Rotifera of various aquatic environments of Costa Rica in reference to Central American rotifer fauna

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Abstract: Detailed surveys on rarely examined aquatic ecosystems often lead to the discovery of new species of high conservation value. This study directed towards the recognition of a variety of aquatic environments in Costa Rica (40 habitats, including lakes, wetlands, and small aquatic systems, e.g., ponds, ditches, puddles, tree holes, and bromelias) established the presence of 105 species of Monogononta representing 33 genera. In total, 91 species and 19 genera were found to be new for Costa Rica, including 29 species recorded for the first time in Central America (e.g., Ascomorpha klementi, Beauchampia crucigera, Brachionus mirabilis, Cephalodella panarista, Filinia saltator, Horoella brehmi, Lecane amazonica, Lecane pawlowskii, Lepadella lindaui, and Mytilina acanthophora). The application of 2 estimates of total species richness allowed us predict that 70 new rotifer species may potentially be found in Costa Rica. Thus, we assume that only about 60% of the potential Costa Rican rotifer diversity was ascertained in our study. The most diverse genus was Lecane with 36 species. Among the most frequent rotifers there were some lecanid species, e.g., Lecane bulla, Lecane hamata, Lecane closteroerca and Lecane leontina, and also Colurella obtusa, Platiesmus patulus, Amuraceps fissa, and Platyias quadricornis.

Key words: Rotifera, taxonomy, distribution, Costa Rica, Central America, new records

1. Introduction

The examination of a great range of various aquatic environments will guarantee a discovery of differentiated communities of organisms, including new species for regional, national or even continental diversity, which in turn may contribute to the importance of the conservation value of a region (Segers, 2007; Sa-arndrit et al., 2013). For Central America, fragmentary data exist, for flora (Karrermans and Bogarin, 2013; Ortiz and Croat, 2017) or fauna, both invertebrates (Pilato and Kaczmarek, 2007; Kaczmarek et al., 2011; Kaczmarek and Roszkowska, 2016) and vertebrates (Savage and Lips, 1993; Ryan et al., 2015; Woodman and Timm, 2017). Despite the availability of some taxonomical information on the zooplankton fauna of Central America (Collado et., 1984; Garcia-Morales and Elias-Gutierrez, 2007), its recognition still requires greater attention, particularly that takes into account various types of water bodies, including larger aquatic systems like lakes, field ditches or ponds, smaller habitats like tree holes or bromelain pools or even temporary ponds e.g., puddles. That is why this study was directed towards the recognition of a variety of aquatic environments in Costa Rica in order to provide a full picture of the existing diversity of rotifers. Studies on marine environments prevail in Costa Rica (Suárez-Morales and Gasca, 1989; Morales and Vargas, 1995; Brugnoli-Olivera et al. 2004; Morales-Ramírez et al., 2014; Décima et al., 2016), while our knowledge of inland waters is based on only very few studies. Some data exist on phytoplankton (Haberyan et al., 1995; Umaña, 2001; Umaña-Villalobos, 2010; Landry et al., 2016). However, information on animal plankton is still very scarce (Dumont, 1994; Morales-Ramírez et al., 2014). Most studies, such as those performed by Haberyan et al. (1995), who examined zooplankton in 17 lakes in Costa Rica, or by Morales-Ramírez et al. (2014) have concentrated on cladocerans and copepods. That is why there is not much data on the smallest fraction of zooplankton- rotifers. Collado et al. (1984) listed only 33 species in the results of their short-term expedition to Central America. The recognition of rotifers in the inland waters of Costa Rica is even more restricted.

Rotifers are a group of highly diverse metazoans with over 2000 species known worldwide. The annotated checklists of Rotifera, given by Segers (2007) and Jersabek and Leitner (2013), present almost 1600 valid Monogononta species and 460 of Bdelloidea. Their success is related
to several communities compared to crustaceans in freshwater and they may also dominate in densities over other groups of zooplankton, e.g., cladocerans and copepods (Chick et al., 2010; Celewicz-Goldyn and Kuczyńska-Kippen, 2017).

Rotifers are known as opportunistic or colonising pioneer organisms, characterised by short life cycles and rapid reproduction. Their success also derives from their great ability to adapt to various, often harsh, environments such as hot springs or cold and glacial habitats (King, 1972; Ricci, 1987; Lubzens et al., 1995; Miracle et al., 1995; Fontaneto et al., 2015; Zawierucha et al., 2018a, 2018b). They can also often be encountered among mosses (Kuczyńska-Kippen, 2008; Bielańska-Grajner et al., 2011; Bielańska-Grajner et al., 2017) or even in moist places such as soil or on the bark of trees (Devetter, 2007; Robeson et al., 2011; Ptatscheck et al., 2018).

The present study describes the results of the rotifer species composition of various freshwater habitats in Costa Rica and also summarizes the information about rotifers that has been recorded to date in Costa Rica and in other parts of Central America. We analysed rotifers (Rotifera) in various types of freshwater; besides, some large-surfaced lakes (e.g., Lake Arenal or Lago de Cachi), a wide range of small aquatic environments such as ponds, ditches, sedimentation tanks, puddles, tree holes, and bromeliads. In addition, the estimated true species diversity for Costa Rican water bodies will also be discussed.

2. Materials and methods

Rotifer sampling was performed in a month-long survey during October and November 2011, in over 40 various types of Costa Rican water body (Table 1).

According to the origin, morphology, locality as well as hydroperiod, the majority of the examined environments were located within ponds (13 stations), then bromeliad tanks (9), lakes (5), ditches and puddles (4 each) and finally artificial water bodies (3), and wetlands (2). Plankton samples were taken in the most representative region of each water body.

The material was taken with the use of a calibrated vessel, then concentrated using a 25-µm plankton net and finally fixed with 96% ethanol. In the case of lakes, ponds, wetlands and artificial water bodies 5 L of water were collected at each station. From puddles and temporary wetlands and artificial water bodies 5 L of water were collected at each station. From puddles and temporary water bodies at least 1 L of water was collected; water samples collected from the tanks of bromeliads had a minimum of 100 mL and were taken with a Pasteur pipette.

Rotifer identification was performed using appropriate identification keys (Koste, 1978; Nogrady et al., 1995; Segers, 1995; De Smet, 1996; De Smet and Pourriot, 1997; Nogrady and Segers, 2002; Radwan et al., 2004).

At each sampling station, the geographic coordinates were established (Table 1). Frequency index, expressed as a percentage, referring to the number of times a certain species occurred in all examined water bodies, was calculated.

Moreover, 2 estimates of total species richness – the bias-corrected Chao2 and Jackknife2 (Chao 1984; Colwell and Coddington, 1994; Dumont & Segers, 1996; Muirhead et al., 2006), which calculate the estimated true species diversity of a sample were also applied in order to discover the closest possible amount of species that could be identified from Costa Rican water bodies. These are computed as follows:

$$S_{Chao2} = S_{obs} + \frac{Q1(Q1-1)}{m(m-1)}Q2$$

where:

- $S_{Chao2}$ = Chao2 estimator of total species richness;
- $S_{obs}$ = the number of species identified in the whole material;
- $$m = \text{the total number of samples};$$
- $$Q1 = \text{number of singletons (number of species that occur in 1 sample)};$$
- $$Q2 = \text{number of doubletons (number of species that occur in 2 samples)}.$$

$$S_{Jack2} = S_{obs} + \frac{Q1(2m-3)}{m}Q2$$

$S_{Jack2}$ = Jackknife2 estimators of total species richness.

3. Results

In the 40 samples that were studied in total, 33 genera with 105 species of Monogononta were identified. Among them 91 species and 19 genera are new for Costa Rica (Table 2). Together with previous studies by Collado et al. (1984), it raises the number of monogonont rotifer species described from Costa Rica to 125. Within these 91 species new to Costa Rica there are 29 species, representing 10 genera, that were recorded for the first time in Central America. This increases the total number of Monogononta species reported from the region to 215 and 50 genera. Among species that were new to Central America were e.g., Ascomorpha klementi (Hauer), Beauchampia crucigera Dutrochet, Brachionus mirabilis Daday, Cephalodella panarista Myers, Filinia saltator (Gosse), Horaella brehmi Donner, Lecane amazonica (Murray), Lecane pawlowskii Wulfert, Lepadella lindau Koste, and Mytilina acaonthophora Hauer (Table 2).

The most variable genera in Costa Rican water bodies were the following: Lecane (36 species), Lepadella (10), Cephalodella (9), Trichocerca (8), Brachionus (4), Colurella (4), Keratella (3), and Mytilina (3). The remaining genera were represented by only 1–2 species (Table 2).

Certain species occurred with various frequency in the collected material, between 3 and a maximum of 35% of all samples (Table 2). There were 9 rotifer species that occurred with the highest frequency (20%–35%):
Table 1. List of stations with co-ordinates, date of sampling, and basic description of the sampling site (Abbreviation: NKK - Natalia Kuczyńska-Kippen).

| Station Description | Coordinates | Date of Sampling | Description |
|---------------------|--------------|-----------------|-------------|
| A small cavity with sedges | 10°04'13.8" N, 83°59'04.7" W | 28.10.2011 | coll. NKK |
| Depression along the road with plants | 09°44'37.9" N, 82°51'53.4" W | 28.10.2011 | coll. NKK |
| River pool | 09°44'46.3" N, 82°49'51.7" W | 30.10.2011 | coll. NKK |
| Pond | 09°36'15.4" N, 82°46'11.8" W | 31.10.2011 | coll. NKK |
| Pond | 09°54'34.4" N, 82°59'11.9" W | 02.11.2011 | coll. NKK |
| Pond | 09°58'43.1" N, 83°50'53.1" W | 03.11.2011 | coll. NKK |
| Pond | 09°58'42.6" N, 83°50'45.8" W | 03.11.2011 | coll. NKK |
| Pond | 09°57'06.9" N, 83°46'42.6" W | 03.11.2011 | coll. NKK |
| Pond | 09°57'09.8" N, 83°46'15.6" W | 03.11.2011 | coll. NKK |
| Pond | 09°50'58.0" N, 83°50'20.2" W | 04.11.2011 | coll. NKK |
| Lake Lago de Cachi | 09°49'21.6" N, 83°49'02.1" W | 04.11.2011 | coll. NKK |
| Lake Turrialba | 09°51'44.5" N, 83°38'47.1" W | 04.11.2011 | coll. NKK |
| Lake Catti | 09°53'23.4" N, 83°39'15.6" W | 04.11.2011 | coll. NKK |
| Lake Turrialba | 09°53'34.3" N, 83°39'28.4" W | 05.11.2011 | coll. NKK |
| Sedimentation tank | 09°53'49.2" N, 83°39'53.5" W | 05.11.2011 | coll. NKK |
| Pond | 09°54'15.7" N, 83°40'56.9" W | 05.11.2011 | coll. NKK |
| Pond | 10°11'53.0" N, 84°14'07.2" W | 06.11.2011 | coll. NKK |
| Pond | 10°11'20.3" N, 84°13'43.3" W | 06.11.2011 | coll. NKK |
| Pond | 10°30'04.1" N, 84°42'30.2" W | 07.11.2011 | coll. NKK |
| Lake Arenal, pelagial | 10°28'20.2" N, 84°46'90.0" W | 07.11.2011 | coll. NKK |
| Pond | 10°27'56.6" N, 84°47'43.9" W | 07.11.2011 | coll. NKK |
| Pond | 10°33'24.1" N, 84°54'32.6" W | 07.11.2011 | coll. NKK |
| Artificial small water body | 10°33'20.1" N, 84°54'32.5" W | 07.11.2011 | coll. NKK |
| Lake Arenal, pelagial | 10°27'20.7" N, 84°43'54.6" W | 08.11.2011 | coll. NKK |
| Lake Arenal, grasses | 10°28'34.9" N, 84°49'54.7" W | 08.11.2011 | coll. NKK |
| Pond | 10°33'39.2" N, 84°57'01.1" W | 08.11.2011 | coll. NKK |
| Lake Arenal, open water | 10°31'37.8" N, 84°57'49.6" W | 08.11.2011 | coll. NKK |
| Puddle | 10°50'10.7" N, 85°37'19.7" W | 09.11.2011 | coll. NKK |
| Pond | 10°50'06.9" N, 85°37'55.7" W | 09.11.2011 | coll. NKK |
| Pond | 10°27'45.3" N, 85°22'00.2" W | 10.11.2011 | coll. NKK |
| Puddle, runoff from rice fields | 10°24'38.6" N, 85°17'58.2" W | 11.11.2011 | coll. NKK |
| Wetland | 10°20'36.1" N, 85°20'30.7" W | 11.11.2011 | coll. NKK |
| Pond | 10°20'39.7" N, 85°20'29.2" W | 11.11.2011 | coll. NKK |
| Well, sludge settler | 10°20'55.2" N, 85°19'57.7" W | 11.11.2011 | coll. NKK |
| Pond | 10°08'53.2" N, 85°25'59.6" W | 11.11.2011 | coll. NKK |
| Pond | 09°32'08.8" N, 84°30'16.2" W | 14.11.2011 | coll. NKK |
| Pond | 09°27'15.1" N, 84°10'24.6" W | 14.11.2011 | coll. NKK |
| Pond | 09°23'52.3" N, 84°08'20.9" W | 19.11.2011 | coll. NKK |
| Artificial lake | 09°58'23.3" N, 84°05'36.8" W | 23.11.2011 | coll. NKK |
| Artificial small water body | 09°58'22.1" N, 84°05'37.9" W | 23.11.2011 | coll. NKK |

Lecane bulla, Lecane hamata–35%; Colurella obtusa, Lecane clusterocera–30%; Platynus patulus–23%; Anuraecopsis fissa, Lecane leontina, Lecane pyriformis, Platlyias quadricornis–20%. Another group of 16 species was found at a frequency level between 10% and 20% of examined stations (Colurella uncinita, Keratella tropica, Lecane quadridentata, Lepadella imbricata, Testudinella patina–18%; Colurella adriatica, Lecane cornuta, Lepadella patella–15%; Lecane hastata, Lecane luna, Mytilina ventralis–13%; Dipleuchlanis propatula, Euchlanis dilatata, Keratella cochlearis, Lecane arcula, Trichocerca pusilla–10%). Moreover, there were only 20 rotifer species from the previous surveys that were not confirmed in our study, e.g., Asplanchna brightwelli, Asplanchna sieboldi, Brachionus caudatus, Brachionus rubens, Brachionus urceolaris, Conochiloides natans, Conochilus unicorns, Dicranophorus robustus, Filinia longiseta, Filinia opolensis, Filinia terminalis, and Pompholyx complanata (Table 2).

Two estimates of total species richness were calculated to the estimated true rotifer species diversity in Costa Rican water bodies – the bias-corrected Chao2 and Jackknife2 – showed that the potential species
Table 2. List of rotifer species in samples from this study with numbers of the stations with their presence (for description of stations see Table 1). Status of species: CR - additional new species for Costa Rica; * - species new for Central America; ** - species found in Costa Rica in previous study (Collado et al., 1984) and not found during the present survey.

| Species                        | Author            | Stations | Status of species |
|-------------------------------|-------------------|----------|-------------------|
| Anuraeopsis fissa             | (Gosse, 1851)     | 13, 23, 25, 28, 31, 32, 39, 40 | CR |
| Ascomorpha klementi           | (Hauer, 1965)     | 27, 30   | CR*              |
| Beauchampia crucigera         | Dutrochet, 1812   | 11       | CR*              |
| Brachionus angularis          | Gosse, 1851       | 22       |                  |
| Brachionus calyciflorus       | Pallas, 1766      | 11, 39, 40 |                 |
| Brachionus mirabilis          | Daday, 1897       | 12, 32   | CR*              |
| Brachionus quadridentatus     | Hermann, 1783     | 39, 40   |                  |
| Cephalodella catellina        | (Muller, 1786)    | 28       | CR*              |
| Cephalodella forficula        | (Ehrenberg, 1832) | 33, 39   | CR               |
| Cephalodella gibba            | (Ehrenberg, 1832) | 27       | CR               |
| Cephalodella gracilis         | (Ehrenberg, 1832) | 11, 23   | CR               |
| Cephalodella hyalina          | Myers, 1924       | 25       | CR*              |
| Cephalodella panarista        | Myers, 1924       | 32       | CR*              |
| Cephalodella tenuiseta        | (Burn, 1890)      | 11, 25   | CR*              |
| Cephalodella tinaformis       | Koste, 1992       | 40       | CR*              |
| Cephalodella trigona          | (Rouseelet, 1892) | 33       | CR*              |
| Colurella adriatica           | (Ehrenberg, 1831) | 5, 11, 12, 13, 32, 33 | CR |
| Colurella colorus             | (Ehrenberg, 1830) | 3        | CR*              |
| Colurella obtuse              | (Gosse, 1886)     | 12, 21, 24, 25, 28, 29, 32, 34, 36, 37, 39, 40 | CR |
| Colurella uncinata            | (Muller, 1773)    | 11, 25, 29, 32, 33, 39, 40 | CR |
| Conochiloides dossuarius      | (Hudson, 1885)    | 13       |                  |
| Dicranophorus grandis         | (Ehrenberg, 1832) | 25       | CR               |
| Dipleuchlanis propatula       | (Gosse, 1886)     | 25, 32, 33, 35 | CR |
| Dorystoma caudatum            | (Bilfinger, 1894) | 12       | CR*              |
| Encentrum saundersiae         | (Hudson, 1885)    | 32       | CR*              |
| Euchlanis dilatata            | Ehrenberg, 1832   | 31, 32, 39, 40 |                 |
| Filinia passa                 | (Muller, 1786)    | 39       | CR*              |
| Filinia saltator              | (Gosse, 1886)     | 39       | CR*              |
| Hexarthra fennica             | (Levander, 1892)  | 5, 29    | CR               |
| Horaeilla brehmi              | Donner, 1949      | 32       | CR*              |
| Keratella americana           | Carlin, 1943      | 22, 30, 31 |                 |
| Keratella cochlearis          | (Gosse, 1851)     | 25, 27, 39, 40 |                 |
| Keratella tropica             | (Apstein, 1907)   | 11, 12, 13, 25, 31, 39, 40 | CR |
| Lecane aculeata               | (Jakubski, 1912)  | 4        | CR*              |
| Lecane aeganea                | Harring, 1914     | 23       | CR               |
| Lecane amazonica              | (Murray)          | 12       | CR*              |
| Lecane arcuata                | (Bryce, 1891)     | 1        | CR*              |
| Lecane arcula                 | Harring, 1914     | 22, 32, 34, 36 |                 |
| Lecane bifurca                | (Bryce, 1892)     | 1        | CR               |
| Species                  | Author, Year       | References | Notes |
|-------------------------|-------------------|------------|-------|
| Lecane bulla            | Gosse, 1886       | 3, 4, 11, 12, 13, 22, 23, 25, 28, 29, 32, 33, 39, 40 | CR    |
| Lecane clorocerca       | Schmarda, 1859    | 4, 11, 12, 13, 21, 22, 25, 32, 33, 34, 36, 39 | CR    |
| Lecane cornuta          | Muller, 1786      | 22, 29, 32, 33, 34, 35 | CR    |
| Lecane curvicornis      | Murray, 1913      | 22, 29, 32 | CR    |
| Lecane decipiens        | Murray, 1913      | 12          | CR    |
| Lecane elegans          | Harring, 1914     | 12          | CR    |
| Lecane elsa             | Hauer, 1931       | 32          | CR    |
| Lecane flexilis         | Gosse, 1886       | 1          | CR    |
| Lecane furcata          | Murray, 1913      | 36          | CR    |
| Lecane halicypta        | Harring & Myers, 1926 | 12, 28, 36 | CR    |
| Lecane hamata           | Stokes, 1896      | 11, 12, 13, 21, 24, 25, 27, 32, 33, 34, 37, 38, 39, 40 | CR    |
| Lecane hastata          | Murray, 1913      | 12, 13, 21, 29, 32 | CR    |
| Lecane hornemannii      | Ehrenberg, 1834   | 39          | CR    |
| Lecane inermis          | Bryce, 1892       | 12, 25      | CR    |
| Lecane leontina         | Turner, 1892      | 4, 12, 22, 28, 29, 32, 33, 36 | CR    |
| Lecane ludwigi          | Eckstein, 1883    | 32, 33      | CR    |
| Lecane luna             | Muller, 1776      | 25, 31, 33, 34, 36 | CR    |
| Lecane lunaris          | Ehrenberg, 1832   | 13, 25, 38 | CR    |
| Lecane monostyla        | Daday, 1897       | 1, 12, 25   | CR    |
| Lecane nana             | Murray, 1913      | 2, 32, 33   | CR    |
| Lecane papuana          | Murray, 1913      | 28          | CR    |
| Lecane pawlowskii       | Wulfert, 1966     | 34          | CR*   |
| Lecane pusilla          | Harring, 1914     | 13          | CR    |
| Lecane pyriformis       | Daday, 1905       | 1, 4, 12, 25, 32, 33, 34, 36 | CR    |
| Lecane quadridentata    | Ehrenberg, 1832   | 13, 29, 31, 32, 33, 34, 36 | CR    |
| Lecane rhytida          | Harring & Myers, 1926 | 32          | CR    |
| Lecane stenroosi        | Meissner, 1908    | 12          |       |
| Lecane syngenes         | Hauer, 1938       | 38, 39      | CR    |
| Lecane undulata         | Hauer, 1938       | 3, 32       | CR    |
| Lecane unguulata        | Gosse, 1887       | 33          | CR    |
| Lepadella acuminata     | Ehrenberg, 1834   | 11, 12, 25 | CR    |
| Lepadella apsicora      | Myers, 1934       | 32          | CR    |
| Lepadella linnaei       | Koste, 1981       | 34          | CR*   |
| Lepadella christinea    | Koste, 1990       | 35          | CR*   |
| Lepadella donneri       | Koste, 1972       | 32          | CR*   |
| Lepadella imbricata     | Harring, 1914     | 11, 25, 32, 33, 34, 37, 39 | CR    |
| Lepadella ovalis        | Muller, 1786      | 32          | CR    |
| Lepadella patella       | Muller, 1773      | 15, 33, 34, 36, 39 | CR    |
| Lepadella rhomboides    | Gosse, 1886       | 33          | CR    |
| Lepadella triba         | Myers, 1934       | 28, 31      | CR    |
| Limnias melicerta       | Weisse, 1848      | 33, 34      | CR    |
| Macrochaetus sericus    | Thorpe, 1893      | 25, 32, 36  | CR    |
| Mytilina acanthophora   | Hauer, 1938       | 33          | CR*   |
Table 2. (Continued).

| Species                  | Author and Year | Reference Numbers | Type |
|--------------------------|-----------------|-------------------|------|
| Mytilina bisulcata       | (Lucks, 1912)   | 32                | CR   |
| Mytilina ventralis       | (Ehrenberg, 1832) | 32, 33, 34, 35, 36 | CR   |
| Notomnata aurita         | (Muller, 1786)  | 32                | CR   |
| Platyonus patulus        | Muller, 1786    | 3, 4, 28, 29, 31, 32, 33, 34, 37 | CR   |
| Platyias quadricornis    | (Ehrenberg, 1832) | 3, 11, 12, 25, 29, 32, 33, 37 | CR   |
| Polyartha vulgaris       | Carlin, 1943    | 31, 39            |      |
| Ptygura elteri           | Koste, 1972     | 36                | CR*  |
| Ptygura melicerta        | Ehrenberg, 1832 | 11, 25            | CR*  |
| Resticula melanodocus    | (Gosse, 1887)   | 6, 12, 13         |      |
| Scaridium longicauda     | (Muller, 1786)  | 32, 33            | CR   |
| Squatinella lamellaris   | (Muller, 1786)  | 11,12             | CR   |
| Taphrocampa selenura     | Gosse, 1887     | 12                | CR*  |
| Testudinella parva       | Ternetz, 1892   | 12                | CR*  |
| Testudinella patina      | (Hermann, 1783) | 11,12,29, 32, 33, 37, 39 | CR   |
| Trichocerca bicristata   | (Gosse, 1887)   | 33                | CR   |
| Trichocerca dixom-nuttalli | (Jennings, 1903) | 5                |      |
| Trichocerca multirinis   | (Kellicott, 1897) | 25, 27           | CR   |
| Trichocerca pusilla      | (Lauterborn, 1898) | 23, 31, 39, 40  | CR   |
| Trichocerca rattus       | (Muller, 1776)  | 12                | CR   |
| Trichocerca similis      | (Wierzejski, 1893) | 25, 27          |      |
| Trichocerca tenior       | (Gosse, 1886)   | 12, 25, 40        | CR   |
| Trichocerca tigris       | (Muller, 1786)  | 12, 25            | CR   |
| Wolga spinifera          | (Western, 1894) | 31                |      |
| Amaraeoiosis coelata     | Beauchamp, 1932 |                   |      |
| Asplanchna brightwelli   | Gosse, 1850     |                   |      |
| Asplanchna sieboldi      | (Leydig, 1854)  |                   |      |
| Brachionus caudatus      | Barrois&Daday, 1894 |                   |      |
| Brachionus havanaensis   | Rousselet, 1911 |                   |      |
| Brachionus plicatilis    | (Muller, 1786)  |                   |      |
| Brachionus rubens        | Ehrenberg, 1838 |                   |      |
| Brachionus urceolaris    | Muller, 1773    |                   |      |
| Conochiloides natans     | (Seligo, 1900)  |                   |      |
| Conochilus unicornis     | Rousselet, 1892 |                   |      |
| Dicranophorus robustus   | Harring&Myers, 1928 |                   |      |
| Dicranophorus tegillus   | Harring&Myers, 1928 |                   |      |
| Filinia longiseta        | (Ehrenberg, 1834) |                   |      |
| Filinia opoliensis       | (Zacharias, 1898) |                   |      |
| Filinia pejeri           | Hutchinson, 1964 |                   |      |
| Filinia terminalis       | (Plate, 1886)   |                   |      |
| Hexarhra intermedia braz.| (Hauer, 1953)   |                   |      |
| Lacinularia flosculosa   | (Muller, 1773)  |                   |      |
| Pompolyx complanata      | Gosse, 1851     |                   |      |
| Trichocerca gracilis     | (Tessin, 1890)  |                   |      |
richness should account for 156 (the bias-corrected Chao2 estimator of total species richness) or even 178 species (Jactknife2 estimators of total species richness).

4. Discussion
Some regions worldwide are examined very intensively. This results in the compiling of very rich lists of rotifers inhabiting certain areas (Kuczyńska-Kippen, 2001; Špoljar, 2013; Poiciecha et al., 2015). However, there are other regions, such as the neotropics, where the intensity of ecological studies is much lower. Thus, the recognition of specific flora or fauna may still be underestimated. In the whole material from the Costa Rican water bodies, no species new to science were found. However, this is a typical phenomenon for rotifer studies. New species are found very rarely, unless the environment is highly specific and has never studied before, although habitats rich in macrophytes may also be a place where new species may still be undiscovered. Thus, new rotifers are usually benthic-periphytic organisms (Segers and Sanoamuang, 1994; Segers and Baribwegure, 1996; Meksuwan et al., 2018; Trinh-Dang et al., 2019). Therefore, in rotifer studies identifying some new species for a national or continental range becomes very desirable and is highly rated by the specialists that deal with this group of invertebrates.

In our study we found in total 105 species of rotifers. Along with earlier identified rotifers (Collado et al., 1984) the total number of monogonont species obtained from various habitats of Costa Rica, 125 species seems to be rather low as compared to other studies which were usually carried out on a large amount of water bodies or habitats, e.g., 190 species from aquatic ecosystems of Italy (Braioni and Gelmini 1983), 398 species from Thailand (Sa-Ardrit et al., 2013), 461 species from north and northwest Russia (Kutikova, 1998), or even 462 species from Poland (Ejsmont-Karabin et al., 2004).

One of the reasons for the above could be the “rotiferologists” effect i.e. sampling intensity, which is among the factors that most influence observed, global or local, species richness (Segers, 2007; Fontaneto et al., 2012). Moreover, covering all climatic seasons (Virro et al., 2009; Sahuquillo & Miracle, 2010) and also carrying out the research on a spatial scale referring to various microhabitats (Kuczyńska-Kippen et al., 2009; Basińska et al., 2014) would possibly contribute to further enrichment of the rotifer fauna. As species richness is strongly dependent on sample size and it increases with the number of samples collected, we decided to calculate the potential number of rotifer species in Costa Rica based on our results.

The application of 2 estimates of total species richness – the bias-corrected Chao2 and Jackknife2 estimators are guaranteed to reduce the bias in underestimating species richness and are likely to show more accurate species richness. With the use of these 2 estimators we found that the potential species richness recorded from Costa Rica should account for 156 and 178 species. Therefore, we obtained between 58%–67% of the potential diversity. A thorough examination of various water bodies in Costa Rica could even bring over 70 new rotifer species. These may soon be identified as the first data from a large survey of rotifers in small water bodies of Costa Rica has lately been published (Gálvez et al., 2018). They may even be more new species recognised in Costa Rican waters as we have found in 40 habitats a high number of 91 species new to the country, including 29 species recorded for the first time in the area of Central America. In the group of species that were identified as new to Central America, there were mainly species typical of macrophyte-dominated areas, such as representatives of genera Cephalodella, Colurella, Lecane, Lepadella, Mytilina, or Ptygura. This indicates the specificity of our water bodies. Apart from examining a few lakes and several temporary water bodies, we mainly concentrated on ponds or wetlands with rich vegetation cover. Some of these species were cosmopolitan, occurring worldwide irrespective of the climatic zone, such as Cephalodella catellina, Cephalodella tenuiseta, Colurella colurus, Encentrum saundersiae, Taphrocampa selentura, or Testudinella parva. But there were also species with a rather narrower geographical range such as Ascomorpha klementi, Beauchampia crucigera, Brachionus mirabilis, Cephalodella panarista, Filinia saltator, Horaella brehmi, Lecane amazonica, Lecane pawlowskii, Lepadella lindaui, or Mytilina acanthophora.

The most diverse genus in Costa Rican waters was Lecane with 36 species. Species of this genus usually inhabit benthic and littoral environments and are often found among macrophytes, both floating-leaved plants, submerged macrophytes or helophytes (Pejler and Bērziņš 1994). The greatest diversity of lecanids is found in standing or slowly flowing waters, particularly in tropical and subtropical climatic zones. Segers et al. (1993), who examined in total 13 locations in the Niger delta, identified the highest species diversity among the Lecane spp. Out of all 207 species of monogonont rotifers that were recorded almost 30% (59 species) were lecanids. Khaleqsefat et al. (2011) examining rotifers in 26 water bodies in northwest Iran found 13 species of lecanids including 6 that were new records for Iran (Lecane flexilis, Lecane hamata, Lecane hastata, Lecane lamellata, Lecane papuana, and Lecane punctata). Some Lecane are considered to be eurytopic, frequently occurring in various aquatic environments. Among the group of 9 rotifer species that occurred with the highest frequency (20%–35%) in Costa Rica there were 5 lecanids. Lecane bulla, Lecane hamata, and Lecane closteroerca were found in every third water body. These 3 species are known to be very common worldwide and occur in various climatic conditions. Two more species - Lecane leontina and Lecane pyriformis, were encountered.
Three more genera were represented by several species–Lepadella (10 species), Cephalodella (9), and Trichocerca (8). These are predominately littoral-associated genera. The remaining genera were represented by a lower number of species, e.g., Brachionus (4), Colurella (4), Keratella (3), and Mytilina (3).

Apart from above mentioned Lecane species, among the most frequent species in Costa Rican waters were Colurella obtusa, Platious patulus, Anuraeopsis fissa, Platylias quadricorpus, which were found in between 30% and 20% of the examined stations. Moreover, a large group of 16 species (Colurella adriatica, Colurella uncinata, Dipleuchlanis propatula, Euchlanis dilatata, Keratella cochlearis, Keratella tropica, Lecane arcula, Lecane cornuta, Lecane hastata, Lecane luna, Lecane quadridentata, Lepadella imbricata, Lepadella patella, Mytilina ventralis, Testudinella patina, Trichocerca pusilla) was recorded from 10%–20% of the investigated water bodies. Most of these species are considered cosmopolitan, having a widespread distribution being a derivative of their potential for long-distance dispersal (Fontaneto, 2019).

In our study we have not confirmed the presence of the 20 rotifer species that were identified from Costa Rica in the eighties of the XX century (Collado et al., 1984). Most of these species were of limnetic origin, e.g., Asplanchna brightwelli, Asplanchna sieboldi, Brachionus caudatus, Brachionus urceolaris, Conochiloides natans, Conochilus unicornis, Filinia longiseta, Filinia opoliensis, Filinia terminalis, and Pompholyx complanata, which suggests that these authors had mainly concentrated on investigating water bodies with large areas of the open water zone where pelagic species predominated. Many of these species are also cosmopolitan, occurring in a wide range of water bodies, and also irrespective of the climate conditions, e.g., Asplanchna brightwelli, Asplanchna sieboldi, Brachionus plicatilis, Brachionus rubens, Brachionus urceolaris, Conochiloides natans, Conochilus unicornis, Dicranophorus robustus, Filinia longiseta, Filinia terminalis, and Pompholyx complanata. In contrast, the new species that were identified for Costa Rica were mainly littoral/benthic organisms.

The results of our study clearly indicate that the character of type of habitat chosen for examination may be one of the key factors responsible for the determination of the level of fauna recognition.

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