Composition and richness of monogonont rotifers from La Plata River Basin, South America

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Abstract: We present here the first study that analyzed the composition and richness of rotifers of the entire La Plata River basin, the second largest in South America, based on simultaneous and standardized sampling. Fifteen large reservoirs and eight river stretches were selected in the upper, middle, and lower portions of the Paraná, Paraguay, and Uruguay Rivers, which are the major rivers of the La Plata basin. We took a total of 86 samples (open water habitats) in 2010. A mean of 27±11 species per sub-basin was found, with the highest richness in the Lower Paraná (41 species), followed by the Paranapanema (40 species) and Lower Uruguay (38 species). Low richness was observed in the Middle Uruguay and Middle Paraná. We found 106 species belonging to 21 families and two orders. The family with the highest number of species was Lecanidae (21), followed by Brachionidae (20), Trichocercidae (9), and Synchaetidae (8). The species with higher occurrences were Conochilus dossuarius, Kellicottia bostoniensis, Keratella americana, Keratella cochlearis and Hexarthra mira. New occurrences of rotifers were registered for Brazil (Colurella adriatica), São Paulo State (Enteroplea lacustris), and Argentina (Gastropus hyptopus, Harringia rousseleti and Lecane thienemanni). Spearman correlation between the number of species and physical and chemical variables demonstrated positive correlation with chlorophyll and temperature, and negative correlation with dissolved oxygen. We extend the distribution list for some native (Lecane ludwigii) and non-native species of rotifers (K. bostoniensis). We also list the monogonont rotifer species found at the sampling stations.

Keywords: Biodiversity; Rotifera; Survey; New records; Lotic; Lentic environments.

Composição e riqueza de rotíferos Monogononta da Bacia do Rio da Prata, América do Sul

Resumo: Apresentamos aqui o primeiro estudo que analisou a composição e riqueza de rotíferos de toda a bacia do Rio da Prata, a segunda maior da América do Sul, com amostragens simultâneas e padronizadas. Quinze grandes reservatórios e oito trechos lóticos foram selecionados nas porções alta, média e baixa dos rios Paraná, Paraguai e Uruguaí, que atuam como os principais formadores da bacia do Prata. Coletamos um total de 86 amostras (habitats de águas abertas) em 2010. Foi encontrada uma média de 27 ± 11 espécies por sub-bacia, com maior riqueza no Baixo Paraná (41 espécies), seguido por Paranapanema (40 espécies) e Baixo Uruguai (38 espécies). Uma baixa riqueza foi observada no Médio Uruguai e no Médio Paraná. Encontramos 106 espécies pertencentes a 21 famílias e duas ordens. A família com maior número de espécies foi Lecanidae (21), seguida por Brachionidae (20), Trichocercidae (9) e Synchaetidae (8). As espécies com maior ocorrência foram Conochilus dossuarius, Kellicottia bostoniensis, Keratella americana, Keratella cochlearis e Hexarthra mira. Novas ocorrências de rotíferos foram registradas para o Brasil (Colurella adriatica), Estado de São Paulo (Enteroplea lacustris) e Argentina (Gastropus hyptopus, Harringia rousseleti e Lecane thienemanni). A correlação de Spearman entre o número de espécies e as variáveis físicas e químicas demonstrou correlação positiva com clorofila e temperatura, e correlação negativa com oxigênio dissolvido. Estendemos a lista de distribuição para algumas espécies nativas (Lecane ludwigii) e não-nativas de rotíferos (K. bostoniensis). Disponibilizamos também uma lista de espécies de rotíferos Monogononta encontrados nas estações amostradas.

Palavras-chave: Biodiversidade; Rotifera; Levantamento; Novos Registros; Lótico; Ambientes lênticos.
Introduction

Species inventories are important tools for conservation measures and management, especially in areas imperiled by human actions. It is also useful to show gaps in the scientific knowledge about zooplankton diversity and directions for future research.

There have been surveys of Rotifera diversity in the La Plata River basin, the second largest in South America. However, these surveys have focused on regions such as in the Upper Paraná floodplain (Lansac-Tôha et al. 2009), waterbodies of São Paulo State (Souza-Soares et al. 2011), and a few tributaries (Neschuk et al. 2002, Kuczyński 2017). There have been no basin-wide surveys that included all the countries drained by the basin.

The La Plata River basin has very distinct environments, with extensively dammed and undammed reaches. For example, there are reservoirs in more than half of the upper reaches in the Paraná River basin, leaving few truly lotic reaches; the opposite occurs in its middle and lower reaches (Agostinho et al. 2007). The situation is very similar for the Uruguay River. However, there are no reservoirs in the Paraguay River (Perbiche-Neves et al. 2016). This results in different habitats with distinct limnological features, which may favor differences in rotifer species composition among lotic and lentic regions.

There have been multiple studies of rotifer richness and distribution in Brazilian and Argentinian waters of the La Plata River basin. For example, Garraffoni & Lourenço (2012) surveyed rotifer species throughout Brazil. Other rotifer surveys were less extensive, such in Mato Grosso do Sul (Roche & Silva 2017), São Paulo (Souza-Soares et al. 2011), the Upper Tietê River basin (Lucinda et al. 2004), and Paraná Reservoir (Padovesi & Andreoni 2011). Despite those surveys, the number of rotifer surveys are underrepresented (Souza et al. 2018), when compared to other groups of zooplankton such as copepods (Silva et al. 2009, Matsumura-Tundisi & Tundisi 2011, Perbiche-Neves et al. 2014).

For Argentina, José de Paggi (1990) listed 279 rotifer taxa. Most rotifer surveys have been in the Paraná River floodplains (Aoyagui & Bonecker 2004) and La Plata River tributaries (Macluf et al. 1998, Modenutti 1998, Bazzuri et al. 2020). Recently, Ferrando & Claps (2016) updated the checklist of Argentinian Rotifera, including a reporting 35 species of monogonont rotifers. According to the authors, “[...] the majority of reports were restricted to the provinces of Santa Fe (68% of the total records), Corrientes and Buenos Aires (50% of the total records), Río Negro and Formosa (30% of the total records)” (Ferrando & Claps 2016; p.2). The rotifer species which are more commonly found in Argentinian Paraná River reaches and La Plata River tributaries were Keratella cochlearis (Gosse, 1851), K. americana Carlin, 1943 and Brachionus calyciflorus Pallas, 1776 (Modenutti 1998, Bonetto & Wais 2006).

Knowledge of the diversity and distribution of rotifers in the Paraguay River basin is scarce and concentrated in Brazil and Argentina, including rivers in the Pantanal (Branco et al. 2018, Brito et al. 2020) and those joining the Paraná River (Frutos et al. 2006). Similarly, few rotifer surveys have been conducted in the Uruguay River basin (e.g., José de Paggi 1978; Picapedra et al. 2019).

Therefore, we provide for the first time a spatially extensive survey of Rotifera species found in the lentic and lotic stretches of the La Plata River basin to characterize its species diversity patterns. In addition, we have expanded the distribution of some Rotifera species not yet reported in the literature, thus contributing to the general knowledge of the diversity of the group in the region.

Materials and Methods

1. Study area

The La Plata River basin has an area of 3.1 million km² (Cuya et al. 2013) and drains portions of five countries: Brazil, Paraguay, Uruguay, Argentina, and Bolivia. The main sub-basins are the Paraná, Paraguay, and Uruguay River basins. The Paraná basin is the largest, covering 48.7% of the basin, followed by the Paraguay (35.3%) and Uruguay (11.8%) basins (Cuya et al. 2013).

2. Sampling

A total of 86 samples were collected at 43 stations, including 15 reservoirs (in dam and upriver zones) and 13 lotic stretches distributed in the three main sub-basins of La Plata River (Figure 1, Table 1). Sites (open water - littoral habitats were not included) were sampled in January (summer - wet season) and July (winter- dry season) 2010. Ten water quality variables were measured at each sampling station during each visit following Perbiche-Neves et al. (2016) and Pessotto & Nogueira (2018): total phosphorus and nitrogen, temperature, transparency, turbidity, conductivity, pH, dissolved oxygen, depth, and total chlorophyll.

Figure 1. Locations of the 43 sites in La Plata River basin, with data of water retention time (WRT) and water velocity of the river stretches. For codes see Table 1. Adapted from Perbiche-Neves et al. (2016).
Table 1. Acronyms of the sites, sub-basin, geographical coordinates and habitat type sampled in the La Plata River basin. Number (n°) represents the sampling stations in the basin. Codes: ARG – Argentina, BRA – Brazil, PAR – Paraguay, URU – Uruguay.

| Site                              | Sub-basin          | Coordinates         | Acronyms   | No | Habitat |
|-----------------------------------|--------------------|---------------------|------------|----|---------|
| Emborcação HPP – MG/GO – BRA      | Paranaíba          | 18°26’28.43”S       | EMB-U      | 1  | Lentic  |
|                                    |                    | 47°58’59.59”W       | EMB-D      | 2  | Lentic  |
| São Simão HPP – MG/GO – BRA       | Paranaíba          | 19°00’04.51”S       | SSIM-U     | 3  | Lentic  |
|                                    |                    | 50°29’47.69”W       | SSIM-D     | 4  | Lentic  |
| Furnas HPP – MG – BRA             | Grande             | 20°39’38.30”S       | FUR-U      | 5  | Lentic  |
|                                    |                    | 46°18’01.65”W       | FUR-D      | 6  | Lentic  |
| Água Vermelha HPP – MG/SP – BRA   | Grande             | 19°51’58.67”S       | AVER-U     | 7  | Lentic  |
|                                    |                    | 50°19’11.62”W       | AVER-D     | 8  | Lentic  |
| Ilha Solteira HPP – SP/MS – BRA   | Upper Paraná       | 20°21’43.24”S       | ISOL-U     | 9  | Lentic  |
|                                    |                    | 51°21’14.53”W       | ISOL-D     | 10 | Lentic  |
| Barra Bonita HPP – SP – BRA       | Tietê              | 22°31’23.48”S       | BBON-U     | 11 | Lentic  |
|                                    |                    | 48°31’56.30”W       | BBON-D     | 12 | Lentic  |
| Três Irmãos HPP – SP – BRA        | Tietê              | 20°39’32.50”S       | TIRM-U     | 13 | Lentic  |
|                                    |                    | 51°16’56.16”W       | TIRM-D     | 14 | Lentic  |
| Jurumirim HPP – SP - BRA          | Paranapanema       | 23°13’02.15”S       | JUR-U      | 15 | Lentic  |
|                                    |                    | 49°13’26.89”W       | JUR-D      | 16 | Lentic  |
| Rosana HPP – SP/PR - BRA          | Paranapanema       | 22°36’02.03”S       | ROS-U      | 17 | Lentic  |
|                                    |                    | 52°51’07.39”W       | ROS-D      | 18 | Lentic  |
| Itaipu HPP – BRA/PAR              | Upper Parana       | 25°24’21.09”S       | ITA-U      | 19 | Lentic  |
|                                    |                    | 54°34’02.38”W       | ITA-D      | 20 | Lentic  |
| Foz do Arela HPP – PR – BRA       | Iguazu             | 26°00’23.84”S       | FARE-U     | 21 | Lentic  |
|                                    |                    | 51°39’45.76”W       | FARE-D     | 22 | Lentic  |
| Salto Caxias HPP – PR - BRA       | Iguazu             | 25°32’25.00”S       | SCAX-U     | 23 | Lentic  |
|                                    |                    | 53°29’30.72”W       | SCAX-D     | 24 | Lentic  |
| Yacireta HPP – Ituzaingó - ARG    | Middle Paraná      | 27°25’28.83”S       | YACI-U     | 25 | Lentic  |
|                                    |                    | 56°37’37.50”W       | YACI-D     | 26 | Lentic  |
| Paraná River – Bella Vista - ARG  | Middle Paraná      | 28°30’04.81”S       | RPAR-M1    | 27 | Lotic   |
|                                    |                    | 59°02’58.21”W       | RPAR-M2    | 28 | Lotic   |
|                                    |                    | 59°02’58.21”W       | RPAR-M3    | 29 | Lotic   |
| La Plata River – Rosário - ARG    | Lower Paraná       | 32°53’08.12”S       | RPAR-L1    | 30 | Lotic   |
|                                    |                    | 60°40’48.69”W       | RPAR-L2    | 31 | Lotic   |
|                                    |                    | 60°40’48.69”W       | RPAR-L3    | 32 | Lotic   |
| La Plata River -- URU/ARG          | Lower Paraná       | 34°00’51.25”S       | RPLA       | 33 | Lotic   |
|                                    |                    | 58°19’21.84”W       |           |    |         |
| Machadinho HPP – SC - BRA         | Upper Uruguay      | 27°31’12.35”S       | MAC-U      | 34 | Lentic  |
|                                    |                    | 51°47’05.01”W       | MAC-D      | 35 | Lentic  |
| Porto Xavier – RS - BRA           | Middle Uruguay     | 27°52’17.26”S       | RURU-M1    | 36 | Lotic   |
|                                    |                    | 55°02’25.49”W       | RURU-M2    | 37 | Lotic   |
| Salto Grande HPP – URU            | Middle Uruguay     | 31°15’44.17”S       | SGRA-U     | 38 | Lentic  |
|                                    |                    | 57°55’47.34”W       | SGRA-D     | 39 | Lentic  |
| Uruguay River - Fray Bentos – URU | Lower Uruguay      | 33°21’02.20”S       | RURU-L     | 40 | Lotic   |
|                                    |                    | 58°25’49.97”W       |            |    |         |
| Paraguay River– Corumbá - BRA     | Upper Paraguay     | 18°59’40.76”S       | RPAG-H     | 41 | Lotic   |
|                                    |                    | 57°39’12.53”W       |            |    |         |
| Paraguay River – Assunción - PAR  | Middle Paraguay    | 25°28’24.65”S       | RPAG-M     | 42 | Lotic   |
|                                    |                    | 57°33’40.53”W       |            |    |         |
| Paraguay River – Paso de la Patria – PAR | Lower Paraguay | 27°15’38.43”S | RPAG-L     | 43 | Lotic   |

La Plata River – Paraguay: 1°40’00.78”S, 58°12’00.78”W
We sampled rotifers through vertical hauls by using a 50 μm mesh conical plankton net. In deep sites, the maximum depth hauled was 40 m (Perbiche-Neves et al. 2019). The sampled rotifers were subsequently packed, labeled, and fixed with 4% formalin solution. Identifications were conducted with an optical microscope (Zeiss Axio Imager.A2m) and by using species keys (Edmondson 1959, Koste 1978, Nogrady et al. 1995, Sgers & Dumont 1995, Smet & Pourriot 1997, Nogrady 2002, Wallace et al. 2019). Voucher specimens were deposited in the Laboratory of Continental Waters Ecology, Institute of Bionosciences of Botucatu at the Universidade Estadual Paulista Júlio de Mesquita Filho (UNESP), Brazil. The number of species was correlated with water quality variables by using non-parametric Spearman correlation and a logarithmic transformation in R Cran Project 3.3.0 (2016) using the Hmisc package of R.

**Results**

The mean rotifer richness was 27±11 species. The sub-basins with higher richness were the Lower Paraná (41 species), followed by the Paranapanema (40 species) and Tietê (35 species). The basins with lower richness were the Middle Paraná and Lower Uruguay (Figure 2A).

The Rotifera fauna of the La Plata River basin was composed of 106 species, distributed in 21 families and 37 genera (Table 2, Figure 2B). The most representative family in the basin is the Lecanidae (21 species), followed by the Brachionidae (20), Trichocercidae (9), and Synchaetidae (8) (Figure 2B). The most speciose genera are *Lecane* Nitzsch, 1827 and *Brachionus* Pallas, 1766 with 21 and 10 species, respectively. We found 44 rotifer species in summer and 17 in winter. These seasonal periods share a combined 45 rotifer species (Figure 3).

**Figure 2.** Rotifer richness per basin for species (A) and family (B).

**Table 2.** Rotifer species collected in lotic and lentic habitas in the La Plata River basin, South America.

| Order/Family          | Species                          | Sites | Frequency (%) |
|-----------------------|----------------------------------|-------|---------------|
| **Order Flosculariaceae** |                                  |       |               |
| Family Conochilidae   | *Conochilus coenobasis* (Skorikov, 1914) | 4     | 2.32          |
|                       | *Conochilus dossuarus* Hudson, 1885 | 1, 3, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 20, 21, 22, 23, 24, 28, 29, 30, 31, 33, 34, 36, 43 | 65.11 |
|                       | *Conochilus natans* (Seligo, 1900) | 7, 8, 15, 34 | 9.3          |
|                       | *Conochilus unicornis* Rousselet, 1892 | 1, 2, 3, 4, 6, 7, 8, 12, 14, 15, 18, 28, 30, 32, 33, 34, 35, 39 | 41.86 |
| Family Flosculariidae | *Ptygura* sp. Ehrenberg, 1832     | 15    | 2.32          |
| Family Hexarthridae   | *Hexarthra intermedia* (Wiszniewski, 1929) | 9, 16, 22 | 6.97          |
|                       | *Hexarthra mira* (Hudson, 1871)   | 2, 5, 7, 8, 9, 10, 12, 15, 17, 21, 22, 23, 24, 27, 28, 30, 39, 43 | 41.86 |
| Family Testudinellidae| *Pompholyx triloba* Pejler, 1957  | 16, 32 | 4.65          |
|                       | *Testudinella macronata* (Gosse, 1886) | 15, 31, 32, 39, 41, 43 | 13.95 |
|                       | *Testudinella oheki* Koste, 1972  | 11    | 2.32          |
|                       | *Testudinella patina* (Hermann, 1783) | 12, 15, 18, 19, 28, 30, 32, 39, 40 | 20.93 |
| Family Trochosphaeridae| *Filinia limnetica* (Zacharias, 1893) | 21, 22 | 4.65          |
|                       | *Filinia longiseta* (Ehrenberg, 1834) | 7, 12, 21, 22, 30, 34 | 13.95 |
|                       | *Filinia opolensis* (Zacharias, 1898) | 6, 7, 12, 16, 39, 43 | 13.95 |
|                       | *Filinia saltator* (Gosse, 1886)   | 41    | 2.32          |
|                       | *Filinia terminalis* (Plate, 1886) | 5, 6, 7, 8, 11, 12, 13, 16, 21, 33, 34, 39 | 27.91 |

Order Ploima

continue...
### Family Asplanchnidae

| Species Name                                      | Count | Size |
|---------------------------------------------------|-------|------|
| Asplanchna priodonta Gosse, 1850                  | 12    | 2.32 |
| Asplanchna sieboldii (Leydig, 1854)               | 7, 12, 18, 22, 24, 25, 30, 34, 35, 39, 43 | 25.58 |
| Harringia rousseleti de Beauchamp, 1912          | 28    | 2.32 |

### Family Brachionidae

| Species Name                                      | Count | Size |
|---------------------------------------------------|-------|------|
| Anuraeopsis fissa Gosse, 1851                     | 12, 21 | 4.65 |
| Anuraeopsis navicula Rousselet, 1911              | 5, 15, 19 | 6.98 |
| Brachionus angularis Gosse, 1851                  | 30    | 2.32 |
| Brachionus budapestinensis Daday, 1885            | 7     | 2.32 |
| Brachionus calyciflorus Pallas, 1766              | 2, 5, 7, 8, 11, 12, 13, 15, 16, 18, 30, 31, 33, 34, 35, 39 | 37.21 |
| Brachionus caudatus Barrois & Daday, 1894         | 29, 30, 31, 32, 37, 38, 39, 43 | 18.6 |
| Brachionus dolabratu Harring, 1914                | 5, 6, 8, 13, 16, 25, 34, 35, 37, 39 | 23.25 |
| Brachionus falcatus Zacharias, 1898               | 3, 5, 6, 7, 11, 12, 16, 23, 34, 35, 38, 39, 42, 43 | 32.56 |
| Brachionus mirus Daday, 1905                      | 10, 11, 12, 14, 21, 30, 31, 34, 39, 42, 43 | 25.58 |
| Brachionus quadridentatus Hermann, 1783           | 32, 43 | 4.65 |
| Brachionus urceolaris Müller, 1773                | 11, 39 | 2.32 |
| Brachionus zehniseri Ahlstrom 1934                | 41    | 2.32 |
| Kellicottia bostoniensis (Rousselet, 1908)        | 4, 5, 6, 11, 12, 15, 16, 21, 22, 23, 24, 25, 29, 32, 33, 34, 35, 36, 38 | 44.19 |
| Keratella americana Carlin, 1943                  | 1, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 21, 22, 24, 35, 36, 38, 39, 43 | 44.19 |
| Keratella cochlearis (Gosse, 1851)                | 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 15, 16, 18, 21, 22, 26, 34, 35, 38, 39, 41, 42 | 51.16 |
| Keratella lenzi Hauer, 1053                       | 5, 8, 10, 11, 12, 13, 15, 34 | 18.61 |
| Keratella tropica (Apstein, 1907)                 | 3, 4, 5, 6, 11, 12, 13, 14, 15, 16, 17, 21, 22, 35, 37, 38 | 37.21 |
| Plationus patulus (Müller, 1786)                  | 11, 12, 13, 17, 21, 25, 26, 30, 32, 38, 39, 40, 42, 43 | 32.56 |
| Platyias leloupi (Gillard, 1957)                  | 12, 17, 19, 27, 29, 30, 31, 32, 42, 43 | 23.25 |
| Platyias quadricornis (Ehrenberg, 1832)           | 17, 28, 29, 30, 43 | 11.63 |

### Family Dicranophoridae

| Species Name                                      | Count | Size |
|---------------------------------------------------|-------|------|
| Dicranophoroides caudatus (Ehrenberg, 1834)       | 10    | 2.32 |

### Family Epiphanidae

| Species Name                                      | Count | Size |
|---------------------------------------------------|-------|------|
| Epiphanes clavulata (Ehrenberg, 1832)              | 1, 11, 12, 15, 30, 43 | 13.95 |
| Epiphanes macroura (Barrois & Daday, 1894)        | 35    | 2.32 |

### Family Euchlanidae

| Species Name                                      | Count | Size |
|---------------------------------------------------|-------|------|
| Beauchampiella eudactyloa (Gosse, 1886)            | 30    | 2.32 |
| Diplouchlanis propatula (Gosse, 1886)              | 41    | 2.32 |
| Euchlanis dilatata Ehrenberg, 1832                 | 11, 12, 19, 25, 27, 32, 37, 41 | 16.28 |

### Family Gastropodidae

| Species Name                                      | Count | Size |
|---------------------------------------------------|-------|------|
| Ascomorpha agilis Zacharias, 1893                  | 39    | 2.32 |
| Ascomorpha ovalis (Bergendal, 1892)                | 34    | 2.32 |
| Ascomorpha saltans Bartsch, 1870                   | 5, 9, 11, 15, 17 | 11.63 |
| Gastropus hyptopus (Ehrenberg, 1838)               | 30, 39 | 4.65 |
| Gastropus stylifer (Imhof, 1891)                   | 17    | 2.32 |

### Family Ituridae

| Species Name                                      | Count | Size |
|---------------------------------------------------|-------|------|
| Itura aurita (Ehrenberg, 1830)                    | 19    | 2.32 |

*Continue...*
| Family          | Species                           | Count | Frequency  |
|-----------------|-----------------------------------|-------|------------|
| **Family Lecanidae** |                                   |       |            |
|                 | *Lecane amazonica* (Murray, 1913) | 32    | 2.32       |
|                 | *Lecane bulla* (Gosse, 1851)      | 12, 19, 21, 15, 30, 43 | 13.95  |
|                 | *Lecane cornuta* (Müller, 1786)   | 43    | 2.32       |
|                 | *Lecane curvicornis* (Murray, 1913) | 11, 12, 17, 18, 19, 30, 32, 33, 39, 41, 42, 43 | 27.91  |
|                 | *Lecane elsa* Hauer, 1931         | 40, 41 | 4.65       |
|                 | *Lecane halicysta* Harring & Myers, 1926 | 21, 41 | 2.32       |
|                 | *Lecane hornemannii* (Ehrenberg, 1834) | 7, 8, 15, 25, 34 | 11.63  |
|                 | *Lecane leontina* Turner, 1892    | 30, 39 | 4.65       |
|                 | *Lecane ludwigii* (Eckstein, 1883) | 33    | 2.32       |
|                 | *Lecane luna* (Müller, 1776)      | 7, 19, 29, 21, 24, 32, 35 | 16.28  |
|                 | *Lecane lunaris* (Ehrenberg, 1832) | 20, 30, 39 | 6.98    |
|                 | *Lecane obtusa* (Murray, 1913)    | 2, 6, 15 | 4.65       |
|                 | *Lecane papuana* (Murray, 1913)   | 7, 39, 42 | 6.98    |
|                 | *Lecane proiecta* Hauer, 1956     | 5, 7, 8, 12, 19, 39 | 13.95  |
|                 | *Lecane quadridentata* (Ehrenberg, 1830) | 19, 30 | 2.32       |
|                 | *Lecane rhytida* Harring & Myers, 1926 | 17    | 2.32       |
|                 | *Lecane robertsonae* Segers, 1993 | 6     | 2.32       |
|                 | *Lecane stenroosi* Meissner, 1908 | 8     | 2.32       |
|                 | *Lecane subtilis* Harring & Myers, 1926 | 18    | 2.32       |
|                 | *Lecane thienemanni* Hauer, 1938  | 19, 21, 28 | 4.65    |
|                 | *Lecane ungulata* Gosse, 1887     | 5, 42  | 2.32       |
| **Family Lepadellidae** |                                   |       |            |
|                 | *Colurella adriatica* Ehrenberg, 1831 | 21    | 2.32       |
|                 | *Colurella obtusa* Gosse, 1886    | 21, 30 | 2.32       |
|                 | *Lepadella cristata* Rousselet, 1893 | 38    | 2.32       |
|                 | *Lepadella donneri* Koste, 1972   | 18    | 2.32       |
|                 | *Lepadella ovalis* Müller, 1786   | 42    | 2.32       |
|                 | *Lepadella patella* Müller, 1786  | 41    | 2.32       |
| **Family Mytilinidae** |                                   |       |            |
|                 | *Lophocharis oxy sternon* (Gosse, 1851) | 5     | 2.32       |
|                 | *Mytilina acanthophora* Hauer, 1938 | 7     | 2.32       |
|                 | *Mytilina bisulcata* Lucks, 1912  | 27    | 2.32       |
|                 | *Mytilina mucronata* Müller, 1773 | 5, 7, 14, 19, 29 | 11.63  |
|                 | *Mytilina ventralis* Ehrenberg, 1830 | 7, 8, 9, 12, 15, 16, 22, 27, 32, 35, 39 | 25.58  |
| **Family Notommatidae** |                                   |       |            |
|                 | *Enteroplea lacustris* Ehrenberg, 1830 | 13    | 2.32       |
|                 | *Monommata maculata* Harring & Myers, 1930 | 30    | 2.32       |
| **Family Proalidae** |                                   |       |            |
|                 | *Proalinopsis staurus* Harring & Myers, 1924 | 7     | 2.32       |
| **Family Scaridiidae** |                                   |       |            |
|                 | *Polyarthra dolichoptera* Idelson, 1925 | 5, 7, 8, 10, 11, 12, 13, 15, 16, 18, 21, 22 | 27.91  |
|                 | *Polyarthra remata* Skorikov, 1896 | 2, 9, 15, 21, 22, 25, 29, 35 | 18.6    |
|                 | *Polyarthra vulgaris* Carlin, 1943 | 10    | 2.32       |
|                 | *Synchaeta oblonga* Ehrenberg, 1832 | 7, 9, 17, 18, 39 | 11.63  |
|                 | *Synchaeta pectinata* Ehrenberg, 1832 | 5, 6, 7, 12, 15, 18, 30 | 16.28  |
|                 | *Synchaeta stylata* Wierzejski, 1893 | 7, 26, 30, 34 | 9.3     |

...continue...
Regarding individual sites, we found a wide range in species richness. Barra Bonita Reservoir (BBON-D; 12) in the Tietê River had the greatest species richness (22). The lowest richness was observed in the Lower (RURU-L; 40) and Middle (RURU-M1; 36) Uruguay River (3 species each; Table 2). The species occurring in >40% of the lotic and lentic sites evaluated were Conochilus dossuarius Hudson, 1885, Kellicottia bostoniensis (Rousselet, 1908), Keratella americana Carlin, 1943 K. cochlearis (Gosse, 1851) and Hexarthra mira (Hudson, 1871).

Our results indicate greater distribution ranges for several species. Colurella adriatica Ehrenberg, 1831, from the Foz do Areia Reservoir, is a new record for Brazil. Gastropus hyptopus (Ehrenberg, 1838) in the La Plata River and Harringia rousseleti de Beauchamp, 1912 and Lecane thienemanni (Hauer, 1938) in the Paraná River, are their first reports in Argentina. Finally, we expand the range of Enteroplia lucustris Ehrenberg, 1830, in São Paulo State (Brazil) and Lecane ludwigii (Eckstein, 1883) in Buenos Aires Province (Argentina).

Almost all the species are native, except Kellicottia bostoniensis which occurred in a new locality. Seven other species are Neotropical endemics (Table 2): Brachionus dolabratus Harring, 1914. B. mirus Daday, 1905, B. zahniseri Ahlstrom 1934. K. americana. Lecane amazonica (Murray, 1913), L. proiecta Hauer, 1956 and Testudinella oblates Koste, 1972.

The mean ± standard deviations of water quality variables (Table 3) stratified by sub-basin reveals that the Tietê River has higher levels of total nitrogen, phosphorus, chlorophyll, and electrical conductivity.
The Lower Paraná River also demonstrates high values for these variables except for nitrogen. Higher temperatures were found in the Paraguay and Iguaçu Rivers. The lowest levels of dissolved oxygen occurred in the Paraguay River. Spearman correlations indicated that total chlorophyll and water temperature were positively correlated with species richness; dissolved oxygen demonstrated a negative correlation (Table 4).

**Discussion**

We found a total of 106 rotifer species in the La Plata basin. Our data represent 14% of the rotifer species richness known to Brazil (Garraffoni & Lourenço 2012), 37% of that for São Paulo State (Souza-Soares et al. 2011), 30% of that for the Upper Paraná (Lansac-Tôha et al. 2009), and 40% for the Upper Paraguay River (Branco et al. 2018). Data from other inventories show that the rotifer fauna in the La Plata River basin is richer than what was demonstrated in our study, possibly because we sampled in few Uruguay and Paraguay River stretches, and exclusively in open water habitats, not in littoral. Therefore, as recommended by Ferrando & Claps (2016), further investigations should be carried out to expand the distribution list of species in the La Plata River Basin.

The most diverse families were Lecanidae (21 spp.) and Brachionidae (20 spp.). These two families compose most rotifer species throughout Brazil and Argentina (Garraffoni & Lourenço, 2012; Ferrando & Claps, 2016), supporting our findings.

The higher summer (wet season) rotifer richness may be associated with the concentrated rainfall events that occur during this season.

| Sub-basin     | Total Nitrogen (µg.L⁻¹) | Total Phosphorus (µg.L⁻¹) | Chlorophyll (µg.L⁻¹) | Depth Max. (m) | Transparency (m) |
|---------------|-------------------------|----------------------------|----------------------|----------------|------------------|
| Paranáiba     | 196.1±43.38             | 9.60±3.08                  | 1.21±0.67            | 61.6±16.29     | 4.13±1.64        |
| Grande        | 311.78±53.54            | 8.53±1.16                  | 2.45±1.60            | 44.32±25.01    | 3.31±1.42        |
| Tietê         | 2131.05±1373.24         | 58.19±45.73                | 7.19±6.54            | 25.93±6.85     | 2.70±1.45        |
| Paranapanema  | 463.92±115.72           | 16.94±5.21                 | 1.51±0.72            | 21.66±6.89     | 1.41±0.64        |
| Iguaçu        | 325.38±37.98            | 15.40±4.67                 | 1.26±0.63            | 57.75±24.13    | 1.45±0.34        |
| Upper Parana  | 622.30±126.81           | 15.40±4.19                 | 1.52±0.80            | 41.14±23.40    | 2.75±1.50        |
| Middle Parana | 468.12±47.37            | 34.33±6.48                 | 3.17±3.03            | 9.85±3.40      | 0.42±0.08        |
| Lower Parana  | 415.29±79.69            | 54.60±13.93                | 3.74±1.63            | 11.8±5.80      | 0.56±0.09        |
| Upper Uruguay | 452.04±93.24            | 14.54±3.22                 | 1.74±0.30            | 95.75±6.88     | 1.86±0.22        |
| Middle Uruguay| 780.90±70.22            | 22.07±5.80                 | 3.12±1.96            | 22.67±15.43    | 0.66±0.11        |
| Lower Uruguay | 650.35±108.47           | 36.10±9.01                 | 2.97±1.36            | 16.93±5.40     | 0.67±0.15        |
| Paraguay      | 426.44±225.85           | 43.00±18.71                | 2.41±0.87            | 10.1±4.37      | 0.81±0.32        |

| Sub-basin     | Temperature (°C) | pH | Conductivity (µS.cm⁻¹) | DO (mg.L⁻¹) | Turbidity (NTU) |
|---------------|-----------------|----|-----------------------|-------------|-----------------|
| Paranáiba     | 24.35±1.81      | 7.21±0.19 | 41.82±4.32 | 6.26±0.97 | 8.64±3.38 |
| Grande        | 24.10±2.8       | 7.20±0.33 | 38.45±7.07 | 7.16±1.16 | 11.58±6.70 |
| Tietê         | 24.11±3.10      | 7.27±0.30 | 182.42±43.98 | 6.92±1.54 | 12.1±6.46 |
| Paranapanema  | 23.01±3.16      | 7.25±0.27 | 55.10±6.56 | 7.91±0.96 | 24.2±11.41 |
| Iguaçu        | 25.14±3.37      | 7.34±0.14 | 51.26±4.74 | 7.57±0.79 | 20.52±7.70 |
| Upper Parana  | 21.73±3.69      | 7.19±0.32 | 46.31±6.44 | 7.80±1.12 | 12.75±4.91 |
| Middle Parana | 23.21±6.19      | 7.36±0.22 | 64.64±4.96 | 7.98±1.36 | 40.49±7.56 |
| Lower Parana  | 22.10±7.40      | 7.47±0.31 | 118.16±24.69 | 7.85±2.21 | 37.80±6.93 |
| Upper Uruguay | 17.71±1.77      | 6.86±0.13 | 32.26±2.13 | 8.68±0.46 | 14.51±2.12 |
| Middle Uruguay| 21.84±4.49      | 7.42±0.14 | 45.75±2.75 | 8.63±0.91 | 32.39±7.41 |
| Lower Uruguay | 22.22±6.75      | 7.44±0.21 | 59.24±20.58 | 8.69±1.22 | 31.30±5.68 |
| Paraguay      | 26.40±3.87      | 6.75±0.24 | 67.84±15.33 | 5.17±1.28 | 27.40±13.22 |

Table 3. Means ± standard-deviations of water quality variables by sub-basin.

Table 4. Spearman correlations between species richness and water quality variables. Bold = significant correlations.
Summer rains can carry nutrients and organic matter from the margins of aquatic environments resulting in increased food concentration and a reduction in competition for resources. The same tendency was observed for the rainy season in a study performed on a tropical lake in Mexico (Jiménez-Contreras et al. 2018). Richness may also be related to the sediment mixture caused by intense rains. This process provides a favorable condition for hatching of dormant stages (i.e., resting eggs), resulting in an increase in rotifer species richness.

Greater rotifer species richness was observed in the Lower Paraná sub-basin. Rotifers have low locomotion capacity and are carried by drifting through the central channel of the river and consequently the species richness increase towards downstream.

Barra Bonita Reservoir in the Tietê River sub-basin was the site with the greatest richness. Despite being a reservoir with a high degree of anthropogenic disturbance, including eutrophication (Tundisi et al. 2008), many studies have shown high biodiversity for other groups, which include rotifers (Matsumura-Tundisi & Tundisi 2005, Rocha et al. 2006). In the Barra Bonita Reservoir, Matsumura-Tundisi & Tundisi (2005) found 32 species of rotifers. However, in our work we found 22 species. The Spearman correlation suggested a positive relation between richness and chlorophyll levels, with Barra Bonita Reservoir demonstrating the highest values of observed chlorophyll. Presumably, this higher richness is a result of greater numbers of tolerant rotifer species (Allen et al. 1999).

The commonest species in the La Plata basin were Keratella americana, K. cochlearis, and Hexarthra mira. Others have reported the occurrence these species in the Uruguay (Di Persia & Neiff 1986), Paraguay (Frutos et al. 2006, Branco et al. 2018) and Upper Paraná Rivers (Bonetto & Wais 2006), indicating the wide distribution of these species in the study area.

Colurella has been found in several inland waters (Arroyo-Castro et al. 2019, Tasesvka et al. 2019, Wei et al. 2019). In the La Plata Basin we found two species of this genus: Colurella Adriatica Ehrenberg, 1831 and C. obtusa (Gosse, 1886). Colurella Adriatica originates in the Adriatic Sea and has been described as endemic (Ehrenberg 1831), but it is now widely distributed, including in Neotropical regions (Segers 2007). We found it in Foz do Areia Reservoir, in the Iguaçu sub-basin, Paraná State, which is its first record in Brazil.

Enteroplea lacustris is widely distributed in the Australasian, Neartic, Neotropical, Oriental, and Paleoeartic regions (Segers 2007). In Brazil, it occurs in Mato Grosso do Sul (Roche & Silva 2017) and Paraná States in the Parana Panema River basin (Dias et al. 2011, Roche & Silva 2017). We found it in Três Irmãos Reservoir, Tietê sub-basin, São Paulo State, near the Paraná River, indicating a gap in previous studies of this region.

For Argentina, Ferrando & Claps (2016) recorded 351 species of monogonont rotifers from lotic and lentic environments. Among the species they recorded, we found 43 (12.2%). Three other species of rotifers (Gastropus hytopus, Harringia rousseleti, and Lecane thiemenmanni) found in our study are new records for Argentina. Gastropus hytopus was found in the La Plata River basin, in Rosario, Argentina. In Brazil, it had been registered in several regions (Serafim Jr. et al. 2003, Bonecker et al. 2005, Serafim-Júnior et al. 2010, Souza-Saore et al. 2011). Harringia rousseleti and L. thiemenmanni were recorded for the first time in Argentine reaches of the Paraná River, in the Bella Vista municipality. A new locality was found for L. ludwigi, which had been recorded in Corrientes Province (José de Paggi 1996); however, there is no previous record in the La Plata River estuary where we collected it.

We found a non-native species in the La Plata River basin, Kellicottia bostoniensis (Rousselet, 1908), which is native to North America (Edmondson 1959). For Argentina, José de Paggi (2002) first recorded the species in the Iguazu River and Salto Grande Reservoir. We found the species in the La Plata River (Uruguay and Argentina reach), where there were no prior records of it. We thus extended the known distribution of K. bostoniensis. It is possible that its occurrence in the La Plata basin is related to aquaculture activities as has occurred in other regions (Coelho & Henry 2017). In many reservoirs of the La Plata basin, there are aquaculture activities, mainly with non-native fish species (Azvedo-Santos et al. 2011, Nobile et al. 2018). This rotifer may be introduced from cage aquaculture in upstream rivers (e.g., Grande and Parana Panema Rivers) and reached downstream areas where we captured it.

Seven Neotropical endemic species (sensu José de Paggi 1996) were found in the La Plata River basin. Their presence highlights the importance of preserving the condition of these ecosystems. However, anthropogenic stressors imperil many areas where these seven species occur. For example, in the Barra Bonita and Três Irmãos Reservoirs, where Brachionus dolobratus, B. mirus, and L. proiecta were captured, waters are polluted (Rodger et al. 2005, Favaro et al. 2018). Similarly, eutrophic tributaries in the Grande River sub-basin (Melo et al. 2017) may affect endemic rotifer species. Another example is the occurrence of L. amazonica in the La Plata River, which also receives water from these polluted river basins. Conservation policies must be discussed for the entire La Plata system because of fluvial connectivity (Azvedo-Santos et al. 2019).

In conclusion, surveys covering wide spatial extents, such as in our study, are important for increasing the knowledge of species diversity and distribution. Our findings may contribute to future monitoring studies as well as management and conservation programs for the La Plata River basin. Finally, we recommend that future rotifer surveys should be concentrated in Paraguay and Uruguay Rivers reaches because of the scarcity of data from them.

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Author Contributions

Bárbara A. Martins: Contribution to data analysis, interpretation, Contribution to manuscript preparation

Paula N. Coelho: Contribution to manuscript preparation, Contribution to critical revision, adding intellectual content.

Marcos G. Nogueira: Substantial contribution in the concept and design of the study, Contribution to data collection, Contribution to critical revision, adding intellectual content.

Gilmar Peribiche-Neves: Substantial contribution in the concept and design of the study, Contribution to data collection, Contribution to critical revision, adding intellectual content.

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Conflicts of Interest

The author(s) declare(s) that they have no conflict of interest related to the publication of this manuscript.

Ethics

The data collection was compiled with the guidelines established by the ethics committees of Universidade Estadual de São Paulo.

Data availability

The species were deposited in the Laboratory of Ecology and Continental Waters, Institute of Biosciences of Botucatu at the Universidade Estadual Paulista Júlio de Mesquita Filho (Unesp), Brazil. Lot 009, samplings 1 to 44.

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