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Article

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ARTICLE

Species richness and abundance of monogonont rotifers in relation to environmental factors in the UNESCO Sakaerat Biosphere Reserve, Thailand

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Abstract: The UNESCO Sakaerat Biosphere Reserve plays an important role in nature conservation and environmental protection. Previous focus on terrestrial habitats and neglect of aquatic ecosystems has resulted in an incomplete picture of biodiversity of the area. Based on the first investigation of planktonic diversity, rotifers were collected seasonally at five localities from September 2013 to May 2014 using a Schindler-Patalas plankton trap and a plankton net. Fifteen families, 25 genera and 71 species of rotifers were identified. The most diverse families were Lecanidae, Brachionidae, Lepadellidae, and Trichocercidae, accounting for 80% of the total species count. The maximum species richness was reported at the reservoir, with 57 species (80% of the total), while the minimum species richness (34) was observed at the ponds. The rainy season had the highest density, followed by winter and summer, with 149.15 N/l from an intermittent stream, and 95.43 and 50.68 N/l from a pond, respectively. Most of the sampling sites at the three seasonal occasions were dominated by a planktonic species *Polyarthra vulgaris*. The results indicate that the seasonal variation of the rotifer assemblage is related to the seasonal variation of physicochemical parameters.

Keywords: Mountainous area, northeastern Thailand, seasonal variation, southeastern Asia, water quality, zooplankton.

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Author contribution: NP was responsible for data collection and analysis, laboratory work and preparation of the manuscript. CB performed multivariate analyses and preparation of the manuscript. SA designed and participated in providing funding and facilities, involved in directing and supervising field and laboratory works, analyzed the data and discussed the results and preparation of the manuscript.

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INTRODUCTION

The UNESCO Sakaerat Biosphere Reserve (SBR), the leading biodiversity hotspot in Thailand, plays an important role in nature conservation and environmental protection. It is an ideal place to conduct ecological and environmental research. Several investigations have clearly shown a high diversity of flora and fauna (e.g., fungi, mushrooms, flowering plants, insects and vertebrates), and new species continue to be discovered, including fungi (*Lauriomyces sakaeratensis*) and grasshoppers (*Arnobia tinae*) (Somrithipol et al. 2006; Tan & Artchawakom 2014). Interest in the diversity of aquatic fauna has been limited to date, however; until recently, only two studies have been reported. The first involved the investigation of harpacticoid copepods (Boonyanusith & Athibai 2014), while the more recent one focused on the discovery of the rare freshwater sponge of Australasia at an intermittent stream (Ruengsawang et al. 2017).

Monogonont rotifers, in general, are the most diverse metazoan zooplankton. On a global scale, they comprise about 1,583 species belonging to 112 genera and 30 families (Segers 2011). In continental water bodies, they are predominant in the littoral zone of both permanent and temporary waters, acting as primary consumers in the trophic stage. Additionally, they are used as bioindicators to study the influence of environmental factors in water bodies (Negreiros et al. 2010). The diversity and distribution of rotifers in Thailand has been investigated primarily in surface water-bodies in lowland areas. Since the first publication for the country (Ueno 1966), the number of known Thai rotifers has increased remarkably. Previous comprehensive studies have provided valuable knowledge of the distribution of rotifers in Thailand (e.g., Sanoamuang et al. 1995; Sanoamuang & Savatenalinton 1999; Chittapun et al. 2007; Segers & Savatenalinton 2010; Athibai et al. 2013; Meksuwan et al. 2013), and 399 taxa of monogonont rotifer have been recorded (Sa-ardrit et al. 2013; Meksuwan et al. 2018). Nevertheless, considering the diversity of zooplankton in SBR it is necessary to fill the gaps in our knowledge. In this contribution, the species list and abundance of monogonont rotifers are provided based on sampling done in three seasons (rainy, winter and summer) at five sampling sites with various aquatic habitats within the Sakaerat Environmental Research Station (SERS), the core portion of the UNESCO SBR.

MATERIALS AND METHODS

Study area

Sakaerat Biosphere Reserve, the first of four UNESCO biosphere reserves in Thailand, is situated in the Sankamphaeng mountain range on the southwestern margin of the Khorat Plateau, Nakhon Ratchasima Province, in northeastern Thailand. Located between 14.445–14.542 ^{0}N and 101.844–101.955 ^{0}E, it covers approximately 82,100ha at an elevation of 250–762 m. The average annual temperature in that region is 26^{0}C, and the average annual rainfall is 1,260mm (Ruengsawang et al. 2017). Sakaerat Environmental Research Station is the core portion of the SBR. It was established to promote long-term ecological research, and to demonstrate sustainable forest management and biodiversity conservation (Trisurat 2010). Within the SERS and its buffer zone, nine habitats have been classified, comprising dry evergreen forest, mixed deciduous forest, dry dipterocarp forest, grassland, secondary growth vegetative forest, plantation, agriculture and settlement, old clearing, and water body (Trisurat 2010). In this study, monogonont rotifers were investigated at five sampling sites (Fig. 1). The location, altitude and habitat type of each are in Table 1.

Rotifer sampling and identification and environmental factors measurement

Qualitative and quantitative samples were collected seasonally in the rainy, summer and winter seasons between September 2013 and May 2014 from the five sampling localities, using a Schindler-Patalas plankton trap and a plankton net (60µm mesh size). The rotifers were then immediately preserved with 4% formaldehyde solution. Nine physicochemical parameters were measured: water temperature, transparency, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), orthophosphate content (PO_4^{3-}), nitrate content (NO_3^-) and total ammonia content (NH_3). The rotifer specimens were subsequently sorted, counted and identified under an Olympus-CH30 compound light microscope. The rotifers were identified to species level, according to Koste & Shiel (1992), Nogrady et al. (1995), Segers (1995), De Smet & Pourriot (1997), and Nogrady & Segers (2002).

Data analysis

The similarity of the faunal assemblages among the sampling sites and the seasons was evaluated by clustering. The operation was based on the Bray-Curtis dissimilarity coefficient. A canonical correspondence

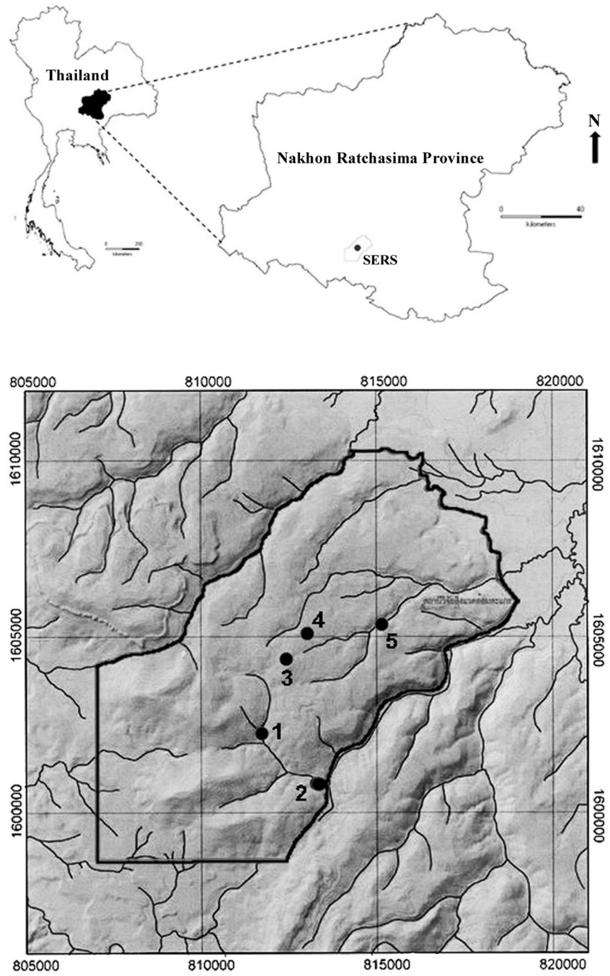

Figure 1. Sakaerat Environmental Research Station in Thailand showing sampling sites.

Table 1. Geographic coordinates of the sampling sites within the Sakaerat Environmental Research Station.

Sampling site code	Latitude ^{0}N	Longitude ^{0}E	Altitude (m)	Habitat type
S1	14.476	101.888	370	Stream
S2	14.466	101.903	392	Reservoir
S3	14.499	101.900	608	Pond
S4	14.501	101.902	560	Pond
S5	14.506	101.919	422	Stream

analysis (CCA) was later performed to examine the relationships between the environmental factors and the rotifer species.

In the data matrix of species abundance, taxa that occurred more frequently than 1% of all samples were included in the analysis (Yang et al. 2005). The data of abundance and environmental parameters were transformed by log10 (x + 1) before analysis. Data analysis was conducted by PC-ORD, version 5.0 (McCune & Mefford 2006).

The differences in nine environmental factors and the density of rotifers during three seasons at five sampling localities were analyzed using one-way ANOVA and IBM SPSS Statistics for Windows, version 19 (IBM Corp., Armonk, NY, USA). Furthermore, comparisons of the means were conducted using Duncan's multiple range test ($p < 0.05$).

RESULTS

Rotifer richness

Rotifer fauna collected on three seasonal occasions from five water-bodies within the SERS were investigated. A total of 71 species, belonging to 23 genera and 15 families of monogonont rotifers, were found (Table 2); illustrations of selected species are shown at Image 1. The most diverse family was Lecanidae (26 species, 36.62%) and Brachionidae (13 species, 18.31%). The next two most-diverse families were Trichocercidae and Lepadellidae, accounting for eight and six species, respectively. The greatest number of rotifer species (56) was reported during the rainy season. Based on the number of species per habitat (α-diversity), the α-diversity recorded from the rainy season was similar to that of the summer season. During the rainy season, the richness of the rotifers varied from nine to 44 species, compared to nine to 43 species found in summer, but the α-diversity was lower in winter (seven to 31 species). When comparing the habitat types, the reservoir had the highest diversity (57 species), followed by the stream (35 species) and the pond (34 species). The most frequently encountered species were *Polyarthra vulgaris* (80% of samples), *Keratella tropica* (73%), and *Lecane bulla* (73%). *Ascomorpha ovalis*, *Brachionus forficula*, *Cephalodella gibba*, *Lecane haliclysta*, *L. obtusa* and *Trichocerca scipio* were recorded during the rainy season only. *Lecane pyriformis*, *L. stenroosi*, *Lepadella quadricarinata* and *Trichocerca cylindrica* were observed only in winter; in contrast, *Brachionus calyciflorus*, *Dipleuchlanis propatula*, *Euchlanis dilatata*, *Lecane aculeata*, *L. latissima*, *Lecane superaculeata* and *L. tenuiseta* were present only in summer. Moreover, *Brachionus calyciflorus*, *Lecane haliclysta*, *L. stenroosi,* and *L. quadricarinata* were recorded only at the stream. *Brachionus forficula*, *Cephalodella gibba, Dipleuchlanis propatula*, *Euchlanis dilatata*, *Lecane aculeata*, *L. latissima*, *L. obtusa*, *L. pyriformis*, *L. superaculeata,* and *Trichocerca scipio* were found only at the reservoir.

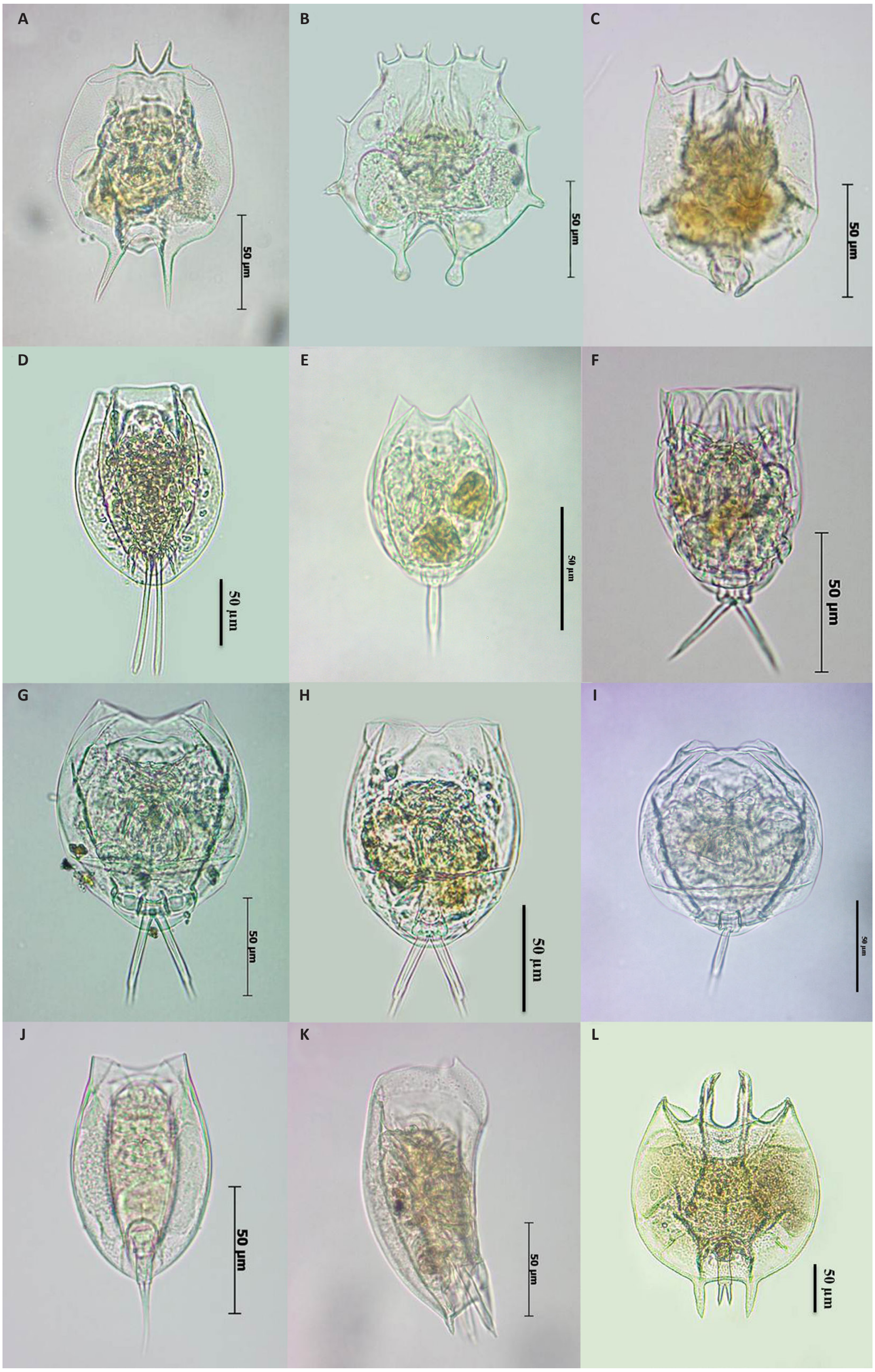

Image 1. Species of Rotifera: A—*Brachionus dichotomus reductus* Koste & Shiel, 1980 | B—*Brachionus donneri* Brehm, 1951 | C—*Brachionus kostei* Shiel, 1983 | D—*Dipleuchlanis propatula* (Gosse, 1886) | E—*Lecane hamata* (Stokes, 1896) | F—*Lecane haliclysta* Harring & Myers, 1926 | G—*Lecane lateralis* Sharma, 1978 | H—*Lecane papuana* (Murray, 1913) | I—*Lecane unguitata* (Fadeev, 1926) | J—*Lepadella rhomboides* (Gosse, 1886) | K—*Mytilina ventralis* (Ehrenberg, 1830) | L—*Platyias quadricornis* (Ehrenberg, 1832).

Table 2. Recorded rotifers found at five inland waters with different habitat types, by season, at the Sakaerat Environmental Research Station. 1—rainy season, 2—winter season, 3—summer season; species occurrence is characterized by present (+), absent (–).

	Sampling sites														
	S1			S2			S3			S4			S5		
Scientific name	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Family Asplanchnidae															
Asplanchna sieboldii (Leydig, 1854)	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–
Family Brachionidae															
Anuraeopsis fissa Gosse, 1851	–	–	+	–	–	+	+	–	+	+	–	+	+	–	+
Brachionus calyciflorus Pallas, 1766	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+
Brachionus dichotomus reductus Koste & Shiel, 1980	–	–	–	+	–	+	–	–	–	+	–	–	–	–	–
Brachionus donneri Brehm, 1951	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–
Brachionus falcatus Zacharias, 1898	+	–	–	+	+	+	–	–	–	+	–	+	–	–	+
Brachionus forficula Wierzejski, 1891	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Brachionus kostei Shiel, 1983	+	–	–	–	–	–	+	+	+	–	–	–	–	–	–
Brachionus quadridentatus Hermann, 1783	+	+	+	+	+	–	–	+	–	–	+	+	–	–	–
Brachionus quadridentatus mirabilis Daday, 1897	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–
Keratella cochlearis (Gosse, 1851)	–	–	–	+	+	+	–	–	+	–	–	–	+	–	–
Keratella tropica (Apstein, 1907)	+	+	+	+	+	+	–	+	+	+	+	+	–	–	–
Plationus patulus (Müller, 1786)	+	–	+	+	–	–	–	–	–	–	–	–	–	–	–
Platyias quadricornis (Ehrenberg, 1832)	+	–	+	+	–	+	–	–	–	+	+	–	–	–	–
Family Euchlanidae															
Dipleuchlanis propatula (Gosse, 1886)	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Euchlanis dilatata Ehrenberg, 1832	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Euchlanis incisa Carlin, 1939	+	+	–	+	+	+	–	–	–	–	–	–	+	–	–
Family Gastropodidae															
Ascomorpha ovalis (Bergendal, 1892)	–	–	–	+	–	–	–	–	–	+	–	–	–	–	–
Family Hexarthridae															
Hexarthra intermedia (Wiszniewski, 1929)	–	–	–	+	–	+	+	–	–	–	–	–	–	–	–
Family Lecanidae															
Lecane aculeata (Jakubski, 1912)	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Lecane bulla (Gosse, 1851)	+	+	+	+	+	+	–	+	–	+	–	+	–	+	+
Lecane closterocerca (Schmarda, 1859)	+	+	–	+	+	–	–	+	–	+	–	–	+	+	–
Lecane curvicornis (Murray, 1913)	+	–	+	+	+	+	–	–	–	–	+	–	–	+	–
Lecane flexilis (Gosse, 1886)	–	+	–	–	–	–	–	–	–	+	+	–	–	–	–
Lecane furcata (Murray, 1913)	–	–	–	–	+	–	–	–	–	–	–	–	+	–	+
Lecane haliclysta Harring & Myers, 1926	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lecane hamata (Stokes, 1896)	+	–	+	+	+	+	–	–	+	–	–	–	+	+	+
Lecane hornemanni (Ehrenberg, 1834)	–	+	–	–	–	+	–	–	+	–	–	+	–	–	–
Lecane lateralis Sharma, 1978	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–
Lecane latissima Yamamoto, 1955	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Lecane leontina (Turner, 1892)	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–
Lecane ludwigii (Eckstein, 1883)	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Lecane luna (Müller, 1776)	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–
Lecane lunaris (Ehrenberg, 1832)	+	+	–	+	+	+	–	–	–	–	+	+	–	–	+
Lecane nitida (Murray, 1913)	–	–	–	+	–	+	–	–	+	–	–	–	–	–	–
Lecane obtusa (Murray, 1913)	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Lecane papuana (Murray, 1913)	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–
Lecane pyriformis (Daday, 1905)	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–

Scientific name	Sampling sites														
	S1			S2			S3			S4			S5		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Lecane quadridentata (Ehrenberg, 1830)	+	+	–	+	+	+	–	–	–	–	–	–	–	–	–
Lecane signifera (Jennings, 1896)	–	–	–	+	+	+	–	+	–	–	–	+	–	–	–
Lecane stenroosi (Meissner, 1908)	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Lecane superaculeata Sanoamuang & Segers, 1997	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Lecane tenuiseta Harring, 1914	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Lecane unguitata (Fadeev, 1926)	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–
Lecane ungulata (Gosse, 1887)	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–
Family Lepadellidae															
Colurella uncinata (Müller, 1773)	–	–	–	–	–	–	–	+	–	–	–	–	+	+	+
Lepadella acuminata (Ehrenberg, 1834)	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–
Lepadella dactyliseta (Stenroos, 1898)	+	+	–	+	+	+	–	–	–	–	–	–	–	–	–
Lepadella patella (Müller, 1773)	+	+	–	+	–	+	–	+	+	–	+	+	–	–	+
Lepadella quadricarinata (Stenroos, 1898)	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Lepadella rhomboides (Gosse, 1886)	+	–	–	–	–	–	–	+	+	–	–	–	+	+	+
Family Mytilinidae															
Mytilina acanthophora Hauer, 1938	+	+	–	–	–	–	+	+	+	–	+	–	–	–	+
Mytilina ventralis (Ehrenberg, 1830)	+	–	–	–	+	+	+	–	–	–	+	–	–	–	–
Family Notommatidae															
Cephalodella forficula (Ehrenberg, 1830)	–	–	–	+	–	+	–	–	–	–	–	–	–	–	+
Cephalodella gibba (Ehrenberg, 1830)	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Monommata longiseta (Müller, 1786)	–	–	–	+	+	+	–	–	–	–	–	–	–	+	–
Family Scaridiidae															
Scaridium longicaudum (Müller, 1786)	–	–	–	+	–	+	–	–	–	–	+	–	–	–	–
Family Synchaetidae															
Polyarthra vulgaris Carlin, 1943	+	+	+	+	+	+	+	+	+	–	–	+	+	–	+
Family Testudinellidae															
Testudinella patina (Hermann, 1783)	+	–	–	+	+	+	–	–	–	–	+	+	–	–	–
Family Trichocercidae															
Trichocerca bicristata (Gosse, 1887)	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–
Trichocerca bidens (Lucks, 1912)	–	–	–	+	+	–	–	+	–	–	+	+	–	–	–
Trichocerca capucina (Wierzejski & Zacharias, 1893)	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–
Trichocerca cylindrica (Imhof, 1891)	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–
Trichocerca insulana (Hauer, 1937)	–	+	–	+	+	–	–	–	–	–	–	–	–	–	–
Trichocerca pusilla (Jennings, 1903)	–	–	–	–	–	–	+	–	+	+	–	+	–	–	–
Trichocerca scipio (Gosse, 1886)	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Trichocerca similis (Wierzejski, 1893)	–	–	–	+	+	+	+	+	+	+	+	+	–	–	–
Family Trichotriidae															
Macrochaetus sericus (Thorpe, 1893)	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–
Trichotria tetractis (Ehrenberg, 1830)	+	–	–	+	+	–	–	–	–	–	–	–	–	–	–
Family Trochosphaeridae															
Filinia longiseta (Ehrenberg, 1834)	–	–	–	+	+	+	+	–	–	+	–	+	+	–	–
Filinia opoliensis (Zacharias, 1898)	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–
Total number of species during each season	23	17	9	44	31	43	9	14	14	13	14	15	10	7	13
Species richness at each sampling site		29			57			24			25			19	

Finally, *Lecane tenuiseta* and *Trichocerca cylindrica* were observed only at the pond.

Rotifer density

The density of the rotifers varied by season and sampling site. The densities at S1 (stream; $F_{2, 8}$ = 23.689, p = 0.001), S2 (reservoir; $F_{2, 8}$ = 11.396, p = 0.009) and S5 (intermittent stream; $F_{2, 8}$ = 42.925, p < 0.001) are seasonally significant differences; by comparison, those of S3 (pond) and S4 (pond) were not significantly different. The greatest number of rotifers at S1, S2, and S5 was 13.91N/l in the rainy season, 29.43N/l in summer, and 149.15N/l in the rainy season, respectively. The sampling site with the highest abundance in the rainy season was S5 (the intermittent stream; 149.15N/l), whereas the greatest number during winter (95.43N/l) and summer (50.68N/l) was at S3 (pond). *Filinia longiseta* was most prominent at S5 in the rainy season, with a density of 96.63 ± 28.57 N/l (64.79%); while S3 was dominated by *Brachionus quadridentatus* in winter and *Polyarthra vulgaris* in summer, with densities of 84.78 ± 51.57 N/l (88.84%) and 28.03 ± 19.73 N/l (55.31%), respectively. In contrast, the lowest densities in the rainy, winter and summer seasons were observed at S2 (6.25N/l), S5 (0.38N/l) and S1 (1.22N/l), respectively. In addition, of the 15 families encountered, Brachionidae, Lecanidae, Trichocercidae, and Synchaetidae were the most dominant. The first three families are most prominent at all of the sampling sites in the rainy season. The intermittent stream S5 had a remarkably different rotifer assemblage to the other sites in the rainy season as the density of Trochosphaeridae was over 60%. During winter, when the highest density of Brachionidae, Synchaetidae, and Trichocercidae occurred, the sampling sites generally showed a low density of rotifers (< 10N/l) except S3, whose density (95.43N/l) was noticeably higher, with Brachionidae accounting for 84.78% of the specimens at the S3 site. Among the 15 families, the Brachionidae was the most frequently observed, being present at over 50% of the study sites. In summer, the densities of rotifers obviously increased from those during winter. Most of the sampling localities were dominated by Brachionidae, Lecanidae, Synchaetidae, and Trichocercidae (Fig. 2). The most prominent species during each season varied slightly. Three species, namely, *Lecane bulla*, *Polyarthra vulgaris,* and *Trichocerca similis* were predominant and common at several sampling sites in all seasons.

Environmental parameters

The physicochemical parameters of water data were obtained during three seasons (rainy, winter and summer) from five sampling sites (S1, S2, S3, S4, and S5); the grouping was categorized into three different habitat types (pond, reservoir, and stream). The statistical analysis showed that five parameters (water temperature, pH, transparency, NH_3, and EC) at each sampling site displayed significant differences among the seasons (p < 0.05). The value of water temperature had the highest in summer and lowest in winter. The pH of water in the rainy season was slightly acidic to neutral (6.51–7.44), whereas that in winter and summer was

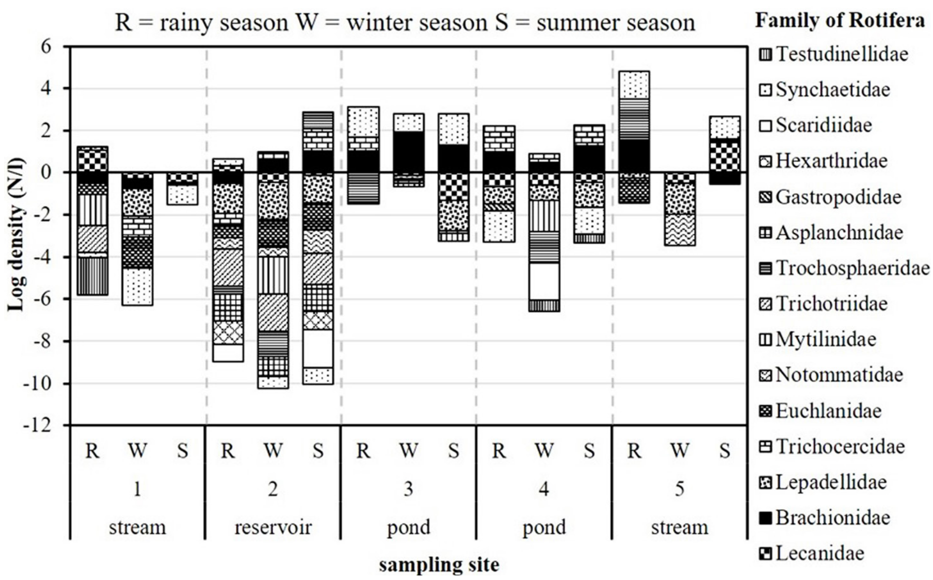

Figure 2. Log density of rotifer families at five sampling sites during different seasons.

slightly acidic (5.17–6.70) and acidic to slightly acidic (4.54–6.32), respectively. The pH was lowest at S5, with a mean of 4.54 ± 0.36. The NH_3 value at S3 was the highest in all seasons, with 2.04 ± 0.12 mg/l in the rainy season, 0.93 ± 0.09 mg/l in winter and 1.92 ± 0.04 mg/l in summer. In addition, the NH_3 value at S1 (the stream) was high in the summer (1.81 ± 0.22 mg/l).

The Pearson correlation from the CCA analysis showed that EC and TDS had a strongly positive correlation with NH_3. The correlation coefficients between EC and TDS, EC and NH_3, and TDS and NH_3 were 0.996, 0.937 and 0.953, respectively. In contrast, EC, TDS, and NH_3 were negatively correlated with DO; the coefficients between EC and DO, TDS and DO, and NH_3 and DO, were 0.568, 0.608 and 0.615, respectively. The ranges of EC, TDS, NH_3 and DO during those two seasons were, respectively, 153–161 µS/cm, 74–81 mg/l, 1.92–2.16 mg/l and 1.0–1.7 mg/l in the rainy season, and 125–133 µS/cm, 65–70 mg/l, 1.88–1.96 mg/l and 1.6–2.4 mg/l during the summer.

Seasonal variation of rotifer community

A cluster dendrogram was constructed; it was based on the data of 12 species at each sampling locality in the three seasons. The results revealed three major groupings (Fig. 3). Sampling sites S1 and S5 were clustered together, which corresponded to the winter community. Both sites were streams and had a low density of rotifers; *Lecane bulla* was predominant at both sites. Cluster 2 comprised the majority of the sampling sites and could be separated into two sub-clusters. Cluster 2A was composed mainly of two lentic habitats (S3 in all seasons, and S4 during the rainy season and summer) and one lotic water (S5 in the rainy season). This subgroup had a high density of six dominant species: *Anuraeopsis fissa*, *Brachionus kostei*, *B. quadridentatus*, *Filinia longiseta, Polyarthra vulgaris,* and *Trichocerca pusilla*. Cluster 2B included two water bodies: S2 (the reservoir) in the winter and the summer, and S4 (one of the ponds) in winter. This sub-cluster was made up of three predominant species: *Filinia opoliensis*, *Keratella tropica,* and *Trichocerca similis*. Cluster 3 consisted of three sampling sites, S1 (the stream) in the rainy season and summer, S2 in the rainy season, and S5 in summer. This cluster was grouped by the occurrence of three species (*Lecane bulla*, *L. curvicornis,* and *Mytilina acanthophora*). Focusing on S1 and S2 in the rainy season, both water bodies showed a strong relationship between them because they were situated in the same watershed, resulting in the similarity of their species occurrences and the equality of their densities.

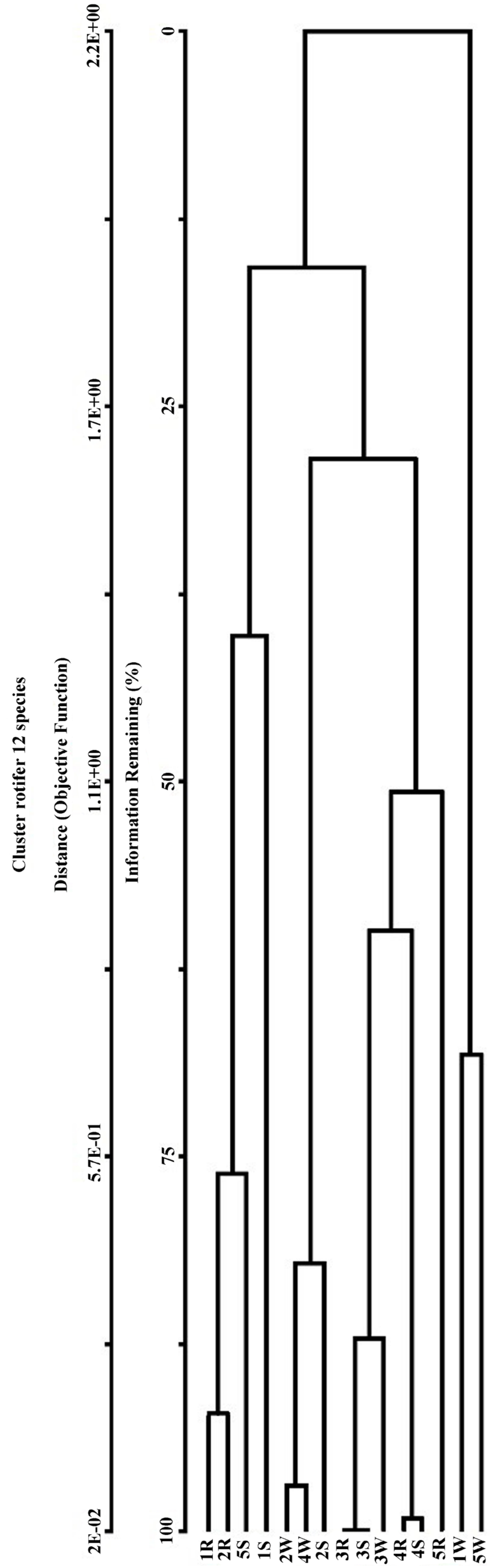

Figure 3. Hierarchical cluster analysis of sampling sites (sites 1, 2, 3, 4 and 5) during different seasons (R: rainy season, W: winter season, S: summer season), using Bray-Curtis similarity distances.

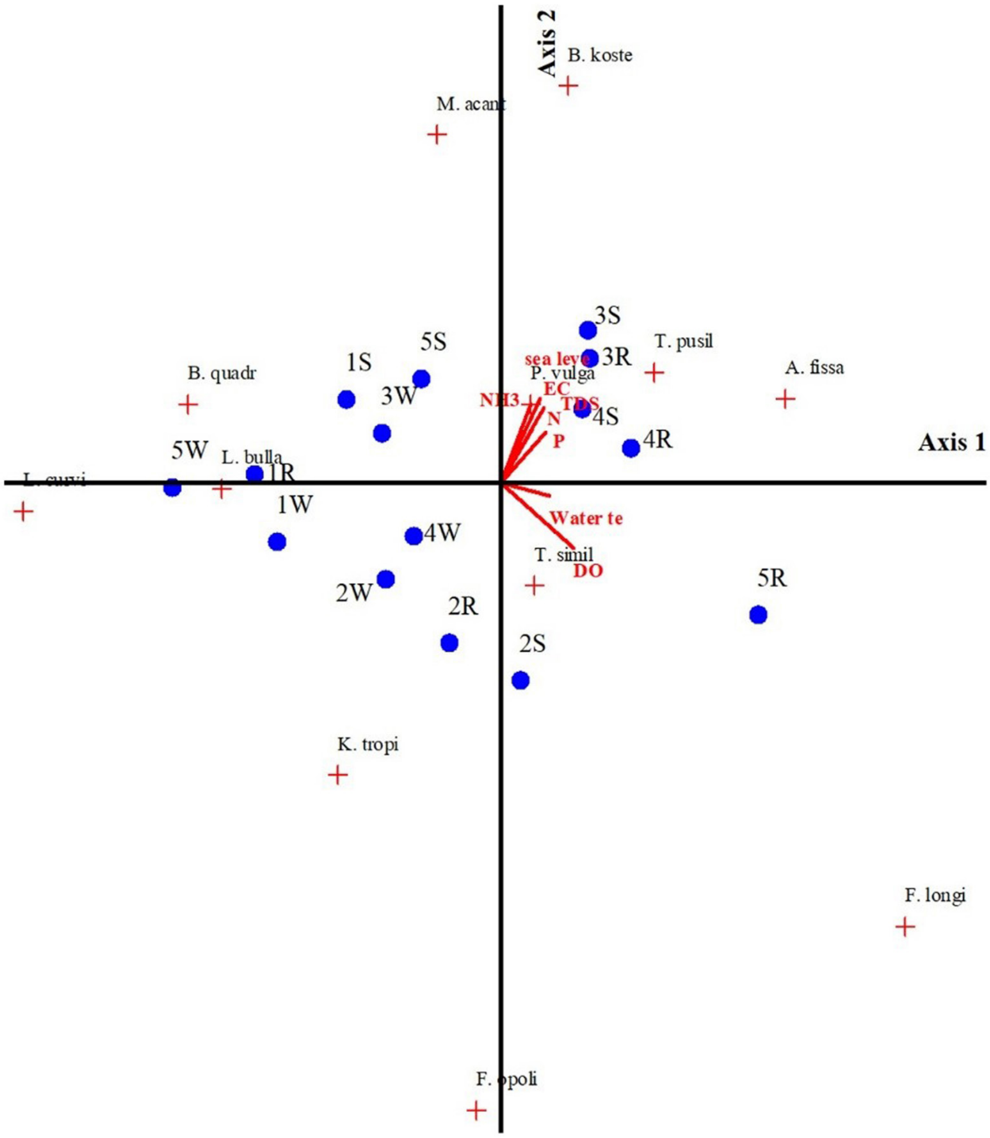

Figure 4. Canonical correspondence analysis (CCA) triplot of rotifer species and physicochemical parameters of water in inland waters of the Sakaerat Environmental Research Station. The physicochemical parameters of water; Water te: water temperature (°C), Transpar: transparency (cm), DO: dissolved oxygen (mgL^{-1}), EC: electrical conductivity (μScm^{-1}), TDS: total dissolved solid (mgL^{-1}), P: orthophosphate (mgL^{-1}), N: nitrate (mgL^{-1}) and NH_3: ammonia (mgL^{-1}). The numbers 1, 2, 3, 4, 5 indicate the sampling site numbers, and the letters R, W and S refer to the rainy, winter and summer seasons, respectively.

Relationships between rotifer community structure and environmental factors

Out of the 71 rotifer species, 12 that had a relative density of more than 1% were used for a CCA analysis. The percentages of the explained variance on the first and the second axes is 22.1 and 16.7, respectively. The species that are positively correlated to EC, TDS, NH_3, NO_3^-, PO_4^{3-}, and altitude are *Anuraeopsis fissa*, *Brachionus kostei*, *Polyarthra vulgaris* and *Trichocerca pusilla* (Fig. 4). The density of those species was high in the two ponds (S3 and S4 in the rainy and summer). A high density of *Brachionus kostei* was found at S3 in the summer season, with 19.57 N/l. Additionally, *Filinia longiseta*, *F. opoliensis,* and *Trichocerca similis* are positively correlated to water temperature and DO. High densities of the three species were present at the intermittent stream (S5) in the rainy season and at the reservoir (S2) in summer, when there were relatively high temperatures and DO levels. In particular, *Filinia longiseta* had the maximum density, with 96.63 N/l at S5 in the rainy season. In contrast, *Keratella tropica* showed a negative correlation with the major factors, including

EC, TDS, NH_3, NO_3^-, PO_4^{3-}, and altitude. *Keratella tropica* predominated at the sites that had low values for those factors, such as the pool region of the S1 stream (in winter), the S4 pond (in winter) and the reservoir (S2, in the rainy season and winter). Four species, *Brachionus quadridentatus*, *Lecane bulla*, *L. curvicornis,* and *Mytilina acanthophora* were negatively correlated with water temperature and DO. They had high densities at the sites that had low values for temperature and DO, the stream S1 (in all seasons), the S3 pond (in winter) and the pool of the intermittent stream (S5, in winter and summer). However, the Monte Carlo permutation test showed that the axis does not have any statistical significance with any of the physicochemical parameters of the water.

DISCUSSION

Rotifer richness

The 71 species of rotifer within the SERS represent 37.37% of the 190 species known at 77 localities within Nakhon Ratchasima Province (Savatenalinton 1999) and circa 17.79% of the 399 monogonont rotifers recorded in Thailand. The diversity of rotifer within the SERS is relatively low, compared with the total number of species of freshwater rotifers recorded in Thailand (Sa-ardrit et al. 2013; Meksuwan et al. 2018). This is probably due to the differences in the number of samples and habitat characteristics. In general, the diversity of plankton is quite high in lowland areas due to a large number of relatively large, stagnant waterbodies (Obertegger et al. 2010). In general, monogonont rotifers are especially diverse in the littoral zones of stagnant waters which have soft, slightly acidic and under oligo- to mesotrophic conditions (Segers 2008). This contrasts with the situation in mountainous areas, where running water, such as streams, is common. Flowing water has been identified as a limiting factor that results in reduced species diversity of rotifers (Sulehria & Malik 2012). However, rotifer species richness at SERS is numerically higher than those found at other conservation and mountain areas, such as Nam Nao National Park, Phetchabun Province, where 11 species of monogonont rotifers were encountered, and Phu Hin Rong Kla National Park, Phitsanulok Province, where 12 species were found in waterfall mosses (Savatenalinton & Segers 2008; Athibai 2014). Only a few species have commonly been encountered at those two parks. Only one cosmopolitan species, *Keratella tropica*, was recorded in the two aforementioned studies as well as the current study. This species was considered as tolerant species because they can live in highly polluted waters (Kulshrestha et al. 1991; Javed 2006) and eutrophic waters (Guevara et al. 2009). This incidence indicates that *Keratella tropica* has a wide range of ecology. In addition, Lecanidae was highly diverse at many sampling sites in the current study, which concurs with previous studies done in northeastern and southern Thailand (e.g., Sanoamuang et al. 1995; Chittapun et al. 2007). Genus *Lecane* has a high diversity in tropical regions and has frequently been found in neighboring countries such as Laos PDR (Segers & Sanoamuang 2007), Cambodia (Sor et al. 2015), and Vietnam (Dang et al. 2013). Several species in our study were widely distributed and found in almost every type of water body such as *Lecane bulla*, *L. closterocerca*, *L. curvicornis*, *L. hamata*, *L. lunaris,* and *L. papuana*. Compared with species richness of monogonont rotifers in Nokrek Biosphere Reserve, India, a number of rotifers in the latter (67 species) were close to the observed species richness in the present study; particularly, rotifer species exhibited 60.8% similarity with 42 shared species between this work and Nokrek Biosphere Reserve (Sharma & Sharma 2011). The species composition of the rotifers at the three different habitat types within the SERS, however, was different. The reservoir had the most diverse habitat, followed by the stream and then the pond. This indicated that the distribution of a certain species depends on the habitat type (Gürbüzer et al. 2017) and whether a habitat shows a high diversity of microhabitats (Arora & Mehra 2003). In case of SERS, the reservoir and streams were densely covered by macrophytes in the littoral region, providing various microhabitats. This has been found to affect the distribution and composition of rotifers (Duggan et al. 1998**).** Similarly, Ali et al. (2007) reported that subtropical freshwater invertebrates had the highest species diversity in various types of macrophytes. Furthermore, the species preferences of rotifers have been shown to differ depending on the macrophyte species (Choi et al. 2014**)**. Given that it is a common species, *Polyarthra vulgaris* was expected to be common and dominant in the inland waters of the SERS. Similarly, this species has been found to be common in certain habitats, such as the Cambodian Mekong River Basin (Meas & Sanoamuang 2008) and the eight lakes in the central Anatolia, Marmara, and western Black Sea regions of Turkey (Ergönül et al. 2016).

Rotifer density

A seasonal variation in rotifer density was evident at all of the sampling sites in the SERS; the densities of the rotifers at S1, S2, and S5 differed significantly between the seasons ($p < 0.05$). At site S5, the density of rotifers was greatest in the rainy season. The physical characteristic of the S5 sampling area was rock pool, and the slow-flowing water was densely covered by free-floating macrophytes (*Lemna perpusilla*) during the rainy season. The macrophytes at that site disappeared in winter but regenerated in summer; during both those seasons, the water level was lower than in the rainy season. Nitrate and orthophosphate contents seem to be influencing factors for rotifer composition in SERS. As to the S5 site, both parameters were high in the rainy season, with 1.93 ± 0.46 and 0.45 ± 0.39 mg/l, respectively. Generally, nitrates and phosphates are common nutrients in aquatic habitats; they promote phytoplankton growth, and their concentrations in the water column can significantly increase or decrease the phytoplankton biomass (Pelczar et al. 2010). Meanwhile, zooplankton growth is impacted by the phytoplanktonic density because the zooplanktons graze upon the phytoplankton (Thompson et al. 1982). Therefore, seasonal variation also influences the plankton communities. Moreover, this site seems to be a eutrophic habitat because the nitrate and orthophosphate content in this study exceeded 1,500µg/l of total nitrogen and 75µg/l of total phosphorus (Dodds & Smith 2016). Those characteristics of the sampling site would affect the rotifer density (Rothhaupt 1995). The greatest density of rotifers was recorded in the rainy season, accounting for 99% of the total density. Three rotifer species were dominant in that period: *Filinia longiseta* (64.78%), *Anuraeopsis fissa* (20.81%) and *Polyarthra vulgaris* (13.23%). Those three species have also been found in eutrophic habitats (Saunders-Davies 1989; Basińska & Kuczynska-Kippen 2009). According to S3 (one of the two ponds), it was observed to have the highest density of rotifers in winter and summer. *Brachionus quadridentatus* was the dominant species in the winter, with an 88.84% relative density, but that species disappeared in the summer. Both *Polyarthra vulgaris* and *Brachionus kostei* were found to be predominant in summer, with relative abundances of 55.31% and 38.61%, respectively. Rotifers in the genus *Brachionus* and *Polyarthra* are euplanktonic rotifers, and several species of the genera are present in the littoral region of water bodies (Virro 1993). From our observations during the sampling, macrophytes were present at only three localities; therefore, the dominant species were probably both the planktonic and epiphytic rotifers. For example; macrophytes (*Hydrilla verticillata*) were present at S1 in the rainy season, and *Lecane* and *Lepadella* were found to be the dominant genera at that site.

Environmental parameters

Seasonal variations in the physicochemical parameters at the five sampling sites in the SERS were reported; five parameters, water temperature, pH, transparency, ammonia, and EC, had seasonally significant differences ($p < 0.05$). Ranging from 19.0–32.9°C, the water temperature was the lowest and the highest in winter and summer, respectively. Generally, water temperature is mainly influenced by factors such as air temperature, solar radiation, wind speed, cloud cover, humidity, precipitation, evaporation, and topography (Li et al. 2017), however, the sampling time should also be considered because it could result in differences in temperature readings throughout the day (Orr et al. 2015). As to pH, the mean pH values of the five sampling sites ranged from highly acidic to circumneutral (4.54–7.44). During summer (May), water in the intermittent stream (S5) recorded the lowest value (4.54 ± 0.36). The physical characteristic of this sampling site was a rock pool with brown water. The evidence is similar to that of a previous study by Tevapawat & Sangpradub (2017), who found that the water at S5 in the summer was brown in color and that its pH (5.59 ± 0.26) was slightly higher than observed in the present study. We assumed that the brown color and high acidity of the water resulted from organic decomposition (Winterbourn & Collier 1987). Moving on to NH_3, high values of NH_3 were reported in pond (S3) in all seasons, but particularly during the rainy season, when it peaked at 2.04 ± 0.12 mg/l. In general, ammonia is considered the first nitrogenous form to occur in freshwater habitats after its release into natural waterways through sewage discharges, the excretion of nitrogenous wastes from animals, and organic matter decomposition (Thurston & Russo 1983). In the present study, the S3 site was a small pond providing water for wildlife, and much leaf litter fell into the site during each of the three seasons. It, therefore, seems probable that the high NH_3 value of this site results from the excretion of nitrogenous wastes from wildlife, leaf litter decomposition, and nutrient loading during the rainy season. In addition to the litter decay in the S3 pond, dissolved oxygen (DO) would seem to be a limiting factor in the environment since oxygen is not only a source of aquatic animal respiration but also an input to the decomposition process. This study revealed that the DO values at S3 were low during all three seasons, with their mean ranging between 1.30 and 2.03 mg/l. The trend of the DO and nitrogen values is similar to the findings of the study by Stoler & Relyea (2016), which reported that DO showed a negative correlation with the leaf litter decay rate and the ratio of carbon to nitrogen (C:N) in the pond at the Pennsylvania State in USA.

Relationship between habitats, environmental factors and rotifer abundance

The clustering showed that two factors affect the distribution and diversity of the rotifers in the SERS. The first is the connectivity between them (Schöll 2009), and the second is the habitat type (Sor et al. 2015). In terms of the location of the five sampling sites, S3 and S4 are the closest. Given that both sites are man-made water bodies constructed as water sources for the local wildlife which can connect and distribute through both regions. The resting eggs of rotifers may attach to the feet, fur and feathers of other wildlife. So, the dispersion of rotifers between the two sites is probably generated by animals (Zhdanova et al. 2016). In the case of the S1 and S2 sites, S1 is the nearest site to S2, S1 is located more in the upper part of the watershed than S2. The clustering clearly showed a separation of the two sites. Although they share the same watershed, the rotifer community of both sites were different. The S1 was separated from S2 due to the dry period in winter and summer seasons. However, the presence of two *Elaphoidella* species (harpacticoid copepods) in S1 and S2 that were not observed at other sampling sites and have never previously been observed elsewhere in Thailand (Boonyanusith & Athibai 2014), is an indication of the connection between S1 and S2. The cluster analysis also revealed that, in the rainy season, S1 and S2 are grouped together, which is supported by the similarity of their rotifer assemblages. S2 could be classified as a relatively large reservoir, and its water level was stable throughout the three sampling occasions. This characteristic supports the continual presence of macrophytic vegetation in the reservoir's littoral zone, in turn ensuring the presence of stable rotifer microhabitats and hence its high diversity of rotifers.

The CCA triplot showed the effects of electrical conductivity, total dissolved solids, ammonia, nitrate, orthophosphate and altitude on the distribution of the rotifer species in the inland waters of the SERS. *Anuraeopsis fissa*, *Brachionus kostei*, *Polyarthra vulgaris,* and *Trichocerca pusilla* were predominant at S3 and S4 in the rainy and summer seasons, with relatively high values for those variables. Conde-Porcuna et al. (2002) reported that the population of *Anuraeopsis fissa* correlated with the soluble reactive phosphorus value in a mesotrophic reservoir in southern Spain. Based on the DO levels and water temperature, the CCA result indicated that DO seems to be an influential factor for *Filinia longiseta*. This species was found to be most abundant in the rock pool of the intermittent stream (S5) in the rainy season (9.13mg/l of DO), whereas *Filinia opoliensis* and *Trichocerca similis* were predominant at the reservoir (S2) in summer, when water temperatures there were at their highest (30.4^{0}C). Similarly, Negreiros et al. (2010) pointed out that pH, EC and DO probably influenced the fluctuations in the rotifer population in the Sapucaí River arm of Furnas Reservoir, MG, Brazil. Sharma (2010) reported that variations of rotifer communities in a Ramsar site, namely Deepor Beel in India were influenced by several factors such as rainfall, water temperature, transparency, EC, DO and PO_4^{3}. Furthermore, Sulehria et al. (2012) found that water temperature, EC, DO, pH and TDS affected the rotifer assemblages in floodplains at Dhan, Pakistan; however, some rotifer species showed a negative correlation with major factors: *Brachionus quadridentatus*, *Lecane bulla*, *L. curvicornis,* and *Mytilina acanthophora* were dominant at sites with low values for DO and water temperature, and *Keratella tropica* had a high density at sites with low values for EC, TDS, NH_3, NO_3^-, PO_4^{3-} and altitude. The results indicate that seasonal changes are important factors affecting the environmental factors, seasonal distribution and seasonal succession in the community of rotifers at each sampling site in the SERS.

CONCLUSİON

The investigation of the monogonont rotifers, regarding differences found in both seasonal and habitat types, provides a detailed description of the seasonal variation found within species assemblage, abundance, and responses to water quality, as well as, the critical factors which result in their distribution throughout the SBR. Seventy-one rotifers were recorded in this study with 36.6% of these composed of lecanid rotifers. The species richness of rotifers was highest during the rainy season. The largest habitat type was the reservoir which also had the highest number of rotifers present. The dominant species in each of the sampling sites were *Lecane bulla*, *Polyarthra vulgaris,* and *Trichocerca similis.* Certain species which showed importance were *Filinia longiseta* which had a maximum density in the intermittent stream during the rainy season and *Brachionus quadridentatus* which showed the highest numbers present in the pond during the winter season. In addition to this, the physicochemical parameters of the water data are similar to those found in natural water bodies throughout conservation areas of Thailand.

Water temperature, pH, transparency, ammonia, and electrical conductivity were found to have both seasonal and spatial fluctuations. The low pH found in the intermittent stream during the summer season resulted in the highly acidic stream found here. Overall, seasons, habitat types, connectivity and location of sampling sites, as well as the environmental factors such as water temperature, dissolved oxygen, electrical conductivity, total dissolved solids, nitrate, orthophosphate, ammonia and altitude strongly influenced the differences found among the rotifer community structure in inland waters of the SBR. To conclude, further studies are required particularly with regard to crustacean zooplankton in order to gain further knowledge on the overall zooplankton biodiversity found in Thailand.

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