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RESEARCH ARTICLE

# Responses of water mite assemblages (Acari) to environmental parameters at irrigated rice cultivation fields and native lakes

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ABSTRACT. Many studies have revealed that water mite communities can be affected by the physical and chemical parameters of the water. The similarity between the water 'mite assemblages in local water bodies and in irrigated rice areas can be a way to measure the water conditions, enabling an assessment of the anthropic impact in the environment. The aim of this study was to evaluate the distribution of water mites in lakes and irrigated rice fields in south Brazil. To accomplish that we characterized the distinctive environments using physical and chemical variables such as pH, turbidity (NTU), water temperature (°C) and dissolved oxygen (mg/L), in order to verify the influence of these abiotic factors on the species composition of water mite communities; and to compare water mite abundance, richness and composition among different habitats. We assessed three native lakes and four sites with irrigated rice cultivation. Our results showed, for the first time in Brazil, strong correlations between the water mite fauna and turbidity. In addition, native lakes were richer and had greater mite abundance when compared with the irrigated rice areas.

KEY WORDS. Coastal plain, habitat, physical and chemical variables, rice field, water mite.

## INTRODUCTION

Most freshwater mites belong to Hydrachnidiae (Acari: Prostigmata), which are represented by ca. 6,000 species. These mites can live in wetlands, temporary pools, springs, marine habitats, torrential waterfalls, ponds, streams and lakes (Smith and Cook 1991, Goldschmidt 2016). Another important acarine group that inhabits aquatic zones includes members of the suborder Oribatida. These mites can be abundant, but their species richness is very low (Fernandez and Athias-Binche 1986). Water mites have been used as environmental quality bioindicators in several ecosystems (Biesiadka and Kowalik 1991, Rousch et al. 1997, Di Sabatino et al. 2002, Dohet et al. 2008, Goldschmidt 2016). Many studies have revealed that water mite communities can be affected by several abiotic factors, such as pollution agents and variations in temperature, dissolved oxygen, conductivity and carbonate concentrations (Schwoerbel 1961, Więcek et al. 2013). Many efforts are being made to effectively employ mites as ecological indicators, including faunal monitoring programs (Goldschmidt 2016).

Brazil is the ninth leading rice grower in the world, and the state of Rio Grande do Sul accounts for approximately 69% of country's rice production (IBGE 2015). With the addition and growth of areas of irrigated crop production such as rice, monitoring water quality has acquired growing importance. In Brazil, the Restinga in the South is one of the regions where there is massive irrigated rice cultivation. This region includes a portion of the Atlantic forest biome and it is under extreme anthropogenic pressure, which has modified the natural landscapes (Ab'Saber 2003). The decline in water quality resulting from intense contamination has resulted in decreasing numbers of water mites, lower water mite diversity and in some cases, a collapse of the water mite fauna (Kowalik and Biesiadka 1981).

In general, the water used to irrigate crops comes from several freshwater lakes and ponds located in the vicinities of crop fields. Therefore, comparisons between the water mite assemblages from native lakes and irrigated rice areas can be used to measure water quality, enabling an assessment of the impact of agriculture on the environment.

The composition of water mite species in irrigated rice areas is generally poorly understood. This work is the first trying to ascertain the water mite community in such an environment. This study has two goals: (1) to compare the abundance, richness and composition of the water mite fauna from different habitats; (2) to verify the influence of the following abiotic factors on species composition: pH, turbidity (NTU), water temperature (°C), and dissolved oxygen (mg/L). Our hypotheses are: (1) Different habitats should influence the abundance, richness and species composition of the water mite community; (2) water mites should respond to the physical and chemical parameters measured, reflecting the different conditions of their sample sites.

## MATERIAL AND METHODS

Our study was conducted in the municipality of Mostardas, Rio Grande do Sul, Brazil. The study area is situated in the coastal plains (Table 1) (Assis et al. 2011, Magnago et al. 2010). The original vegetation cover is open. It is dominated by herbaceous plants and shrubs that have xerophytic adaptations (Assis et al. 2011, Lima et al. 2011), together with other associated Atlantic forest elements (Magnago et al. 2010).

All rice areas from which samples were taken for this survey had been cultivated for three months, and were in the mid to late vegetative phase (tillering to stem elongation) to mid to late reproductive phase (heading to flowering), when the rice fields were flooded. We chose seven sampling areas: four at an irrigated rice cultivation area (R1, R2, R3, R4), in which sampling was carried out during the rice growing season (January-March/15); and three in native lakes (L1, L2, L3) (Figs 1–9). Both L2 and L3 are connected by a narrow water channel. The rice areas R1 and R2 are supplied by L2 and L3 (distance among rice areas to native lakes: 1 km) placed in Farm 1, whereas R3 and R4 are supplied by the northern portion of a lagoon known as Lagoa dos Patos. This lagoon is separated from the Atlantic Ocean by a barrier beach system. According to Madeira-Falceta (1974), the salinity levels in the northern part of this lagoon are very low (freshwater). The L1 area is a permanent native lake, isolated from human disturbances and away from rice areas. The distance from R3, R4 to L1 is 2 km, the former two located in Farm 2. The distance between these two farms (Farm 1 and 2) is 5 km.

The native lake areas had the following characteristics: permanent lakes, and surrounding vegetation consisting basically of grasses. Cattle rearing and fishing are a very common practice near L2 and L3. Additionally, there are aquatic macrophytes (*Salvinia* spp., *Pistia* spp., *Eleocharis* spp., *Lemma* spp.) often covering the surface of the water.

Table 1. Seven sampled areas with geographical coordinates and numbers of samples collected between January to March 2015.

| Site name | Longitude | Latitude | Number of samples | Altitude (m) |
|---|---|---|---|---|
| Rice area 1 (R1) | 30°33′55.29″S | 50°36′39.76″W | 4 | 4 |
| Rice area 2 (R2) | 30°34′14.75″S | 50°36′35.52″W | 4 | 5 |
| Rice area 3 (R3) | 30°35′25.13″S | 50°39′25.91″W | 4 | 9 |
| Rice area 4 (R4) | 30°35′30.68″S | 50°39′18.85″W | 4 | 7 |
| Lake 1 (L1) | 30°35′11.29″S | 50°40′38.92″W | 4 | 5 |
| Lake 2 (L2) | 30°33′15.40″S | 50°36′51.10″W | 4 | 0 |
| Lake 3 (L3) | 30°33′39.88″S | 50°36′49.02″W | 4 | 1 |

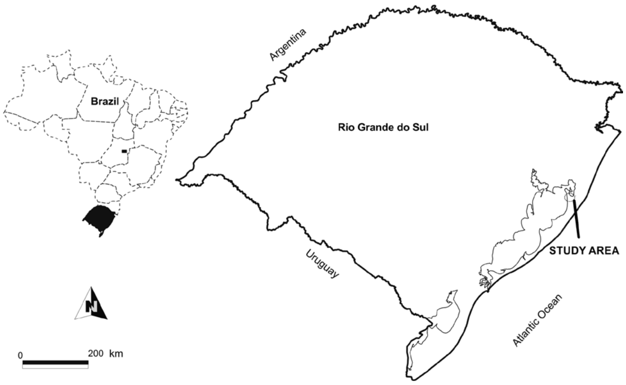



Figure 1. Schematic map of Brazil and Rio Grande do Sul State illustrating the study area.

Samplings were carried out from January to March 2015, two per month. In March, only one sampling was performed, on the first week of the month. A total of five samplings were carried out at each area. For the assessment of species' composition, only adult mites were evaluated. For this reason, L1, L2, L3, R1 were used in all data analyses, whereas only three samplings from rice areas R2 and R3, and four from R4, were analyzed.

Samples were collected five meters from the margin of the lake and rice field at maximum of 40 cm depth. Each sample consisted of 10 liters of water collected using a plastic tray (50 x 30 cm), and filtered through a net (mesh size 250 µm). The water mites caught in the net were transported to the laboratory in water gallons, and were later preserved in Koenike's fluid (Mitchell and Cook 1952, Barr 1973).

Specimens were identified to species using a phase-contrast light microscope (Leica DM750) with the help of identification keys (Rosso de Ferradás and Fernández 2009, Smith et al. 2009). Specimens collected were deposited in the mite reference collection of the Museum of Natural Sciences of the University Center UNIVATES (ZAUMCN), Lajeado, Rio Grande do Sul, Brazil.


Figures 2–9. View of the study sites: (2) Detailed view of the rice-water samples, (3) Rice area 1 – R1, (4) Rice area 2 – R2, (5) Rice area 3 – R3, (6) Rice area 4 – R4, (7) Lake 1 – L1, (8) Lake 2 – L2, (9) Lake 3 – L3.

We measured the values of water temperature, turbidity, pH and dissolved oxygen using portable instruments (DM-2P; DM-4P; DM-TU: Digimed) and all variables were measured when and where samples were collected. There were no records of phytosanitary treatments with pesticides during the study, in the sampling areas.

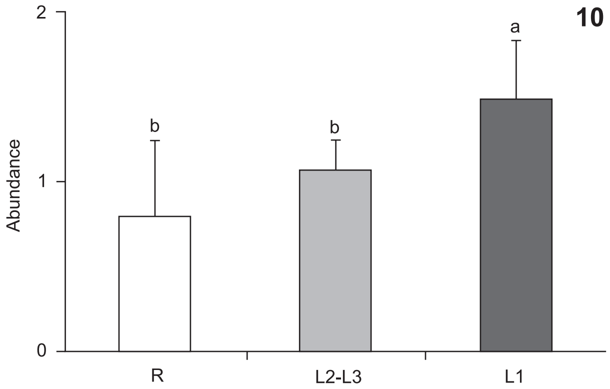
At each sampling point, species composition was analyzed considering the abundance of each species per location (quantitative data). In order to investigate whether abundance and richness of mite species varied according to the different areas, factor analyses of variance (Factorial ANOVA) were performed. These areas were characterized in three clusters of environments (R1-R4, L2-L3, L1). Based on these quantitative data, we obtained an association matrix between sampling points using Bray-Curtis similarity indices.

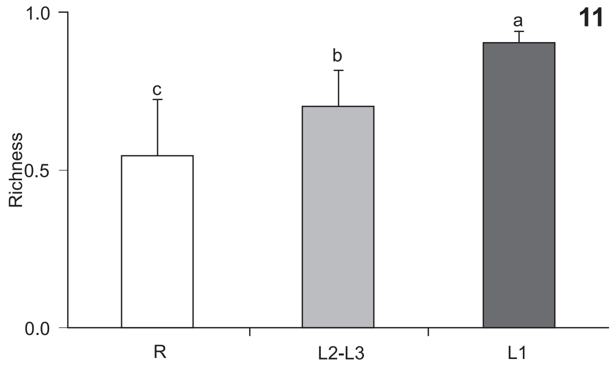
Using distance matrices calculated based on mite species composition, we performed an ordination using a Non-Metric Multidimensional Scaling (NMDS) with Bray-Curtis (quantitative) and Jaccard (qualitative) distance and two dimensions to visualize how species composition varied between environments (Rice Areas R1-R4 vs. Native lakes L2-L3 vs. L1). Species abundance and values of abiotic and biotic factors were Log transformed (x+1) and subsequently normalized and centralized through vectored transformations. Additionally, in order to reveal the effects of the environment on community dissimilarity, we tested whether abiotic and biotic factors adjusted to the ordination model (NMDS) by using the Envfit function. The One-factor Similarity Analyses (ANOSIM) (Clarke and Warwick 2001) tested for statistical differences in the composition of communities from different environments. SIMPER analysis (Similarity Percentage) was applied to assess which species contributed to the similarity/dissimilarity among environments (Clarke and Warwick 2001). The contribution amounts of each species were expressed as a percentage. Transformations of abundances and values of environmental factors were calculated using MULTIV software (Pillar 2004). Factorial ANOVA's and linear regressions were verified using the statistical program SYSTAT 13 (Systat Inc.). ANOSIM and SIMPER multivariate analyses were carried out using the PASt program (Paleontological Statistics, version 1.97) (Hammer et al. 2009). Mantel's, NMDS and Envfit analyses were performed using the R program, "vegan" package. The significance level was $p < 0.05$ for all statistical tests.

## RESULTS

We found a total of 514 water mites, 477 were adults, distributed in 9 families, 10 genera and 19 species/morphospecies (Table 2).

The most abundant water mite morphospecies were *Koenikea* sp. 1 (Unionicolidae) (179 specimens), followed by *Limnesia* sp. 1 (84) (Limnesiidae) and *Koenikea* sp. 3 (38). Among the areas evaluated, L1 was the richest (15 species), followed by L2 (10) and L3 (9); and the order of abundance was L1 (197 specimens) followed by R2 (88) and L2 (61).



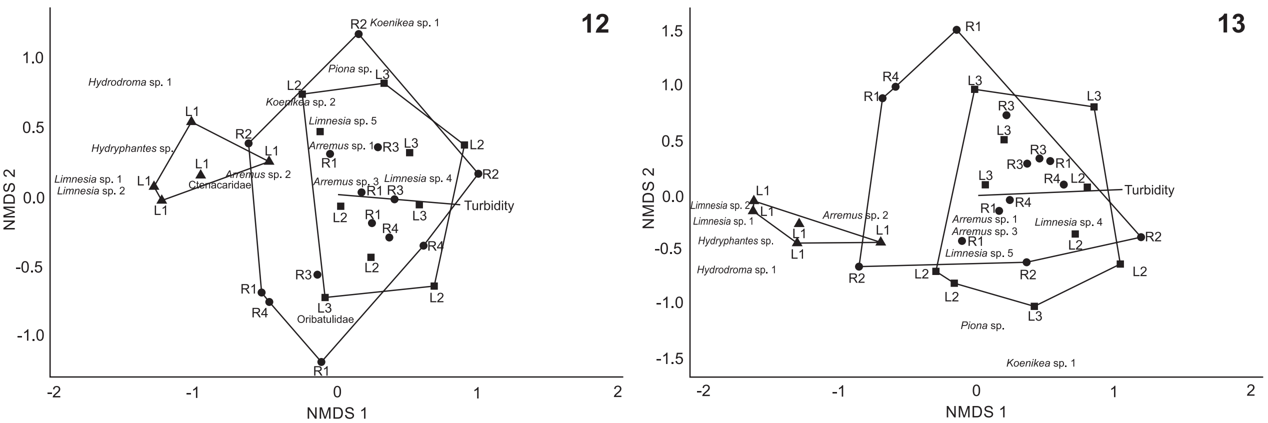

Figures 10–11. Abundance and richness of mites in rice areas cultivation and native lakes: (10) abundance adults (± SD) (Log10 X+1); (11) richness (± SD) (Log10 X+1). Different letters indicate significant differences, Tukey test, $p < 0.05$.

The abundance (N) of adult mites differed among the environments surveyed ($F_{2,27} = 6.871$, $p = 0.004$). The Tukey post-hoc test revealed differences between L1 and the rice areas (R1-R4) ($p = 0.003$), but not between L1 and L2, L1 and L3 ($p = 0.117$); thus, R1-R4 and L2-L3 ($p = 0.178$) (Fig. 10). Regarding richness, there was a significant difference among environments ($F_{2,27} = 11.663$, $p < 0.001$). The Tukey post-hoc test revealed a difference in richness between L1 and the rice areas (R1-R4) ($p < 0.001$), L1 with L2-L3 ($p = 0.005$) and R1-R4 with L2-L3 ($p = 0.003$) (Fig. 11).

The mite fauna composition among environments was significantly different (Bray-Curtis: $R2 = 0.2657$, $p = 0.01$; Jaccard: $R2 = 0.1551$, $p < 0.001$) (Figs 12, 13). The post-hoc test showed differences in mite composition among L1 and the rice areas (R1-R4) (Bray-Curtis, $p = 0.002$; Jaccard, $p = 0.003$) and among L1 and L2, L3 (Bray-Curtis, $p = 0.004$; Jaccard, $p = 0.002$), but not among R1-R4 and L2-L3 (Bray-Curtis, $p = 0.2946$; Jaccard, $p = 0.3934$). Through SIMPER analysis, the *Limnesia* sp. 4 (Limnesiidae) (Contrib.% 20.1), Oribatulidae (Contrib.% 16.44) and *Arrenurus* sp. 1 (Arrenuridae) (Contrib.% 14.35) with higher val-

Table 2. List of water mite species and number of individuals collected (January to March/2015) in three lakes (L1, L2, L3) and four irrigated rice area cultivation (R1, R2, R3, R4) in Southern Brazil.

| Order | Family | Species | Rice area 1 (R1) | Rice area 2 (R2) | Rice area 3 (R3) | Rice area 4 (R4) | Lake 1 (L1) | Lake 2 (L2) | Lake 3 (L3) | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Trombidiformes | Arrenuridae | *Arrenurus* sp. 1 | 7 | 3 | 6 | – | 5 | 4 | 7 | 32 |
| | | *Arrenurus* sp. 2 | – | – | – | 1 | 5 | 2 | – | 8 |
| | | *Arrenurus* sp. 3 | – | – | – | – | 1 | 1 | – | 2 |
| | Eylaidae | *Eylais* sp. | – | – | – | – | 1 | – | – | 1 |
| | Hydrodromidae | *Hydrodroma* sp. 1 | – | – | – | – | 36 | – | – | 36 |
| | | *Hydrodroma* sp. 2 | – | – | – | – | 1 | – | – | 1 |
| | Hydryphantidae | *Hydryphantes* sp. | – | – | – | – | 5 | – | – | 5 |
| | Limnesiidae | *Limnesia* sp. 1 | 6 | 2 | 18 | 11 | 2 | 21 | 24 | 84 |
| | | *Limnesia* sp. 2 | – | – | – | – | 1 | 2 | 4 | 7 |
| | | *Limnesia* sp. 3 | – | 1 | 1 | – | – | 1 | 4 | 7 |
| | | *Limnesia* sp. 4 | – | – | – | – | – | – | 4 | 4 |
| | | *Limnesia* sp. 5 | – | – | – | – | – | – | 2 | 2 |
| | Pionidae | *Piona* sp. | 5 | – | 3 | 8 | – | 11 | 3 | 30 |
| | Unionicolidae | *Koenikea* sp. 1 | 3 | 47 | 1 | 2 | 121 | 3 | 2 | 179 |
| | | *Koenikea* sp. 2 | – | 4 | – | – | 8 | – | – | 12 |
| | | *Koenikea* sp. 3 | 1 | 31 | 1 | 3 | 1 | 1 | – | 38 |
| | | Neumania sp. | – | – | – | – | 1 | - | – | 1 |
| Sarcoptiformes | Oribatulidae | sp. | – | – | – | – | 6 | 15 | 4 | 25 |
| | Ctenacaridae | sp. | – | – | – | – | 3 | – | – | 3 |
| | Total | | 22 | 88 | 30 | 25 | 197 | 61 | 54 | 477 |




Figures 12–13. Ordination diagram (first two axes) of Non-Metric Multidimensional Scaling (NMDS) using (12) Bray-Curtis and (13) Jaccard indexes with Envfit function for the evaluated environments. (▲ Lake 1, ■ Lake 2 and 3, ● Rice Area). Stress: 0.15.

ues of abundance R1-R4 and at L2-L3, Ctenacaridae (Contrib.% 16.07) and *Hydryphantes* sp. (Hydryphantidae) (Contrib.% 10.31) contributed the most to the dissimilarity among environments. Thus, *Arrenurus* sp. 2 (Contrib.% 4.721) and *Limnesia* sp. 2 (Contrib.% 2.085) had higher values of abundance in L1.

Among the evaluated environmental parameters (Table 3), the Envfit analysis demonstrated that turbidity (r2 = 0.2725, p = 0.01) was the only factor that contributed substantially to variations in the water mite communities of the aquatic environment. Additionally, among the environmental parameters evaluated only turbidity was statistically significant ($F_{2,27}$ = 6.292, p = 0.006). The greatest turbidity levels were measured in L2, L3, followed by R1-R4 and finally, L1, which had the lowest turbidity levels.

Table 3. Physiochemical variables (mean ± SE) evaluated from different habitats in this study (Jan-Mar/15).

| Site name | pH | Water temperature (°C) | $O_2$ dissolved (mg/l) | Turbidity (NTU) |
|---|---|---|---|---|
| Rice area 1 (R1) | 7.73 ± 0.5 | 26.13 ± 1.49 | 5.08 ± 0.86 | 41.43 ± 20.33 |
| Rice area 2 (R2) | 7.56 ± 0.5 | 26.5 ± 1.58 | 4.8 ± 0.88 | 46.89 ± 46.05 |
| Rice area 3 (R3) | 7.51 ± 0.9 | 28.38 ± 2.14 | 5.55 ± 1.64 | 31.42 ± 33.48 |
| Rice area 4 (R4) | 7.67 ± 0.7 | 29.88 ± 3.28 | 6.25 ± 1.37 | 7.05 ± 2.46 |
| Lake 1 (L1) | 8.31 ± 0.2 | 28.5 ± 1.58 | 5.2 ± 0.84 | 5.80 ± 6.51 |
| Lake 2 (L2) | 8.09 ± 0.6 | 25.5 ± 1.68 | 3.48 ± 0.71 | 29.14 ± 10.67 |
| Lake 3 (L3) | 8.01 ± 0.9 | 26.63 ± 1.89 | 5 ± 1.07 | 43.1 ± 18.65 |

## DISCUSSION

We found differences in the composition of the water mite communities between rice areas and the isolated native lake in which the parameter turbidity influenced the composition of the population of water mites. In addition, it was possible to observe that the native lakes carry a greater richness of water mite species when compared with irrigated rice areas. The greatest number of species was found in native ponds, not in rice areas. *Eylais* sp., *Hydrodroma* species, *Neumania* sp. and Ctenacaridae were exclusively collected in L1, *Limnesia* sp. 3 and *Limnesia* sp. 4 in L3. Only two species were present in all samples sites, *Koenikea* sp. 1 and *Limnesia* sp. 1, while all species that were present in rice areas were also found simultaneously in one of the native lakes. No species occurred exclusively in rice areas.

The greater abundance and richness of water mites in L1 may be due to the low levels of turbidity, and the fact that this lake is isolated and does not suffer the impact of human action. The turbidity of the water is caused by the suspended sediment. These can originate from the organic input from microorganisms, including bacteria and algae, and external input from leaf litter and debris, and decaying carcasses of invertebrates (Laessle 1961, Maguire Jr 1971). In addition, high turbidity levels can decrease the penetration of light and reduce the water quality, significantly reducing the water resources utilized by these mites (Copatti et al. 2013). Some of the water mite species are strongly positively phototropic; however, each family responds differently to various wavelengths (Roberts et al. 1978). No relationships were found between the composition of water mite species and the other physical and chemical variables such as pH, dissolved $O_2$ and water temperature. Więcek et al. (2013) found a strong correlation between the water mite fauna, and the environment variables such as conductivity and pH gradient; however, those authors did not measure turbidity. Both pH and conductivity can be used to assess the mineral richness of the water.

An explanation for a higher richness of water mites at certain sites than at others is the differing dispersion ability of these arthropods. The dispersion process is very important, since it allows the expansion of mite populations, the colonization of different areas, and escaping from natural enemies (Binns 1982, Zawal et al. 2013, Knee et al. 2013). Most larval water mites are parasites of insect, which facilitates their dispersal (Smith et al. 2009, Williams and Proctor 2002). The phoretic behavior observed in several families of water mites allows for a passive transport of dispersion (Zawal et al. 2013). There are several records of *Arrenurus*, *Hydrachna* and *Limnochares* involving parasitized insects (Munchberg 1954, Mullen 1975, Stechmann 1980, Smith and Cook 1991, Snell and Heath 2006, Milne et al. 2009, Kirkhoff et al. 2013). It is possible that the absence of mite host taxa could be responsible for the low number of mites. Another, simpler explanation, is that richness has decreased in response to environmental changes.

Furthermore, we suggest that the dispersion pathways used by water mites to colonize adjacent environments are related to the route of the flow paths, as it can be observed in many species collected in this study (*Arrenurus* sp. 1, *Limnesia* sp. 1, *Limnesia* sp. 3, *Piona* sp., *Koenikea* sp. 1, *Koenikea* sp. 3) and which were found simultaneously in the native lake areas (L2-L3) that supply the rice areas (R1-R2).

Several species of water mites exploit aquatic plants, since these plants create the substrate required for the life cycles of water mites and their hosts. Several water mites lay eggs and transform from deutonymphs to tritonymphs among aquatic mosses and macrophytes (Smith et al. 2009). Macrophyte plants offer suitable conditions for various host taxa, playing a large role in the dispersion and colonization of new patches by water mites (Martin 2008). Therefore, the presence of macrophytes in general in lakes probably is probably a factor influencing water mite diversity. Więcek et al. (2013) reported that some species of *Arrenurus* are associated with abundant growth of macrophytes.

The conservation of native lakes is very important to preserve biodiversity. Thus, aquatic mites might be used as diversity bioindicators when comparing natural and anthropized environments. Young (1969) described that water mite communities (diversity, abundance and community structure) are sensitive to contamination. Several sensitive species are restricted to very clean water and immediately respond to the early contamination of their environment. Thus, water mites are excellent indicators of pure water conditions and provide a powerful early warning system (Zawal 1996, Miccoli et al. 2013). Species of the genus *Limnesia* are very sensitive to altered sites (Van der Hammen and Smit 1996) and, according to our study, *Limnesia* sp. 4 showed greater dissimilarity in R1-R4 and L2-L3 environments while Ctenacaridae, *Hydryphantes* sp., *Arrenurus* sp. 2 and *Limnesia* sp. 2 to L1.

The abundance and diversity of water mites was significantly higher in unpolluted sites (Growns 2001). Water mites can be powerful biomonitoring tools, fulfilling all adequate requirements for a bioindicator (Goldschmidt 2016). Our results confirm that anthropized areas have lower richness of water mites than native areas, as suggested by Katayama et al. (2015). They observed a decline in richness and abundance at a consolidated rice field. In the future, it is possible that water mites will be implemented in faunal surveys as an important group for biomonitoring, becoming an important tool in areas of environmental protection where there are watercourses. The water mite community is not sufficiently known yet. Considering Brazil's vast territory with large affluent and unexplored areas, it would be important to carry out more studies in the country. This study compared, for the first time, the water mite species from native lakes associated with irrigated rice areas in southern Brazil.

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