites. The lichen community presented greater homogeneity in riparian forest sites of the urban-industrial matrix. Modifications in the species' composition and structural parameters of the lichen community demonstrated a gradient of disturbances in the different matrices. Preservation actions of riparian forests are essential for the conservation of the species and landscape connectivity since they act as an important reservoir of biodiversity in sites of subtropical watersheds.
Key words: Atlantic Forest, lichenized fungi, rare species, urbanization.

Resumo
As florestas ripárias sustentam expressiva riqueza e diversidade de espécies e os impactos antropogênicos em determinados locais podem ocasionar modificações na estrutura das comunidades. O objetivo do estudo foi analisar a composição e parâmetros estruturais da comunidade liquênica em florestas ripárias. O estudo foi realizado em sete áreas inseridas em diferentes matrizes: rural, urbana e industrial. Os liquens foram mapeados utilizando o método do acetato e foram analisadas a composição e os parâmetros fitossociológicos. Um total de 208 espécies foram identificadas. As áreas florestais da matriz rural diferiram das outras pela dominância das formas morfológicas crostosas e esquamulosas, assim como pela predominância de espécies de ambientes úmidos e sombreados. *Phyllopsora lividocarpa*, *Phyllopsora parvifolia* e *Herpothallon minimum* apresentaram os maiores valores de importância nas áreas florestais. As modificações na composição de espécies e nos parâmetros estruturais demonstraram um gradiente de perturbação nas diferentes matrizes. Ações de preservação nas áreas florestais ripárias são essenciais para a conservação das espécies e conectividade da paisagem uma vez que atuam como importante reservatório de biodiversidade em áreas de bacias hidrográficas subtropicais.
Palavras-chave: Floresta Atlântica, fungos liquenizados, espécies raras, urbanização.

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Introduction

Riparian forests maintain and preserve water courses, soil, and biodiversity (Ribeiro-Filho *et al.* 2009). These forest areas present high levels of biological diversity and productivity (Bennet & Simon 2004) and are responsible for housing highly adapted species in addition to generalist taxa (Gundersen *et al*. 2010). Anthropogenic disturbances in these sites cause habitat loss and changes in the composition of communities, which may lead to the extinction of species (Aragón *et al*. 2019). The knowledge of biodiversity, ecology and communities is important for the protection of forests. Assessing the quality of forest sites, such as riparian forests, as well as their continuity, human impact or number of threatened species is essential for the conservation of these ecosystems (Resl *et al*. 2018). Therefore, species composition, richness and diversity are considered good indicators of ecological continuity, reflecting the recent history of disturbance in forest areas (Aragón *et al.* 2019).

Epiphytic lichens are essential components in tropical forests due to their role in water and nutrient cycling (Benítez *et al.* 2018). These organisms are considered environmental indicators due to their capacity to demonstrate human and microclimatic disturbances (Chuquimarca *et al*. 2019; Käffer *et al*. 2021), helping evaluate ecosystem health (Bartholmess *et al*. 2004). Additionally, they are considered highly effective in diagnosing the quality of forest environments due to their sensitivity to the substrate (Tripp *et al*. 2019). Lichens can be used to assess the successional stage of forests (Koch *et al*. 2013) by demonstrating whether the ecosystem has remained unchanged over time (Aragón *et al.* 2019).

Lücking *et al*. (2009) estimated approximately 7,000 lichen species for the tropical region and considered the knowledge of the species richness of tropical taxa and their taxonomy to be important to other research areas. The same author reports that the high richness in the tropics is attributed to different variables, including the absence of snow and the good conditions for photosynthesis. Recent studies in the South region of Brazil reported 107 new records for the state of Rio Grande do Sul (Aptroot *et al*. 2021, 2022).

In the last 25 years, forest areas had a net loss of 129 million ha, especially in developing tropical countries, where forests are used for agricultural purposes (Ripple *et al*. 2017). The Hydrographic Basin of Sinos River (HBSR) located in southern Brazil, is considered one of the most polluted in the country and is located in the Atlantic Forest Biome, which constitutes one of the 36 biodiversity hotspots in the world (<https://www.conservation.org>). The forest areas inserted in the HBSR region have been altered over the years, presenting different degrees of anthropogenic disturbance and causing direct changes in the ecosystem's dynamics. Specifically, past studies in this Basin found composition change and richness reduction in fern and lycophyte species, as well as in vascular epiphytes (Rocha-Uriartt *et al*. 2016), over a gradient of urbanization. The knowledge about the diversity and structure of the lichen community in the Atlantic Forest is of great importance for ecosystem conservation studies (Cáceres *et al*. 2016). Studies show that changes in the composition and richness of lichenized mycota in tropical forests are due to the influence of agricultural activities and urbanization (Chuquimarca *et al*. 2019; Koch *et al*. 2019). Accordingly, the determination of the composition, diversity and structure of the lichen community can be used as a diagnostic model of environmental quality in an urbanization gradient. On the other hand, the phytosociological approach of the lichen community as a tool in the analysis of forest areas in tropical and subtropical environments is still incipient (Leite *et al*. 2015; Käffer *et al*. 2015). Thus, we hypothesize that the structural parameters, diversity and composition of the lichen community are different in forest sites according to the matrices in which they are inserted, and we assume that there will be: (1) reduction of species richness in the rural-urban-industrial matrices; (2) modification in the structural parameters of the lichen community with a predominance of characteristic taxa in the urban-industrial matrices, and (3) homogenization of the lichen community in the most urbanized and industrialized environments. Therefore, the present study aims to: (1) verify possible differences in the composition and diversity between forest sites (2) analyze the composition of the lichen community occurring in different riparian forest sites, and (3) assess the phytosociological parameters of the corticicolous lichen community in riparian forest sites in different matrices in southern Brazil.

Material and Methods

Study sites

The Hydrographic Basin of Sinos River (HBSR) is in the northeastern region of Rio Grande do Sul, Brazil. It covers an area of 3,746.68 km², encompassing 32 municipalities with a total population estimated at around 1,249,100 inhabitants (Sema 2019). The HBSR is inserted in the Atlantic Forest Biome. The basin's vegetation cover is reduced, although forest patches remain predominantly at the sources of the Sinos River and the streams that form it. The increasing urbanization associated with population growth caused several impacts on the HBSR, especially the decrease in the vegetation cover (Prosinos 2011).

The HBSR forest sites are characterized by several tropical species. The forest sites analyzed in this study correspond to two formations. Semideciduous Seasonal Forest, comprising the most extensive formation of the basin, with an amplitude of altitudinal distribution from 12 to 600 m, is characterized by generally less density and humidity with a less diverse and open understory. The Ombrophilous Forest occurs in an altitudinal amplitude ranging from 600 to 905 m and presents a humid habitat with dense understory, in addition to a herbaceous layer dominated by ferns and trunks covered by epiphytes. The families Myrtaceae, Meliaceae, Lauraceae, and Salicaceae predominate in number of individuals. This formation concentrates some of the largest and most preserved stretches of continuous forest in the basin, including the Caraá Environmental Protection Area, which houses one of the springs of the HBSR main river (Molz *et al*. 2016). The climate is classified as humid subtropical (cfa) with well-defined summers and winters, as well as rains throughout the year (Peel *et al*. 2007).

Selection of forest sites

The riparian forest sites (S1 to S7) were selected along the HBSR (from the source towards the mouth of the main river) in seven municipalities distributed into three different environmental matrices (rural, rural-urban, and urban-industrial). Levels of urbanization were considered for each matrix (Tab. 1; Fig. 1). Each riparian forest site was selected based on its availability in the three different environmental matrices. All forests had an area of at least 1 ha and the phorophytes were 5 m to 15 m apart.

Sampling and identification

The lichen community was sampled using the acetate sheet method, which consists of placing five acetate sheets (20 × 20 cm) in sequence along the trunk from a height of 100 cm to 180 cm on the north and south sides of the trees (cardinal directions determined by a compass) (Fig. 2). The contour of the species' thalli was drawn with a pen (Käffer *et al*. 2015) and later used to calculate

Table 1 – Location of forest sites (from the source to the mouth) located in the Hydrographic Basin of Sinos River. Brazil.

Sites	City	Matrix	Elevation (asl.)	Coordinates
S1	São Leopoldo	Urban/Industrial	8	29°45' 84.0"S 51°10' 83.0'W
S2	Campo Bom	Urban/Industrial	17	29º 39' 07.9"S 51º 07' 04.0"W
S3	Nova Santa Rita (mouth of the Sinos River)	Urban/Industrial	14	29º 52' 45.8"S 51º 15' 39.0"W
S4	Rolante/Santo Antônio da Patrulha	Rural/Urban	18	29º 43' 62.5"S 50º 38' 23.2"W
S5	Taquara	Rural/Urban	16	29º 41' 09.7"S 50º 47' 54.2'W
S6	Santo Antônio da Patrulha/Caraá	Rural	34	29° 46´ 57.0" S 50º 28' 25.5"W
S7	Caraá (source of the Sinos River)	Rural	470	29º 42' 05.8"S 50º 17' 46.1"W

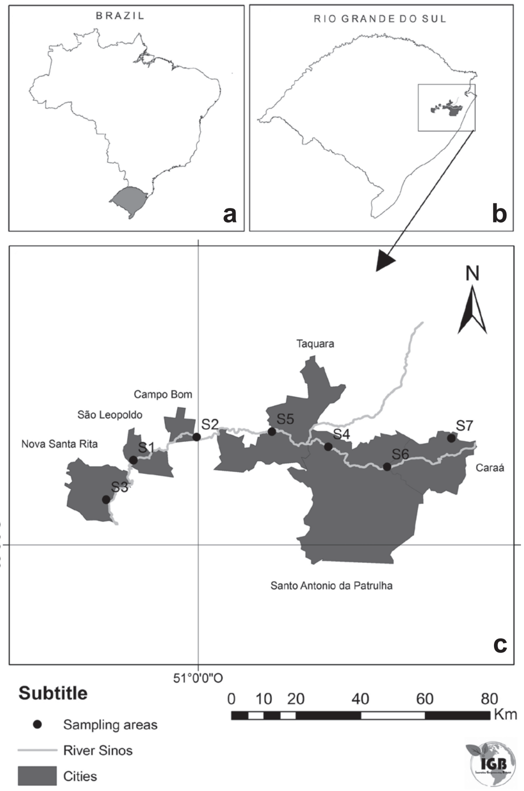

Figure 1 – a-c. The riparian forest sites of the Hydrographic Basin of Sinos River, southern Brazil. (Site 1 = São Leopoldo; Site 2 = Campo Bom; Site 3 = Nova Santa Rita; Site 4 = Rolante/Santo Antônio da Patrulha; Site 5 = Taquara; Site 6 = Santo Antônio da Patrulha/Caraá; Site 7 = Caraá).

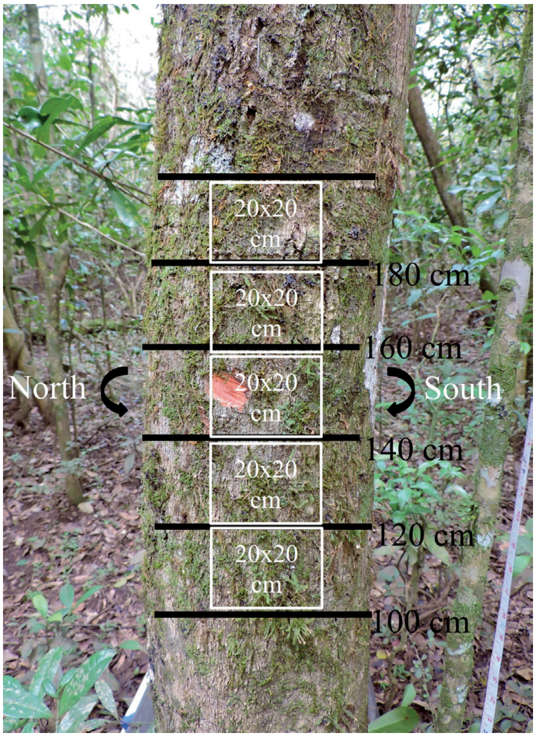

Figure 2 – Schematic representation of the method used to sample the lichen community in the phorophytes analyzed in the riparian forest sites of the hydrographic basin. The rectangles represent the acetate sheets (20 × 20 cm) arranged at a height of 100 cm to 180 cm on both sides of the trunk (north and south).

the species' coverage. For lichen community sampling, 10 phorophytes were randomly chosen in each riparian forest site, totaling 70 trees. The phorophytes were selected according to the following characteristics: diameter at breast height (DBH) ≥ 12.0 cm, similar trunk structure and no branches below 2.0 m from the ground (Tab. S1, available on supplementary material <https://doi.org/10.6084/m9.figshare.22626970.v1>).

Lichen species that could not be identified in the field were collected for later identification in the Botany Laboratory of the Feevale University, RS, Brazil. To identify the species, stereoscopic and optical microscopes, chemical tests on the cortex, medulla and/or reproductive structures, taxonomic keys, and consultation of herbarium material were used, as well as confirmation by specialists in the lichen groups. The species classification followed Lücking *et al.* (2017) and the nomenclature was consulted in the Index Fungorum. More representative samples of the collected material were deposited in the Anchieta Herbarium (PACA118285 - 118500), São Leopoldo, RS, with duplicates deposited in the didactic collection of the Botany Laboratory of the Feevale University.

Data analysis

For the analysis of the composition of the lichen community, all species recorded in the sampling area (acetate sheet method) were considered, as well as the collections carried out tree trunks located on the access trails to the forest sites (additional samples).

The Lichen Diversity Index (LDI) was calculated for the lichen communities in each riparian forest site. To calculate the LDI, the sum of the frequency of all species occurring on both sides of the trunk (N/S) was used for the 10 phorophytes analyzed in each forest site (Asta *et al*. 2002a adapted). To classify the diversity, the LDI scale proposed by Asta *et al*. (2002b) was used. This scale goes from 0 to 100, where the values of 0–20 = very low; 20.1–40 = low; 40.1–60 = moderate; 60.1–80 = high and 80.1–100 = very high. Cluster analysis was performed using Sørensen distance and group average (set to -0.25) as a clustering algorithm. Indicator species analysis and Monte-Carlo test were performed on the frequency (species occurring in more than two riparian forest sites) and abundance data of the lichen species (McCune *et al*. 2002). The analysis was performed in the program PC-Ord 6.08 (McCune & Mefford 2011).

The phytosociological parameters of the community (number of thalli, richness, frequency, coverage, and importance value) were calculated for each riparian forest site using only the data obtained by sampling the species using the acetate sheet method. Richness considered the species present on both sides (N and S) and the 10 analyzed phorophytes in each site. Frequency was calculated using the total number of occurrences of the species on both sides (N and S) and in the 10 analyzed phorophytes in each riparian forest site. Coverage (CA) was estimated by the sum of all the lichen thalli present on both sides (N and S) and the 10 sampled phorophytes for each riparian forest site. For the calculation of absolute coverage (CA), the acetate sheets were superimposed on a sheet with 100 squares of 2 cm each. The relative coverage (CR%) was calculated considering the value of the species' coverage divided by the total sum of the community's CA and multiplied by 100. The absolute frequency (FA) was estimated by the number of occurrences of each species and divided by the total number of phorophytes (10), while the relative frequency (FR%) was calculated considering the FA of each species divided by the total sum of the FA of the community and multiplied by 100. The Importance Value (IV) of each species was calculated considering the sum of the frequency and relative coverage data (Mueller-Dombois & Ellenberg 1974 adapted from lichen community).

To evaluate the relationship between phytosociological parameters of the lichen community (number of thalli, coverage, and importance value) and the different matrices (rural-urban-industrial), a one-way analysis of variance (ANOVA) was used. The analyses were performed using the software SPSS Statistics 2.0.

Results

Composition and structure of the lichen community

A total of 208 species were recorded distributed into 25 families and 60 genera. From the total number of species, 43 are additional samples collected to characterize the sites' composition. Two species are new records for Brazil: *Herpothallon minimum* and *Pyrenula montocensis*. Eight species are new occurrences for the state of Rio Grande do Sul: *Bacidina varia*, *Bacidiopsora squamulosula*, *Coenogonium subdentatum*, *Cresponea melanocheiloides*, *Cryptolechia nana*, *Fissurina dumastii*, *Phyllopsora lividocarpa*, and *Pyrenula massariospora* (Tab. S2, available on supplementary material <https://doi.org/10.6084/m9.figshare.22626970.v1>; Fig. 3).

As for the morphological characteristics, the predominant growth form was crustose, with 47.1%, followed by foliose (40.4%), fruticose (6.7%), squamulose (4.8%), filamentous and dimorphic (0.5% each). Species associated with chlorophytes represented 91.8% of the community, while those carrying cyanobacteria were 8.2%. The family with the largest number of representatives in the lichen community was Parmeliaceae (39 species), followed by Graphidaceae (25), and Ramalinaceae (23). The genera with the largest number of representatives were *Parmotrema*, with 15 species, *Graphis*, with 11 species, and *Porina*, with nine species (Tab. S2, available on supplementary material <https://doi.org/10.6084/m9.figshare.22626970.v1>).

The lichen diversity index (LDI) ranged from 32.8 to 11.9, with low values recorded for rural matrix (S6 and S7) and a very low LDI for an urban-industrial matrix (S3) (Fig. 4).

In the cluster analysis, we verified a greater similarity between two sites from the urban-industrial matrix and a closer relationship between three sites of the urban-industrial, rural-urban and rural matrices, while the other rural-urban site appeared distant from the other sites (Fig. 5). The two sites of the urban-industrial matrix were very similar, with more than 50% of the species of each forest site (S1 = 77.3% and S2 = 56.2%) belonging to the families Parmeliaceae, Graphidaceae and Physciaceae, which presented the largest number of representatives in this study. The forest sites of the urban-industrial, rural-urban e rural matrix were characterized by the presence of typical species of shaded environments and the predominance of taxa of the families Arthoniaceae, Porinaceae and Ramalinaceae, especially the genera *Herpothallon*, *Porina* and *Phyllopsora*. The species *Leptogium diaphanum* (Sw.) Mont. (IV = 100.0; $p \leq 0.05$), *Letrouitia domingensis* (IV = 100.0; $p \leq 0.05$), *Malmidea fuscella* (IV = 100.0; $p \leq 0.05$), *Porina mastoidea* (IV = 93.6; $p \leq 0.05$) and *Cresponea melanocheiloides* (IV = 66.7; $p \leq 0.05$) were indicators of the riparian forest sites from the rural and rural-urban matrix, while *Graphis librata* (IV = 75.0; $p \leq 0.05$) was indicator of the riparian forest sites from the urban-industrial matrix.

Phytosociological parameters

The riparian forest sites of the rural matrix differed from the others by the dominance of the morphological forms crustose with perithecia and squamulose. Nevertheless, the highest richness was recorded in the riparian forest site (S2) of the urban-industrial matrix, while the lowest richness was observed in the riparian forest site of the rural-urban matrix (S5), contrary to expectations. However, the greater richness in the urban-industrial matrix is associated with a high incidence of species of the family Graphidaceae, especially of the genus *Graphis*, and Parmeliaceae of the genus *Parmotrema*, which are prevalent in urbanized areas and areas with more solar incidence. In a forest site of the rural-urban matrix (S5), the most representative genera were *Porina*, *Leptogium* and *Ramalina*.

The species with the highest importance value (IV) presents expressive frequency and coverage in riparian forest sites. In the sites of the urban-industrial matrix, five species presented

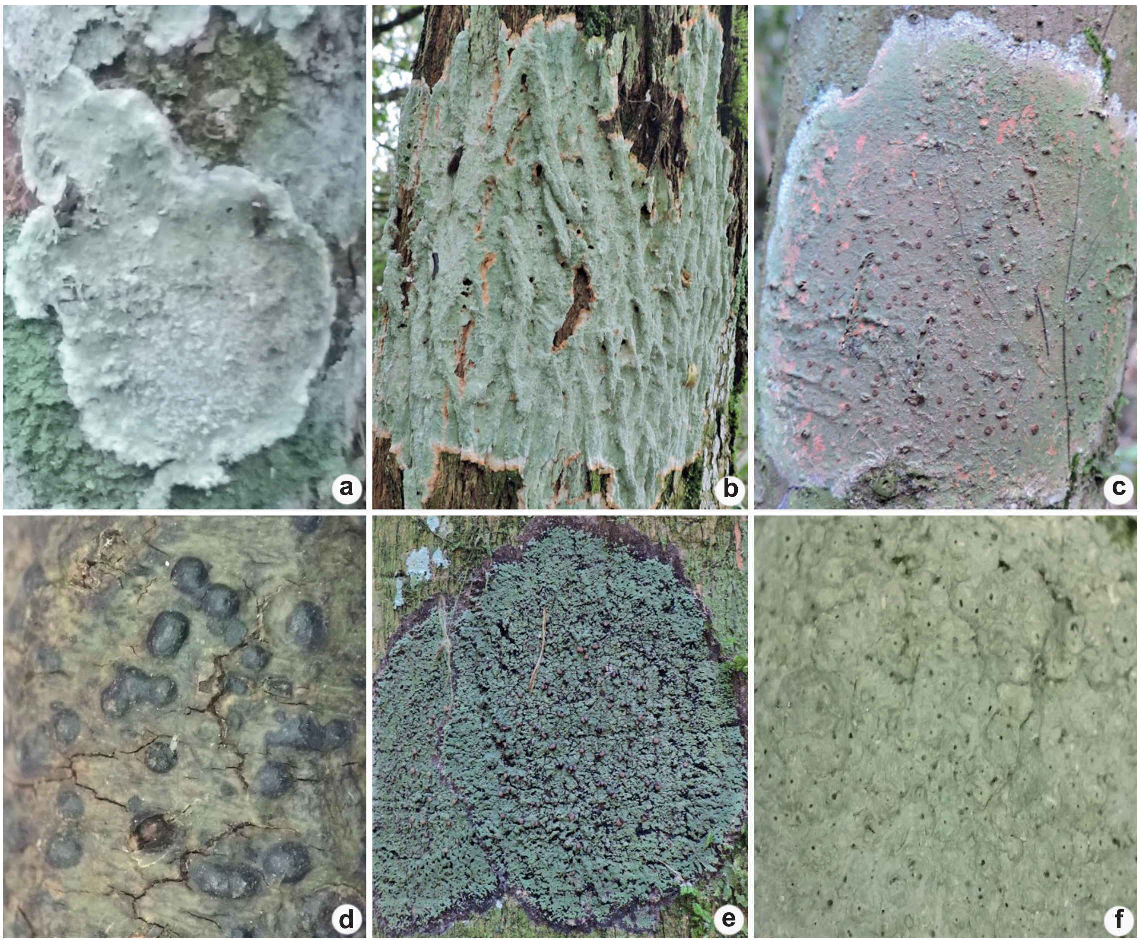

Figure 3 – a-f. Lichen species occurring in the riparian forest site of the Hydrographic Basin of Sinos River, southern Brazil – a. *Herpothallon minimum*; b. *Herpothallon pustulatum*; c. *Malmidea piperis*; d. *Pyrenula massariospora*; e. *Phyllopsora* sp. 2; f. *Porina tetracerae*. Scale bars: d-f =1 mm.

the highest values of relative importance and coverage: *Canoparmelia carneopruinata* (CR = 12.81%), *Parmotrema tinctorum*, *Heterodermia albicans*, *Punctelia constantimontium* and *Physcia tribacoides* for site S1 (IV = 71.04 / ∑ = 200.00); *Porina tetracerae* (CR = 10.12%), *Graphis duplicata*, *Leptogium isidiosellum*, *Pyrenula pyrenuloides* and *Fissurina instabilis* for site S2 (IV = 49.69); and *Phyllopsora lividocarpa* (CR = 42.89%), *Herpothallon minimum*, *Herpothallon rubrocinctum*, *Herpothallon roseocinctum* and *Physcia sinuosa* for site S3 (IV = 144.00 / ∑ = 200.00). For the forest sites of the rural-urban matrix, species with the highest IV in relation to the total values (∑ = 200) were: *Phyllopsora parvifolia* (CR = 13.64%), *Herpothallon pustulatum*, *Phyllopsora buettneri*, *Herpothallon rubrocinctum* and *Porina eminentior* (IV = 80.91) for site S4; and *Malmidea vinosa* (CR = 36.79%), *Leptogium atlanticum*, *Pyrenula massariospora*, *Phyllopsora parvifolia* and *Leptogium azureum* (IV = 26.15) for site S5.

In the forest sites of the rural matrix, the species with the highest IV were: *Herpothallon minimum* (CR = 8.9%), *Letrouitia dominguensis*, *Heterodermia obscurata*, *Physcia* cf. *sorediosa* and *Strigula muriconidiata* for site S6 (IV = 58.8); and *Porina cryptostoma* (CR = 14.37%), *Porina tetracerae*, *Malmidea vinosa*, *Coenogonium subdentatum* and *Coenogonium strigosum* for site S7

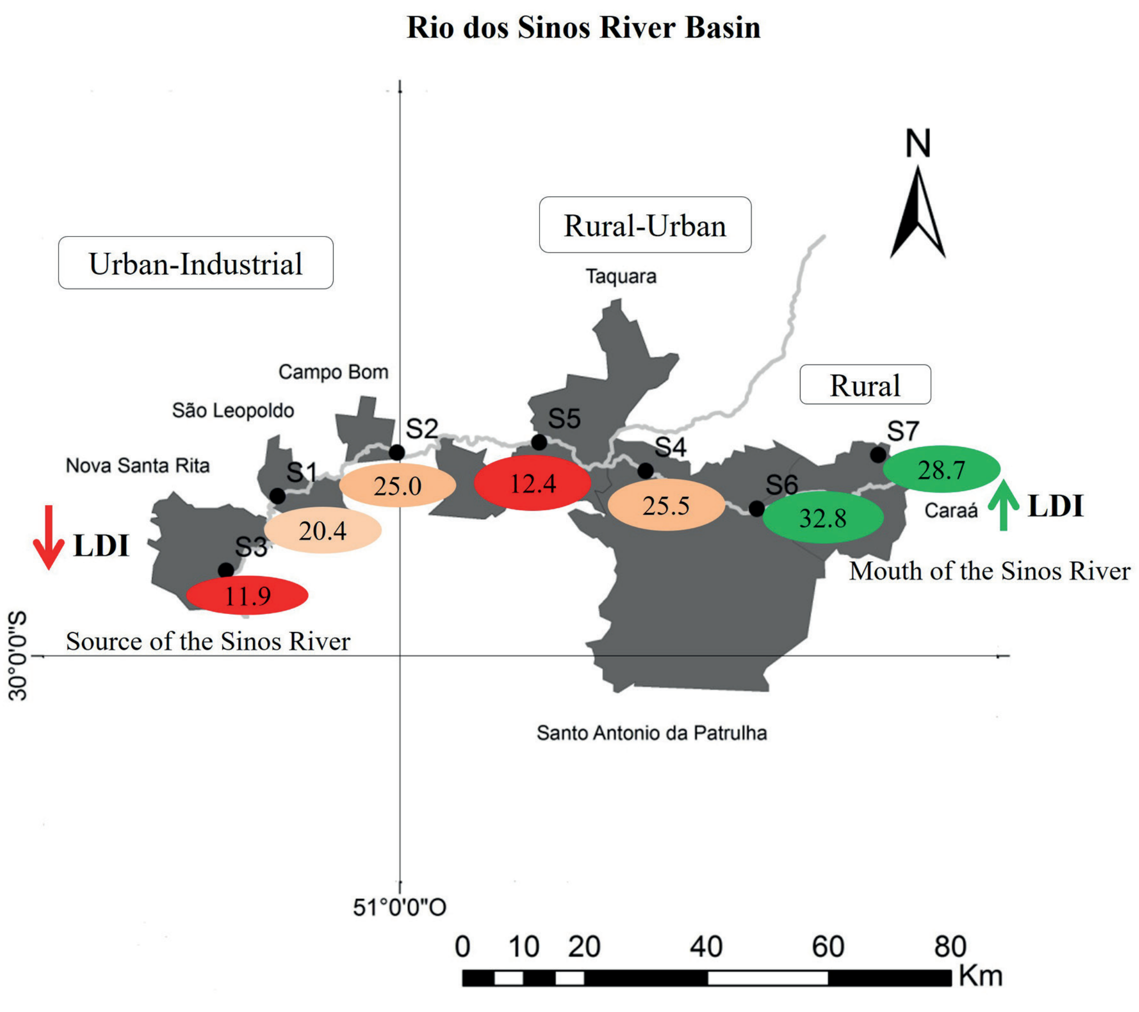

Figure 4 – Lichen diversity index (LDI) in different matrices (rural-urban-industrial) in forest areas of the Sinos River Basin, southern Brazil. (S1 = São Leopoldo; S2 = Campo Bom; S3 = Nova Santa Rita; S4 = Rolante/Santo Antônio da Patrulha; S5 = Taquara; S6 = Santo Antônio da Patrulha/Caraá; S7 = Caraá).

(IV = 21.33) in relation to the total values (∑ = 200) (Tab. S3.1 to Tab. S3.7). The species with the highest values of IV, FR and CR belong to the morphological groups crustose, foliose and squamulose. In general, *Herpothallon minimum* and *Porina tetracerae* (Ach.) Müll. Arg. were the most frequent species, occurring in 90% of the analyzed sites (Tab. S2, available on supplementary material <https://doi.org/10.6084/m9.figshare.22626970.v1>).

Differences were recorded between the forest sites of the urban-industrial and rural-urban matrices for the parameters number of thalli (ANOVA, F = 10.21, $p < 0.001$) and importance value (F = 10.40, $p < 0.001$); the same parameters were also different between the urban-industrial and urban matrices (number of thalli: F = 5.12, $p < 0.001$; importance value: F = 7.07, $p < 0.001$). For the forest sites of the rural matrix, significant differences were found for the parameters coverage (F = 9.92, $p < 0.001$) and importance value (F = 12.59, $p < 0.001$) in relation to forest sites of the rural-urban matrix.

Discussion

The differences in structural parameters and species composition associated with homogenization of the lichenized community in forest sites inserted in urban-industrial matrices, together with the predominance of taxa characteristic of these regions, corroborated our initial hypothesis.

In this study, the species of the families Parmeliaceae (*Parmotrema*), Physciaceae (*Physcia*) and Graphidaceae, with *Graphis* being the predominant genus, were dominant in the riparian forests of the urban-industrial matrix. These families are characterized as cosmopolitan (Galloway 2008; Thell *et al*. 2012) and dominant in tropical regions (Rivas-Plata *et al*. 2012).

In the forest areas of rural-urban and rural matrices, the species of *Phyllopsora*, *Malmidea*, *Porina* and *Herpothallon* stood out with their higher importance values, causing differences in the composition of the lichen community, especially in relation to the forest areas of the urban-industrial matrix. Species of the genus *Phyllopsora* prefer partially shaded habitats and are more restricted to riparian forests, occurring on tree trunks of tropical lowland forests (Timdal 2008). *Malmidea* and *Porina* are characteristic of tropical regions, and species of the family Porinaceae are dominant in the lichen community of tropical forests (Kalb *et al*. 2011). Species of the genus *Herpothallon* are common in shaded tropical forests, growing on wet bark or bryophytes (Aptroot *et al*. 2009). Biological characteristics of the species and the forest structure of riparian forest sites, especially concerning humidity and shading, may be related to the predominance of these taxa. As for the higher representativeness of the abovementioned families, they predominated in the studies related to lichenized mycota in forest and/or urban environments for subtropical regions (Käffer *et al*. 2015; Koch *et al*. 2016; Lucheta *et al*. 2018, 2019).

Lichens are affected by deforestation and forest exploitation and consequently, the conversion of forest sites by tree extraction changes microclimatic conditions, such as luminosity and humidity (Aragón *et al.* 2019), especially by changes in canopy coverage, and affects the composition of lichen species (Benítez *et al*. 2018; Soto-Medina *et al*. 2019). According to Lakatos *et al*. (2006), some crustose lichens, mainly in tropical forests, have adaptations to repel water because they have a dense layer of flattened hyphae or projections of hyphae from the medulla forming a hydrophobic layer. Thus, this layer could help them tolerate excessive humidity in certain locations. The riparian forests present heterogeneity in the composition and structuring of the species (Ribeiro-

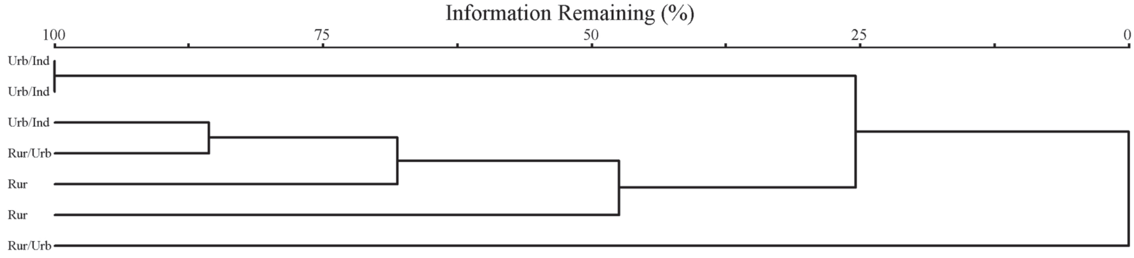

Figure 5 – Cluster analysis considering the composition of species in the riparian forest sites of the Hydrographic Basin of Sinos River, southern Brazil. (Urb/Ind = Urban-Industrial; Rur/Urb = Rural-Urban; Rur = Rural).

Filho *et al*. 2009), and many environmental aspects are changing globally due to human activities, including changes in climatic variables, which directly affect the lichen community. Studies with vascular epiphytes in the HBSR area have verified changes in richness and diversity of the riparian forest sites in different matrices and have emphasized the importance of their conservation and preservation (Rocha-Uriartt *et al*. 2016). In this study, we found that the preservation actions associated with agropastoral practices were decisive for the conservation of habitats, such as in the S4 forest site of the rural-urban matrix, in which rare species were found, including *Herpothallon pustulatum* (crustose) and the genera *Ricasolia* and *Sticta*, which are known to occur in more preserved environments (Käffer & Martins 2014; López *et al.* 2016; Lehnen *et al.* 2017).

The decrease in the richness of lichen species on isolated trees in squares and parks inserted in rural sites towards urban-industrial areas of the HBSR was also observed by Lucheta *et al*. (2018) and differentiation in the environmental quality of forest areas of the HBSR for lichen communities were related especially to luminosity and altitude (Käffer *et al.* 2021). Furthermore, structural parameters and morphological characteristics can certainly be applied as indicators in the analysis of the effects of land use on riparian ecosystems (Chuquimarca *et al*. 2019).

In this study, changes in species composition, associated with changes in landscape structure, demonstrated the gradient of disturbances in riparian forest sites in different matrices. Thus, the maintenance of the subtropical riparian forests preserves the heterogeneity in the composition of the species of the HBSR.

Modifications in the structure of riparian forest sites (fragmentation) associated with microclimate change contributed to the results. Strategies for conservation and preservation of riparian forest sites are essential for the balance and maintenance of the biota in general, but especially of rare species, and improve the connectivity of the landscape with organisms, acting as important reservoirs of biodiversity, such as in sites of subtropical watersheds.

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References

Aptroot A, Thor G, Lücking R, Elix JA & Chaves JL (2009) The lichen genus *Herpothallon* reinstated. Bibliot Lichenol 99: 19-66.

Aptroot A, Spielmann AA & Gumboski EL (2021) New lichens of Santa Catarina and Rio Grande do Sul, Brazil. Archive For Lichenology 23: 1-18.

Aptroot A, Souza MF, Cáceres MES, Santos LA & Spielmann AA (2022) New lichens records from Brazil. Archive For Lichenology 31: 1-51.

Aragón G, Martínez I, Hurtado P, Benítez A, Rodríguez C & Prieto M (2019) Using growth forms to predict epiphytic lichen abundance in a wide variety of forest types. Diversity 151: 1-14. <https://doi.org/10.3390/d11040051>.

Asta J, Erhardt W, Ferretti M, Fornasier F, Kirschbaum U, Nimis PL, Pirintsos S, Scheidegger C, Haluwyn C van & Wirth V (2002a) European guideline for mapping lichen diversity as an indicator of environmental stress [online]. Available at <http://www.merseysidebiobank.org.uk/>. Access on 10 May 2019.

Asta J, Erhardt W, Ferretti M, Fornasier F, Kirschbaum U, Nimis PL, Purvis OW, Pirintsos S, Scheidegger C, Van Haluwyn C & Wirth V (2002b) Mapping lichen diversity as an indicator of environmental quality. *In*: Nimis PL, Scheidegger C & Wolseley PA (eds.) Monitoring with Lichens-Monitoring Lichens, vol. 7. Kluwer Academic Publishers, Dordrecht. Pp. 273-279. <https://doi.org/10.1007/978-94-010-0423-7_19>.

Bartholmess H, Erhardt W, Frahm JP, Franzen-Reuter I, John V, Kirschbaum U, Turk R, Windisch U & Wirth V (2004) Biologische messverfahren zur ermittlung und beurteilung der wirkung von luftverunreinigungen auf flechten (Bioindikation). Kartierung der diversitat epiphytischer flechten als indikator fur die luftgüte. VDI 3957, Part 13. Verein Deutscher Ingenieure, Dusseldorf. 27p.

Bennet SJ & Simon A (2004) Riparian vegetation and fluvial geomorphology. Water Science and

Application 8. American Geophysical Union, Washington, DC. 282p.

Benítez A, Aragón G, González Y & Prieto M (2018) Functional traits of epiphytic lichens in response to forest disturbance and as predictors of total richness and diversity. Ecological Indicators 86: 18-26. <https://doi.org/10.1016/j.ecolind.2017.12.021>.

Cáceres MES, Aptroot A & Lücking R (2016) Lichen fungi in the Atlantic rain forest of Northeast Brazil: the relationship of species richness with habitat diversity and conservation status. Brazilian Journal of Biology 40: 145-156. <https://doi.org/10.1007/s40415-016-0323-6>.

Chuquimarca L, Gaona FP, Iñiguez-Armijos C & Benítez A (2019) Lichen responses to disturbance: clues for biomonitoring land-use effects on riparian andean ecosystems. Diversity: 11-73. <https://doi.org/10.3390/d11050073>.

Galloway DJ (2008) Lichen biogeography. *In*: Nash T (ed.) Lichen Biology. Cambridge University Press, New York. Pp. 315-335.

Gundersen P, Laurén A, Finér L, Ring E, Koivusalo H, Sætersdal M, Weslien JO, Sigurdsson BD, Högbom L, Laine J & Hansen K (2010) Environmental services provided from Riparian Forests in the Nordic Countries. Ambio 39: 555-566. <https://doi.org/10.1007/s13280-010-0073-9>.

Kalb K, Rivas Plata E, Lücking R & Lumbsch T (2011) The phylogenetic position of *Malmidea*, a new genus for the *Lecidea piperis* and *Lecanora granifera*-groups (Lecanorales, Malmideaceae), inferred from nuclear and mitochondrial ribosomal DNA sequences, with special reference to Thai species. Bibliotheca Lichenologica 106: 137-163.

Käffer MI & Martins SMA (2014) Evaluation of the environmental quality of a protected riparian forest in Southern Brazil. Bosque (Valdivia. Impresa) 35: 325-331. <http://dx.doi.org/10.4067/S0717-92002014000300007>.

Käffer MI, Martins SMA, Dantas RV & Maciel FC (2015) Composição da comunidade liquênica em floresta ribeirinha na APA do Ibirapuitã, RS, Brasil. Hoehnea 42: 273-288. <https://doi.org/10.1590/2236-8906-54/2014>.

Käffer MI, Port RK, Brito JBG & Schmitt JL (2021) Lichen functional traits and light influx in the analysis of environmental quality of subtropical riparian ecosystems. Ecological Indicators 125: 107510. <https://doi.org/10.1016/j.ecolind.2021.107510>.

Koch NM, Martins SMA, Lucheta F & Müller SC (2013) Functional diversity and traits assembly patterns of lichens as indicators of successional stages in a tropical rainforest. Ecological Indicators 34: 22-30. <https://doi.org/10.1016/j.ecolind.2013.04.012>.

Koch NM, Branquinho C, Matos P, Pinho P, Lucheta F, Martins SMA & Vargas VMF (2016) The application of lichens as ecological surrogates of air pollution in the subtropics: a case study in South Brazil. Environmental Science Pollution Research International 23: 20819-20834. <https://doi.org/10.1007/s11356-016-7256-2>.

Koch NM, Matos P, Branquinho C, Pinho P, Lucheta F, Martins SMA & Vargas VMF (2019) Selecting lichen functional traits as ecological indicators of the effects of urban environment. The Science of the Total Environment 654: 705-713. <https://doi.org/10.1016/j.scitotenv.2018.11.107>.

Lakatos M, Rascher U & Büdel B (2006) Functional characteristics of corticolous lichens in the understory of a tropical lowland rain forest. New Phytology 172: 679-695. <https://doi.org/10.1111/j.1469-8137.2006.01871.x>.

Lehnen PG, Kaffer MI, Lucheta F & Schmitt JL (2017) Estrutura da comunidade de liquens corticícolas em área urbana e rural no município de Novo Hamburgo, Rio Grande do Sul, Brasil. Iheringia Serie Botanica 72: 66-74. DOI: 10.21826/2446-8231201772107

Leite ABX, Menezes AAD, Souto LDS, Aptroot A, Lücking R, Santos VMD & Cáceres MED S (2015) Epiphytic microlichens as indicators of phytosociological differentiation between Caatinga and Brejos de Altitude. Acta Botanica Brasilica 29: 457-466. http://dx.doi.org/10.1590/0102-33062015abb0116

López LGC, Soto Medina EA & Peña AM (2016) Effects of microclimate on species diversity and functional traits of corticolous lichens in the Popayan Botanical Garden (Cauca, Colombia). Cryptogamie, Mycologie 37: 205-215. <https://doi.org/10.7872/crym/v37.iss2.2016.205>.

Lucheta F, Koch NM, Martins SMA & Schmitt JL (2018) Comunidade de liquens corticícolas em um gradiente de urbanização na Bacia Hidrográfica do Rio dos Sinos, no sul do Brasil. Rodriguésia 69: 323-334. <https://doi.org/10.1590/2175-7860201869205>.

Lucheta F, Koch NM, Käffer MI, Riegel RP, Martins SMA & Schmitt JL (2019) Lichens as indicators of environmental quality in southern Brazil: an integrative approach based on community composition and functional parameters. Ecological Indicators 107: 105587. <https://doi.org/10.1016/j.ecolind.2019.105587>.

Lücking R, Rivas-Plata E, Chaves JL, Umaña L & Sipman HJM (2009) How many tropical lichens are there really? Bibliotheca Lichenologica 100: 399-418.

Lücking R, Hodkinson BP & Leavit SD (2017) The 2016 classification of lichenized fungi in the Ascomycota and Basidiomycota - approaching one thousand genera. Bryologist 119: 361-416. <https://doi.org/10.1007/s13225-016-0374-9>.

McCune B, Grace JB & Urban DL (2002) Analysis of ecological communities. MjM Software, Gleneden Beach. 300p.

McCune B & Mefford MJ (2011) PC-ORD. Multivariate Analysis of Ecological Data. Version 6.08. MjM Software, Gleneden Beach. Available at <http://www.pcord.com>. Access in May 2021.

Molz M, Franz I, Mauhs J & Duarte A (2016) Unidades de conservação e formações florestais na bacia do Rio dos Sinos: diagnóstico e planejamento a partir da diversidade de árvores e aves. *In*: Anschau C (ed.) Atlas do Projeto Verdesinos. Ed. Anschau, Porto Alegre. Pp. 23-56

Mueller-Dombois D & Ellenberg H (1974) Aims and methods of vegetation ecology. John Wiley, New York. 574p.

Peel MC, Finlayson BL & McMahon TA (2007) Updated world map of the Koppen-Geiger climate classification. Hydrology and Earth System Sciences 11: 1633-1644. <https://doi.org/10.5194/hess-11-1633-2007>.

Prosinos (2011) Caracterização Socioambiental da região da Bacia Hidrográfica do Rio dos Sinos. Available at <www.prosinos.rs.gov.br>. Access on 20 August 2020.

Resl P, Fernández-Mendoza F, Mayrhofer H & Spribille T (2018) The evolution of fungal substrate specificity in a widespread group of crustose lichens. Proceedings of the Royal Society 285: 20180640. <https://doi.org/10.1098/rspb.2018.0640>.

Ribeiro-Filho AA, Funch LS & Rodal MJN (2009) Composição florística da floresta ciliar do Rio Mandassaia. Parque Nacional da Chapada Diamantina, Bahia, Brasil. Rodriguésia 60: 265-276. <http://dx.doi.org/10.1590/2175-7860200960203>.

Ripple WJ, Wolf C, Newsome TM, Galetti M, Alamgir M, Crist E, Mahmoud MI, Laurance WF & 15,364 scientist signatories from 184 countries (2017) World scientists' warning to humanity: a second notice. BioScience 67: 1026-1028. <https://doi.org/10.1093/biosci/bix125>.

Rivas-Plata E, Parnmen S, Staiger B, Mangold A, Frisch A, Weerakoon G, Hernández JE, Cáceres MES, Kalb K, Sipman HJM, Common RS, Nelsen MP, Lücking R & Lumbsch HT (2012) A molecular phylogeny of Graphidaceae (Ascomycota: Lecanoromycetes: Ostropales) including 428 species. MycoKeys 6: 55-64. <https://doi.org/10.3897/mycokeys.6.3482>.

Rocha-Uriartt L, Becker DFP, Graeff V, Koch NM & Schmitt JL (2016) Functional patterns and species diversity of epiphytic vascular spore-producing plants in riparian forests with different vegetation structure from southern Brazil. Plant Ecology and Evolution 149: 261-271. <http://dx.doi.org/10.5091/plecevo.2016.1234>.

Secretaria do Ambiente e Desenvolvimento Sustentável. Bacia hidrográfica do Rio dos Sinos (2019) Bacias Hidrográficas. Available at <https://sema.rs.gov.br/bacias-hidrograficas>. Access on 20 June 2018.

Soto-Medina E, Lücking R, Silverstone-Sopkin PA & Torres AM (2019) Changes in functional and taxonomic diversity and composition of corticolous lichens in an altitudinal gradient in Colombia. Cryptogamie, Mycologie 40: 97-115. <https://doi.org/10.5252/cryptogamie-mycologie2019v40a6>.

Thell A, Crespo A, Divakar PK, Kärnefelt I, Leavitt SD, Lumbsch HT & Seaward RD (2012) A review of the lichen family Parmeliaceae - history, phylogeny and current taxonomy. Nordic Journal of Botany 30: 641-664. <https://doi.org/10.1111/j.1756-1051.2012.00008.x>.

Timdal E (2008) Studies on *Phyllopsora* (Ramalinaceae) in Peru. The Lichenologist 40: 337-362. <https://doi.org/10.1017/S0024282908007846>.

Tripp EA, Lendemer JA & McCain CM (2019) Habitat quality and disturbance drive lichen species richness in a temperate biodiversity hotspot. Oecologia 190: 445-457. <https://doi.org/10.1007/s00442-019-04413-0>.

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