SPECIES DIVERSITY OF ROTIFERS (ROTIFERA: MONOGONONTA) IN FRESHWATER PSAMMON WITH THREE NEW RECORDS TO VIETNAM

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(Received: November 8, 2021; Accepted: December 12, 2021)

Abstract - This study aims to evaluate the diversity of rotifers in psammon in the Central Coast of Vietnam. A total of 64 rotifer species belonging to 17 genera and 14 families were recorded in 10 samples collected at hygropsammon zones of freshwater lakes and ponds in Thua Thien Hue province. *Lepadella cristata* (Rousselet, 1893), *Cephalodella tenuior* (Gosse, 1886), and *Lindia torulosa* Dujardin, 1841 were new record to Vietnam rotifers fauna. Species from the families Lecanidae, Lepadellidae, and Trichocercidae are abundant (containing about 44%, 14%, and 12%, respectively) in the total rotifer species recorded. Psammonxenic species accounted for the largest percentage of the psammic rotifer community with 83%, followed by psammonphiles (11%) and psammonbionts (6%). Our study results enrich the data on the diversity and the ecology of rotifers in Vietnam.

Key words - Rotifers; psammon; diversity; community structure; freshwater lake

1. Introduction

Rotifers have been found to appear with a high abundance in the interface of aquatic and terrestrial zones of lakes and beaches. This so-called psammic rotifers group is thus believed to be an essential linkage that ensures the connections among different kinds of ecosystems via matter and energy flows [1]. Recently, many worldwide efforts have been made in order to explore the diversity as well as the functioning of rotifers inhabiting highly unstable habitats both in lotic and lentic water [2] - [12].

Nonetheless, psammic communities still generally remain understudied compared to planktonic or benthic ones [13]. Especially in Southeast Asia and also in Vietnam, this group of organisms has received even less attention despite the fact that biogeography of Southeast Asia has been discovered very special because of the particularly complex geological and biological history [14] and might result in diverse species composition and a high number of endemic species. Evidently, only one study conducted by Trinh-Dang in the Central Coast of Vietnam has already confirmed the presence of a total of 98 rotifers species in psammon, with three taxa being new to science and 48 taxa new to Vietnam [15]. These results supported the hypothesis of high biodiversity of rotifers in Vietnam though more intensive samplings are required. This work aimed to continue these efforts by investigating the diversity and community structure of psammic rotifers in freshwater habitats in Thua Thien Hue province, Vietnam.

2. Materials and Methods

The studied area comprises ten freshwater lakes and ponds in white sand dunes in Northern Thua Thien Hue province, Vietnam (Figure 1). These water bodies are generally characterized by mesotrophic, eutrophic and hypereutrophic conditions (Table 1) due to waste from aquaculture, livestock, and poultry farming activities, with the total nitrogen (TN) and phosphate (PO_4^{3-}) concentrations respectively ranging from 0.53 to 11.13 mg/L and from 0.17 to 0.34 mg/L. The water temperature (Temp) and dissolved oxygen (DO) concentration were quite homogenous among lakes and ponds, with average values of 21.3 ± 0.5°C and 6.6 ± 0.4 mg/L, respectively. pH of the water was from slightly acidic to slightly alkaline (5.7 - 8.4). Besides, the water was quite evident as the turbidity (Turb) fluctuated in the range of 2.2 - 13.8 NTU (Table 1).

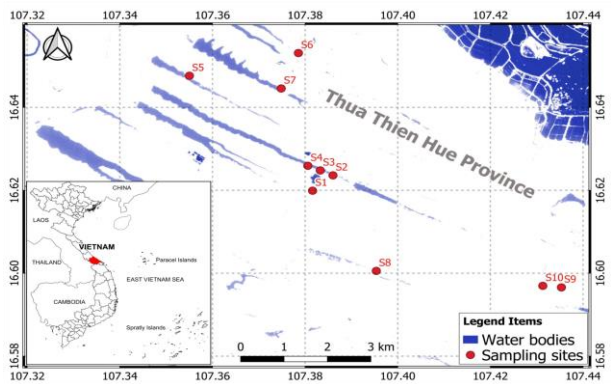

Figure 1. *Map of the study area with sampling sites*

The sampling campaign was conducted during the rainy season in October 2018. Psammon samples were obtained by collecting a 3 cm thick section of sand in the hygropsammon zone using a sharp-edged bailer and immediately fixed with formaldehyde (4%). Faunal specimens were examined using a Hund Wetzlar H600 microscope and identified based on taxonomy and nomenclature of the rotifers as in [16]. Psammobionts, psammophiles, and psammoxenes taxa were classified following [2], [5], [11], [12], [17]. Additionally, the species not on those lists were assigned to subjectively categories based on our observations of their habitats and literature data, as appropriate.

Rarefaction analysis was applied to achieve species richness accumulation curves while incidence-based (Chao 2 and Jackknife 2) and abundance-based (Bootstrap) richness estimators were used to estimate the total species

richness. Comparison of species composition among sampling sites was made using the Jaccard similarity index. Calculations of these parameters were implemented in the R program [18] using the vegan package [19].

***Table 1**. Environmental conditions of the sampling sites*

Site	TN (mg/L)	PO4 (mg/L)	Nutrient state	Trophic state (TSI)	Temp. (ºC)	pH	Turb. (NTU)	DO (mg/L)
S1	0.54	0.25	N limited	mesotrophic	21.6	6.5	6.3	5.7
S2	2.66	0.17	balanced	eutrophic	20.8	7.1	9.1	6.2
S3	5.81	0.34	balanced	hypereutrophic	21.4	6.9	13.8	7.3
S4	4.48	0.34	balanced	hypereutrophic	21.1	7.2	8.7	6.8
S5	1.43	0.32	N limited	eutrophic	20.5	6.0	6.1	6.9
S6	11.13	0.30	P limited	hypereutrophic	20.5	8.4	2.2	6.5
S7	8.63	0.31	balanced	hypereutrophic	21.5	5.7	8.4	6.3
S8	0.53	0.31	N limited	mesotrophic	21.5	7.1	5.4	6.5
S9	3.02	0.17	balanced	eutrophic	21.9	6.8	2.9	6.8
S10	0.64	0.26	balanced	eutrophic	21.8	5.9	7.1	6.8
mean	*3.89*	*0.28*	-	-	*21.3*	*6.8*	*7.0*	*6.6*
sd	*3.66*	*0.06*	-	-	*0.5*	*0.8*	*3.3*	*0.4*

3. Results

3.1. Species diversity of psammic rotifers

A total of 64 taxa of rotifers belonging to 2 orders, 14 families, and 17 genera were identified from ten freshwater bodies in Thua Thien Hue province (Table 2). Of these, four species were classified as psammobiont, seven psammonphiles, and 53 psammoxenes.

There were three species recorded for the first time in Vietnam, including *Lepadella cristata* (Rousselet, 1893), *Cephalodella tenuior* (Gosse, 1886), and *Lindia torulosa* Dujardin, 1841 (Figure 2).

***Table 2.** List of rotifer fauna from Thua Thien Hue province, Central Vietnam (* = new to Vietnam, a = psammobiont, b = psammonphiles, c = psammoxenes)*

Family Asplanchnidae	
1.	*Asplanchna priodonta* Gosse, 1850 [b]
Family Brachionidae	
2.	*Brachionus angularis* Gosse, 1851 [c]
3.	*Brachionus calyciflorus* Pallas, 1766 [c]
4.	*Brachionus patulus* Müller, 1786 [c]
5.	*Keratella cochlearis* (Gosse, 1851) [c]
Family Dicranophoridae	
6.	*Dicranophorus epicharis* Harring & Myers, 1928 [c]
Family Euchlanidae	
7.	*Euchlanis meneta* Myers, 1930 [c]
Family Gastropodidae	
8.	*Ascomorpha ovalis* (Bergendal, 1892) [c]
Family Lecanidae	
9.	*Lecane abanica* Segers, 1994 [b]
10.	*Lecane agilis* (Bryce, 1892) [c]
11.	*Lecane arcula* Harring, 1914 [c]
12.	*Lecane bifurca* (Bryce, 1892) [c]
13.	*Lecane bulla* (Gosse, 1851) [c]
14.	*Lecane closterocerca* (Schmarda, 1859) [c]
15.	*Lecane dorysimilis* Trinh Dang, Segers & Sanoamuang, 2015 [b]
16.	*Lecane doryssa* Harring, 1914 [c]
17.	*Lecane furcata* (Murray, 1913) [c]
18.	*Lecane haliclysta* Harring & Myers, 1926 [c]
19.	*Lecane hamata* (Stokes, 1896) [c]
20.	*Lecane hornemanni* (Ehrenberg, 1834) [c]
21.	*Lecane inermis* (Bryce, 1892) [c]
22.	*Lecane kunthuleensis* Chittapun, Pholpunthin & Segers, 2003 [c]
23.	*Lecane leontina* (Turner, 1892) [c]
24.	*Lecane lunaris* (Ehrenberg, 1832) [b]
25.	*Lecane minuta* Segers, 1994 [a]
26.	*Lecane pertica* Harring & Myers, 1926 [c]
27.	*Lecane phapi* Trinh Dang, Segers & Sanoamuang, 2015 [a]
28.	*Lecane pyriformis* (Daday, 1905) [c]
29.	*Lecane quadridentata* (Ehrenberg, 1830) [c]
30.	*Lecane signifera* (Jennings, 1896) [c]
31.	*Lecane simonneae* Segers, 1993 [c]
32.	*Lecane spiniventris* Segers, 1994 [a]
33.	*Lecane subtilis* Harring & Myers, 1926 [c]
34.	*Lecane superaculeata* Sanoamuang & Segers, 1997 [c]
35.	*Lecane undulata* Hauer, 1938 [c]
Family Lepadellidae	
36.	*Colurella obtusa* (Gosse, 1886) [b]
37.	*Colurella sinistra* Carlin, 1939 [c]
38.	*Colurella uncinata* (Müller, 1773) [c]
39.	*Lepadella cristata* (Rousselet, 1893) *[c]
40.	*Lepadella dactyliseta* (Stenroos, 1898) [c]
41.	*Lepadella desmeti* Segers & Chittapun, 2001 [c]

42.	*Lepadella monodactyla* Berzinš, 1960 [c]
43.	*Lepadella patella oblonga* (Ehrenberg, 1773) [c]
44.	*Squatinella sp* [c]
Family Lindiidae	
45.	*Lindia torulosa* Dujardin, 1841 *[c]
Family Notommatidae	
46.	*Cephalodella cf. apocolea* Myers, 1924 [c]
47.	*Cephalodella gibba* (Ehrenberg, 1830) [b]
48.	*Cephalodella gracilis* (Ehrenberg, 1830) [c]
49.	*Cephalodella tenuior* (Gosse, 1886) *[c]
50.	*Monommata grandis* Tessin, 1890 [c]
51.	*Notommata cerberus* (Gosse, 1886) [b]
Family Scaridiidae	
52.	*Scaridium longicaudum* (Müller, 1786) [c]
Family Synchaetidae	
53.	*Polyarthra dolichoptera* Idelson, 1925 [c]
54.	*Polyarthra vulgaris* Carlin, 1943 [c]
Family Testudinellidae	
55.	*Testudinella patina* (Hermann, 1783) [c]
Family Trichocercidae	
56.	*Trichocerca bauthiemensis* Trinh Dang, Segers & Sanoamuang, 2015 [a]
57.	*Trichocerca bidens* (Lucks, 1912) [c]
58.	*Trichocerca similis* (Wierzejski 1893) [c]
59.	*Trichocerca dixonnuttalli* (Jennings, 1903) [c]
60.	*Trichocerca pusilla* (Jennings, 1903) [c]
61.	*Trichocerca siamensis* Segers & Pholpunthin, 1997 [c]
62.	*Trichocerca simoneae* De Smet, 1990 [c]
63.	*Trichocerca tigris* (Müller, 1786) [c]
Family Trichotriidae	
64.	*Macrochaetus collinsii* (Gosse, 1867) [c]

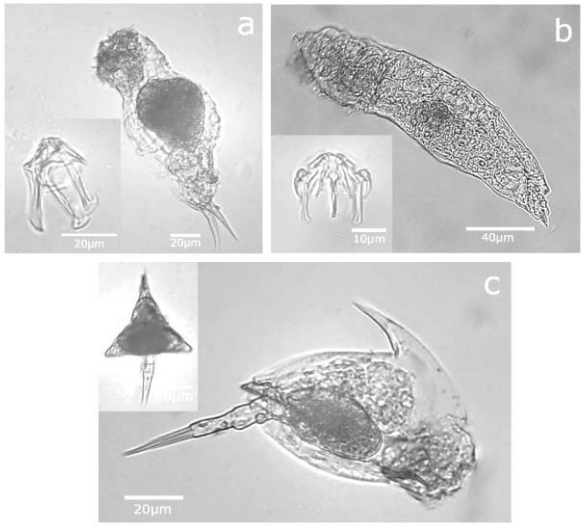

Figure 2. *Three new rotifer species to Vietnam (a) Cephalodella tenuior, (b) Lindia torulosa, (c) Lepadella cristata*

Diversity and species richness was assessed using a species accumulation curve and species richness estimators, as shown in Figure 3. The fitted accumulation curve ($y=12.95 + 21.42\log(x)$, $R^2=0.99$) rose almost linearly with an increasing number of samples and had not reached the asymptote yet. This demonstrated the potential of high biodiversity of the psammic rotifers community in this area, with about 13 additional species being expected to be found in a new sample. Further efforts are required in order to have a more comprehensive assessment. Species richness estimated based on the Chao 2, Jacknife 2, and Bootstrap methods indicated that the total number of species present in this habitat could be higher than the actual recorded number, specifically up to 90 taxa (Chao 2), 103 taxa (Jacknife 2) or 75 taxa (Bootstrap).

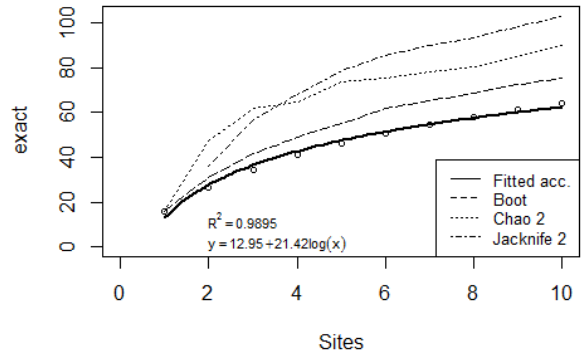

Figure 3. *Species accumulation curves and species richness estimators of psammic rotifer in Thua Thien Hue province*

3.2. Community structure of psammic rotifers

Community structure was unequally distributed amongst rotifers families with the dominance of Lecanidae, Lepadellidae, Trichocercidae. Lecanidae was the most diverse family in the psammon habitat, with 29 species recorded, accounting for 44%. Followingly, Lepadellidae and Trichocercidae contributed 9 and 8 species to the community, respectively, which are equivalent to 14% and 12%. Other families had only 1 to 6 species in the list each (Figure 4).

At the species level, *Dicranophorus epicharis, Lecane agilis, Lecane hamata, Lecane lunaris, Lecane spiniventris, Lecane agilis, Colurella obtusa,* and *Cephalodella gibba* were commonly-found species, which are present in most sampling sites.

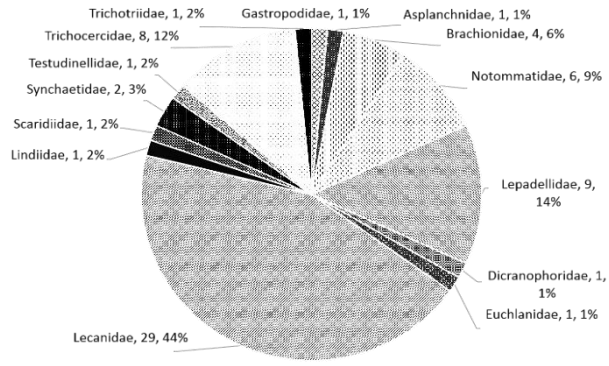

Figure 4. *Community structure at the family level of psammic rotifer in Thua Thien Hue province*

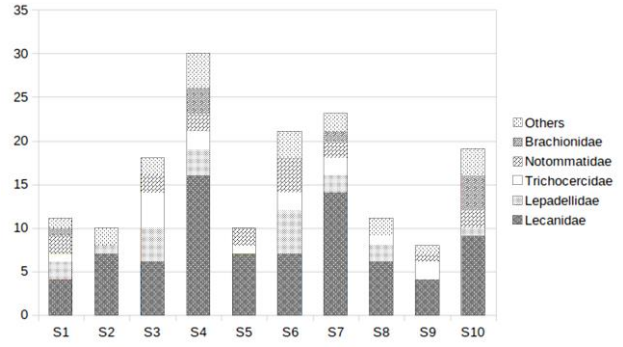

Figure 5. *Faunal composition at each sampling site*

There were differences in the community structure of rotifers at different sampling sites (Figure 5). The highest number of rotifers were recorded in S4 (30 species) while only 8 species were found in S9, being the lowest one. Half of the sampling sites hosted more than 15 species, including S3, S4, S6, S7, S10. With regard to composition, Lecanidae was the only family found in all samples with the dominance of species belonging to the *Lecane* genera. Other than that, no particular pattern in the distribution of rotifers families has been observed. At point S5, we only found species belonging to Lecanidae, Trichocercidae, and Notommatidae with 7, 1, and 2 taxa, respectively.

Table 3. *Matrix of similarity index among sampling sites*

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
S1	1									
S2	0.24	1								
S3	0.16	0.27	1							
S4	0.08	0.22	0.27	1						
S5	0.17	0.18	0.12	0.15	1					
S6	0.28	0.24	0.22	0.28	0.15	1				
S7	0.1	0.23	0.43	0.46	0.19	0.26	1			
S8	0.57	0.4	0.21	0.11	0.11	0.39	0.18	1		
S9	0.27	0.13	0.18	0.12	0.2	0.21	0.15	0.27	1	

Jaccard similarity index was calculated for every pair of samples (Table 3). Results ranged from 0.07 (S8 - S10) to 0.57 (S1 - S8), indicating low to intermediate similarities in species composition between sampling sites. Noticeably, sampling points positioned close to each other did not share many species in common, for instance the case of S1-S2-S3-S4 or S9-S10. In contrast, S1-S8, S2-S8 or S3-S7, S4-S7 were explored to have more than 40% shared species regardless of great distances, plus no geographical connection being observed between them.

Environmental factors seemed to play a role in regulating the species richness and distribution here, which was revealed by a principal component analysis (Figure 6).

It can be seen from figure 6 that the sampling sites dispersed along 2 main gradients of the environment, which combinedly explained 73.87% of the variation in data. The first axis was likely to correlate to TN and pH with scores of 0.67 and 0.66, respectively, while the second one showed strong relations with NTU (0.68) and PO4 (0.67). It is possible to classify S1, S2, S5, S8, S9, and S10 into a group that is generally lower in nutrient concentrations, turbidity, and pH whereas S3, S4, and S7 formed another group characterized by more eutrophic and turbid water. S6 was discriminated from the rest mainly due to extremely high values of pH (8.4) and TN (11.133 mg/l). This result partly explained the variations in species richness, specifical habitats with the higher trophic states tend to host more taxa.

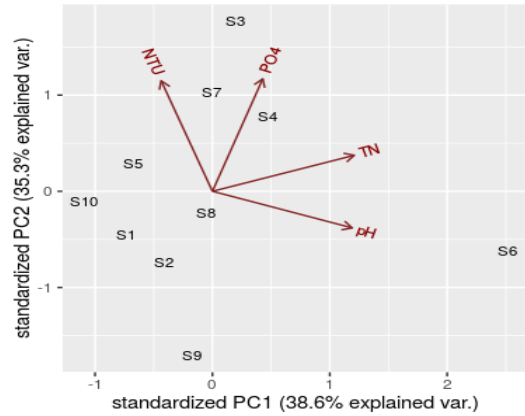

Figure 6. *Principal component analysis of water characteristics at 10 sampling sites*

4. Discussion

The diversity of zooplankton in general and rotifer, in particular, has been understudied in Vietnam [20] compared to other countries, including its neighbors [21], [22]. Thailand, for instance, has been proven to host numerous diverse rotifers communities, with a total of 399 species being recorded in the whole country. Based on the similarity in climatological characteristics of the Oriental region, we expect a high value of diversity of this group in Vietnam as well. Indeed, recent efforts have significantly increased the amount of information about Vietnamese rotifers. To date, 227 taxa of rotifers have been identified. This study updated the Vietnamese list with three new records from psammic habitat in freshwater lakes in a coastal province Thua Thien Hue. In comparison with our previous report in an adjacent area (Bau Thiem lake [15]), this study found a lower number of species-level taxa but a similar diversity potential. Besides, the accumulation curve in the previous study estimated about 60 species in 10 samples as well.

Rotifer assemblage in the studied area was dominated by psammoxenes with 53 species while only 4 were psammobionts, the rest were psammophiles. A similar pattern was reported in studies of Myers, who recorded 17 psammobiotic species, 25 psammophile species, and 101 psammoxene species [5], and Bielańska-Grajner, which reports 11 psammobiotic species, 18 psammophile species, and 35 psammoxene species [2].

Regarding community structure, our findings were generally similar to those of a study by Trinh-Dang [15]: Lecanidae, Lepadellidae, and Trichocercidae being 3 most-richest families in both studies, which together accounted for more than 60% taxa in community. Most studies on the diversity of rotifers in the psammon of freshwater lakes worldwide share a common pattern of *Lecane* being the

most diverse genera [3], [23] – [26]. Our result was not an exception as Lecane was found with at least 4 species in all samples regardless of the variation in environmental conditions between sampling sites. This may be explained by the fact that Lecanidae is one of the largest families of Rotifera, mainly consisting of relatively versatile and euryoecious species ([27] - on the ecology of lecane). Furthermore, Lecane rotifers have some advantages over other microfaunal groups to dominate the interstitial habitat. With their malleate trophi, Lecanids are classified as microphagous sedimentation that feeds on minute particles or microorganisms [28]. Besides, the typical hard shell potentially allows Lecanids to tolerate collision and friction with sand grains better.

The environmental condition of water bodies in the study area has experienced drastically anthropogenic impacts, which were reflected through a significant change in the trophic state of Bau Thiem lake water (S2, S3, S4) from oligotrophic (observations in [15]) to eutrophic-hypereutrophic (this study). This is due to the changes in land use, notably the increase of unmanaged aquaculture livestock, poultry farming which releases a large amount of nutrient-rich wastes into aquatic systems. During the sampling campaign, there was a phenomenon called brownification in surface waters. The yellow-brownish color of water could be mainly attributed to elevated concentrations of organic matters derived from primary producers, i.e. phytoplankton and macrophytes [29]. The situation was more difficult in the northwest of the study area, especially in Bau Thiem lake, than in other places because the aquatic systems here were formed in an endorheic basin.

It has been suggested that the community of psammic fauna, including rotifers, was likely to be influenced by water parameters [7], [8], [30], [31]. Trophic state has been proven to be one of those. Bielańska-Grajner reported a higher number of psammonic rotifer species and a higher Shannon index value in lakes with lower trophic levels [2]. This was supported by findings of Lokko in her study on Estonian lakes, which found that the zoopsammic community in mesotrophic lake Saadjärv was more diverse than that in eutrophic lake Võrtsjärv [28]. Our results showed a different pattern as higher numbers of rotifer species were recorded in sampling sites that were typically richer in total nitrogen and phosphorus concentrations (S3, S4, S6, S7). This might be considered as a result of plentiful foods for rotifers. Lokko suggested that competition for living resources between psammic taxa might be eased in sand enriched by large amounts of decaying plant debris [24]. Indeed, we observed in these sampling sites a thick dark-brown layer of humic soil in the hygropsammic zone which was overlaid by a green-brown layer of microphytobenthos (Figure 7). However, Ejsmont-Karabin noted that the correlation between the trophic status of a lake and the structure of the psammic rotifers community is not always significantly determined [32]. Further study is needed to fully understand this relationship [32].

Figure 7. *Soil layers and brownification water*

According to Wiszniewski, pH strongly affects the diversity of the rotifer in the sand [33]. Bielańska-Grajner suggested that lakes with low water pH had poor species richness [7]. Results from our study showed no clear correlation between water pH and species richness. Specifically, only 8 taxa were recorded in S9, whereas that number of S4 was up to 30 taxa despite there being no great difference in pH values (6.81 compared to 7.19 respectively). Furthermore, at acidic site S7, the presence of 23 species was still confirmed.

It is noteworthy that the differences in population densities and diversity are not only attributed to the trophic state of water bodies [34]. For example, sediment type should be considered when studying the ecology of zoopsammon since physical and chemical parameters of interstitial habitat are dependent on sand grain size [35]. However, information about the influences of this factor on rotifers is generally scarce and controversial.

5. Conclusions

In conclusion, this study provided novel taxonomic data on interstitial rotifers in the Central Coast, Vietnam. Sixty four species-level taxa of 17 genera, 14 families were identified in 10 samples collected in lacustrine psammon in Thua Thien Hue province, in which *Lepadella cristata* (Rousselet, 1893), *Cephalodella tenuior* (Gosse, 1886) and *Lindia torulosa* Dujardin, 1841 were recognized as three new species to Vietnam. The result on species richness suggested a potential of high biodiversity level of psammic rotifers in this area despite harsh living conditions. Regarding community structure, Lecanidae, Lepadellidae, and Trichocercidae are 3 most-richest families, which together accounted for 70% of taxa in the community.

Acknowledgments: We would like to thank the Faculty of Biology and Environmental Science, The University of Danang - University of Science and Education for providing research facilities. This research is funded by Funds for Science and Technology Development of the Ministry of Education and Training, Vietnam, grant number B2020-DNA-08.

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