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Original Article

Lecane (Rotifera: Lecanidae) community in psammon habitat in Central Coast Vietnam: Diversity and relation to environmental condition

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Abstract: Characteristics of the *Lecane* (Rotifera) community in psammon in Central Coast Vietnam were investigated. A total of 50 taxa were identified in samples collected at hygropsammon zones of temporary pools, contributing 4 new species to rotifers' record of Vietnam. Psammonxenic species accounted for the largest percentage of *Lecane* community with 82%, followed by psammophiles (12%) and psammonbionts (6%). Influences of some environmental factors on the distribution of psammic lecanids were also observed. This group of organisms showed a slight tendency towards sand with grain sizes larger than 125 µm. Besides, other abiotic factors including pH, total phosphorus (TP) and total dissolved solids (TDS) were also found to significantly related to the distribution of some common *Lecane* species.

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Introduction

Psammon is a highly unstable environment due to aperiodic influences of water (Schmid-Araya, 1998). Nevertheless, this dynamic habitat has been proven to host a wide range of biota, including rotifers (Pejler, 1995; Schmid-Araya, 1998; Fontaneto and Ricci, 2006; Covazzi Harriague et al., 2013; Lokko et al., 2014; Lokko and Virro, 2014). Appearing with a high abundance in psammic zone of lakes and beaches' shore, rotifer is believed to have a significant contribution to ensure the flows of energy and matter between terrestrial and aquatic ecosystems (Wallace, 2002). In addition to some common species similar to those in other environments, psammon was found to have the presence of some specific rotifer species, which have been regarded as "pronounced specialists on a psammic life" (Pejler, 1995). However, knowledge on the structure and functioning of rotifer communities in this type of habitat is still quite limited.

The dominance of the *Lecane* in psammic rotifers community was reported in many studies worldwide (Radwan and Bielańska-Grajner, 2001; Segers and Chittapun, 2001; Karabin and Ejsmont-Karabin, 2005; Muirhead et al., 2006; Trinh-Dang et al., 2015), indicating a possibly important role of this genus in biochemical processes in psammon. Therefore, this study was conducted with the aims: (1) to examine the diversity of Lecane in psammic habitat and (2) to explore correlations between the Lecane community and environmental conditions. These results are expected to contribute not only to taxonomic data but also to knowledge about the ecology of rotifers in general and of the *Lecane* in specific.

Materials and Methods

Sample collection and analysis: Samples were collected at 12 temporary pools on the sandy coast of Quang Nam province, Vietnam in dry and rainy seasons 2019 (Fig. 1). At each pool, two samples of psammon rotifers were taken for qualitative and quantitative analysis. The sand was collected from the top 2 cm of the hygropsammon zone using a PVC bailer and then mixed with filtered water (through a 30 µm mesh-size net) to re-suspend the rotifers. Rotifer suspension was retrieved by filtering the mixture

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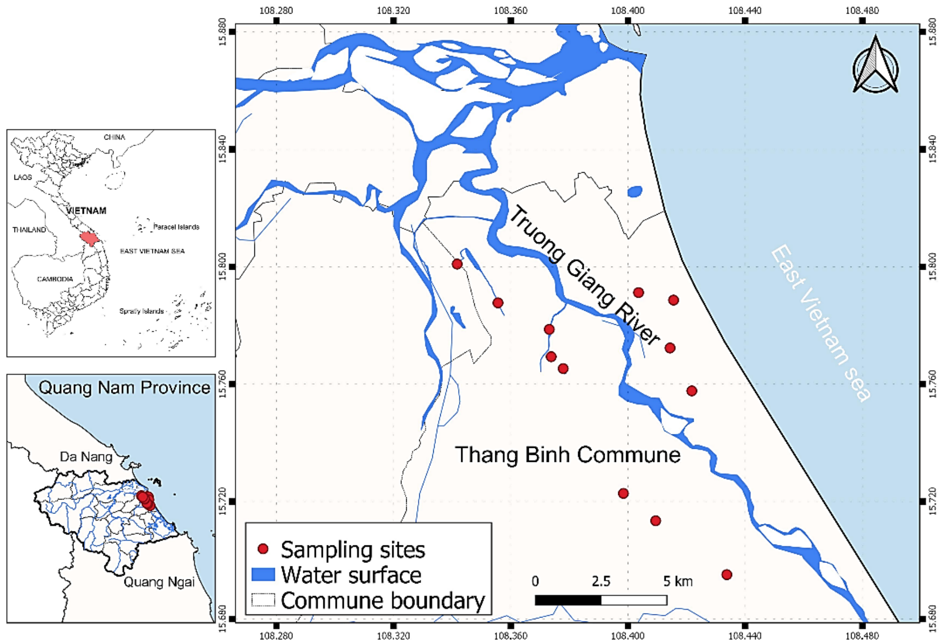

Figure 1. Study area - sandy coast in Central Vietnam.

through a 50 µm mesh-size net. Samples were preserved in formaldehyde 5% for further analysis in the laboratory. For quantitative analysis, samples were retrieved from sand collected in a 0.5x0.5 m sampling frame using the above-described protocol.

Rotifer specimens were sorted from samples and examined using a Hund Wetzlar H600 microscope. Identification was based on taxonomy and nomenclature of the rotifers as in Segers (2007). The rotifers were classified into three categories: psammobiont, psammophile, and psammoxene following Bielańska-Grajner (2005), Myers (1936), and Wiszniewski (1937, 1934a, b). Additionally, the species not on those lists were assigned to subjectively categories based on our observations of their habitats and literature data, as appropriate.

Water quality parameters, including temperature, pH, total dissolved solids (TDS), conductivity were directly measured in-situ by a multiparameter water quality sonde YSI 6920. Concentrations of total nitrogen (TN) and total phosphorus (TP) in water were analyzed in the laboratory by standard methods (APHA, 2017). Sand samples were also collected to determine grain size, which categorized into 3 groups based on the average grain size of sand: very fine sand (<125 µm), fine sand (125-250 µm) and medium sand (>250 µm) (Wentworth, 1922). Ejsmont-Karabin (2004) and Lokko et al. (2017) suggested that psammon rotifer community are likely to be dependent on grain size.

Data analysis: The species accumulator and species richness estimators were calculated using the vegan package (Oksanen et al., 2013) in R program (R Core Team, 2014). Relationship between abundances of taxa and environmental data was investigated through canonical correspondence analysis (CCA). Environmental variables tested were TN, TP, TDS, conductivity, and pH of pool water and grain sizes of sand. Explanatory environmental variables were selected by the forward selection in the CCA, selecting only those variables that were significantly related to taxonomic abundances ($P \leq 0.05$) according to Monte Carlo permutation tests. *Lecane* taxa that were observed in less than 10% of all samples were excluded from CCA to prevent these rare taxa from having an inordinate influence on the statistical results.

Results

Lecane community in study area: In total, 50 species of *Lecane* were identified in which 4 species were new to Vietnam, specifically *L. blachei* Bērziņš

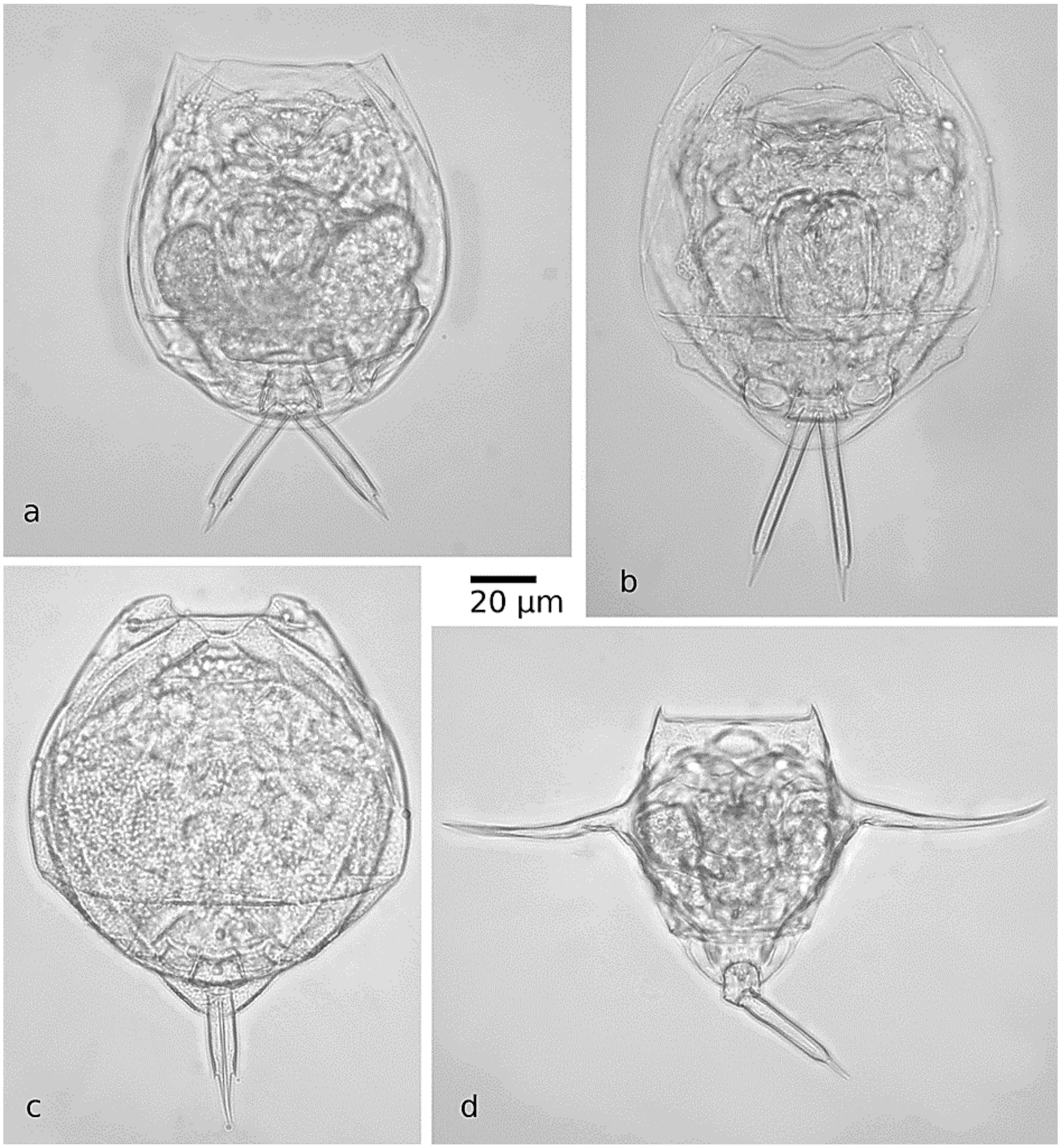

Figure 2. Species habitus: (a) *Lecane elsa* Hauer 1931, (b) *Lecane lateralis* Sharma 1978, (c) *Lecane blachei* Bērziņš 1973 and (d) *Lecane monostyla* (Daday, 1897).

1973, *L. elsa* Hauer 1931, *L. lateralis* Sharma 1978 and *L. monostyla* Daday 1897 (Fig. 2). Among these, only 3 species were classified as psammonbionts, including *L. minuta, L. phapi* and *L. spiniventris*; 6 species were psammophiles; and 41 species belonged to the psammoxenic group, accounting for 6, 12 and 82% of the total species number, respectively (Table 1).

Species diversity in the rainy season was slightly higher than that in the dry season, with the number of species recorded was 39 taxa and 33 taxa, respectively. This result was also reflected by the species accumulation curve, where the fitted accumulation curve slope in the rainy season (12.47) was higher than that in the dry season (10.23) (Fig. 3). Moreover, the estimators, which estimated the maximum number of taxa could be present in the lake, again confirmed the higher species diversity in the rainy season. In detail, according to the Chao 2 estimator index, the number of taxa that could appear in the rainy season was 49±7 taxa, and in the dry season was 43±7 taxa. According to the Jackknife 2 index, these numbers were 59 taxa in the rainy season and 50 taxa in the dry season. For the Bootstraps index, the numbers of taxa were 46±4 and 38±3 taxa in the rainy and dry season, respectively (Fig. 3).

Table 1. Composition, occurrence, abundance of psammic *Lecane* species (abundance of taxa: ind.m^{-3}, +: present, - : absent, *: new to Vietnam).

Species	Very fine sand	Fine sand	Medium sand	Ecological group
L. abanica Segers, 1994	-	+	15.291	pph
L. aculeata (Jakubski, 1912)	+	7.645	+	px
L. aeganea Harring, 1914	+	-	-	px
L. batillifer (Murray, 1913)	-	-	3.581	px
L. bifurca (Bryce, 1892)	-	+	-	pph
L. blachei Bērziņš, 1973*	-	-	+	px
L. bulla (Gosse, 1851)	11.470	138.252	64.914	px
L. closterocerca (Schmarda, 1859)	+	3.581	13.339	pph
L. crepida Harring, 1914	-	+	91.743	px
L. curvicornis (Murray, 1913)	+	+	5.495	px
L. dorysimilis Trinh-Dang, Segers & La-orsri, 2015	-	+	-	pph
L. doryssa Harring, 1914	1.194	+	-	px
L. elsa Hauer, 1931*	+	-	7.645	px
L. eswari Dhanapathi, 1976	-	-	+	px
L. furcata (Murray, 1913)	+	+	7.645	px
L. haliclysta Harring & Myers, 1926	+	7.645	+	px
L. hamata (Stokes, 1896)	8.043	13.187	34.149	px
L. hornemanni (Ehrenberg, 1834)	+	-	1.194	px
L. inermis (Bryce, 1892)	-	-	+	pph
L. inopinata Harring & Myers, 1926	15.291	95.566	19.114	px
L. kunthuleensis Chittapun, Pholpunthin & Segers, 2003	-	+	-	px
L. lateralis Sharma, 1978*	-	-	15.291	px
L. leontina (Turner, 1892)	-	137.615	7.645	px
L. ludwigii (Eckstein, 1883)	-	15.291	10.033	px
L. luna (Müller, 1776)	-	7.645	23.701	px
L. lunaris (Ehrenberg, 1832)	7.645	163.099	79.002	px
L. minuta Segers, 1994	-	+	-	pb
L. mitis Harring & Myers, 1926	-	7.645	-	px
L. monostyla (Daday, 1897)*	-	-	+	px
L. namatai Segers & Mertens 1997	-	+	-	px
L. obtusa (Murray, 1913)	+	2.387	22.936	px
L. papuana (Murray, 1913)	7.645	96.840	20.387	px
L. pertica Harring & Myers, 1926	-	45.872	+	px
L. phapi Dang, Segers & Sanoamuang, 2015	-	+	-	pb
L. pyriformis (Daday, 1905)	-	+	22.936	px
L. rhenana Hauer, 1929	3.581	754.332	7.645	px
L. signifera (Jennings, 1896)	7.645	32.826	8.541	px
L. simonneae Segers, 1993	-	+	+	px
L. sola Hauer, 1936	-	-	42.049	px
L. sp.	-	-	+	px
L. spiniventris Segers 1994	7.645	-	7.645	pb
L. stichoclysta Segers, 1993	+	+	-	px
L. subtilis Harring & Myers, 1926	-	+	-	px
L. superaculeata Sanoamuang & Segers 1997	-	-	15.291	px
L. tenuiseta Harring, 1914	-	+	-	pph
L. thailandensis Segers & Sanoamuang, 1994	+	-	-	px
L. thienemanni (Hauer 1938)	-	-	7.645	px
L. undulata Hauer, 1938	+	7.944	13.538	px
L. unguitata (Fadeev, 1925)	-	15.291	-	px
L. ungulata (Gosse, 1887)	-	-	2.387	px
Total	**21**	**34**	**36**	

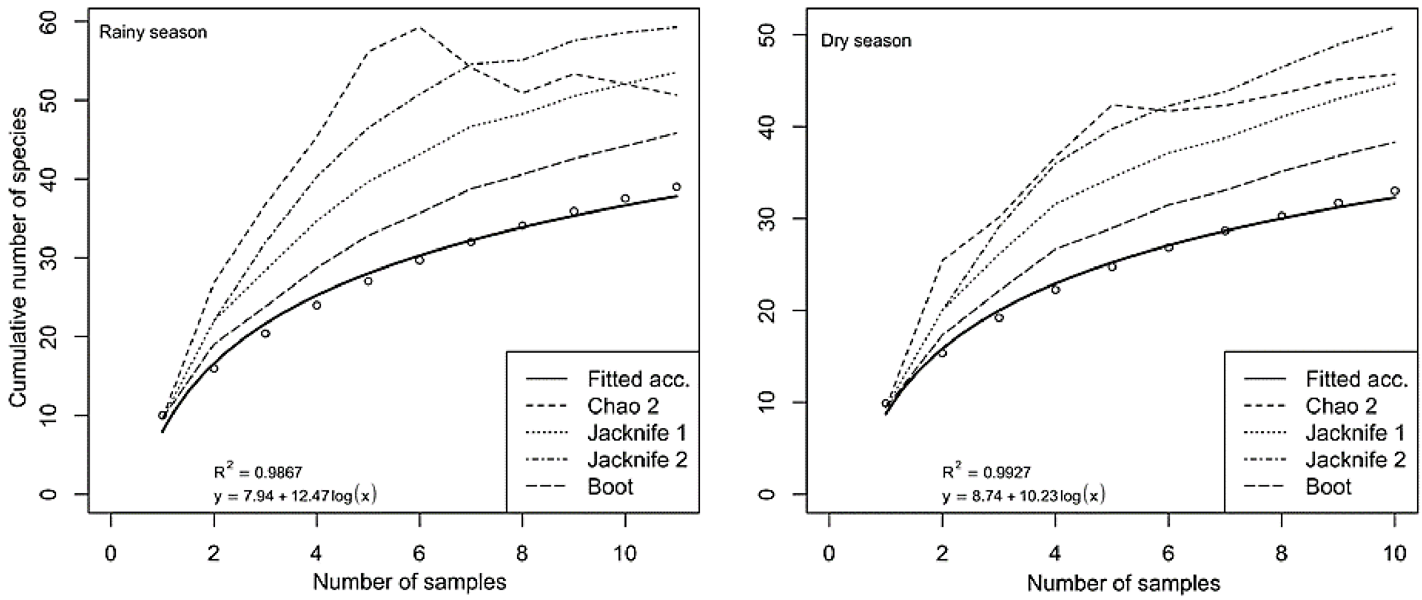

Figure 3. Species accumulator of species richness at study sites during rainy (left) and dry season (right), with the fitted curve and estimator curves.

The result also showed that the number of species was higher in samples characterized by larger grain size, specifically 21 taxa in the very fine sand group, 34 taxa in the fine sand group, and 36 taxa in the medium sand (Table 1). Nevertheless, in the consideration of unique species, the fine sand size group comprised the largest number of unique species (10 species), followed by the medium sand group with 7 unique species. The very fine sand group had the least unique species with only 2 species (Table 1). Moreover, the total average density of *Lecane* species in the fine sand group was recorded as the highest (1.63×10^6 ind.m^{-3}), followed by the medium sand group with the density of 0.57×10^6 ind.m^{-3}, and especially lowest in the very fine sand group (0.07×10^6 ind.m^{-3}). It was noticeable that most *Lecane* species appeared with a very low density in the very fine sand group (less than 1×10^4 ind.m^{-3}), excepting for 2 species of *L. bulla* and *L. inopinata* whose densities were high in all three sand size groups. Species with high densities (over 1×10^5 ind.m^{-3}) such as *L. bulla* (1.38×10^5 ind.m^{-3}), *L. leontina* (1.37×10^5 ind.m^{-3}), *L. lunaris* (1.63×10^5 ind.m^{-3}), and *L. rhenana* (7.54×10^5 ind.m^{-3}) only appeared in the fine sand group (Table 1).

In order to compare species diversity among sand types, species accumulation curves were used. Fine and medium sand groups showed a similar pattern which increased rapidly in the first 6 samples with a slope of 11.87 and 11.73, respectively, indicating a comparable diversity level. However, the average number of *Lecane* species found per sample was higher in samples belonging to medium type compared to the fine type (8.8>5.47). Besides, richness estimators suggested that the estimated species richness of *Lecane* in fine and medium sand could be up to approximately 40-60 species (Fig. 4).

In addition, the number of very fine sand samples were not enough to form a clear pattern. Nonetheless, it was quite obvious that the diversity of *Lecane* inhabiting this sand type was relatively lower than two other groups, expressed by a slope of 10.51. However, the average number of species recorded per sample of this sand group in our study was fairly high (about 9 species/sample). Total species richness was expected to be 20-35 species in 3 samples according to the models.

Relation to water parameters: The value of water quality parameters surveyed tends to be higher in the dry season than those in the rainy season, most notably the pH value. CCA plot demonstrated that sand samples collected in two seasons were discriminated by two main environmental gradients (Fig. 5). Interestingly, the abundance of *Lecane* species in

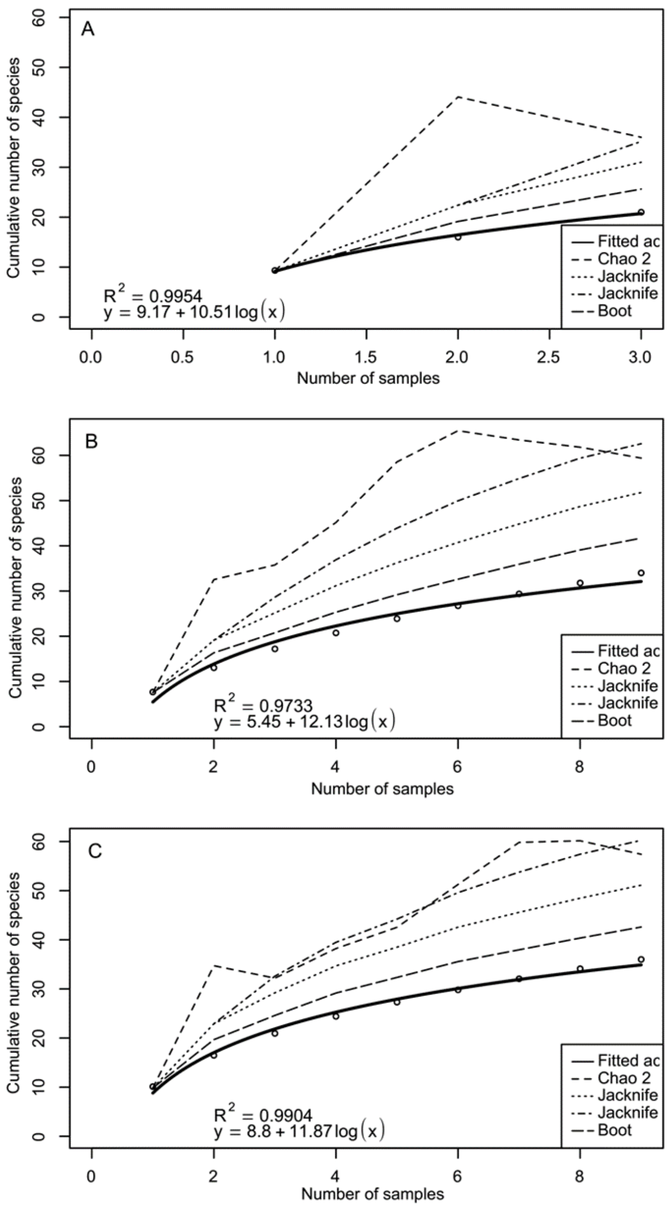

Figure 4. Species accumulator with fitted curve and estimator curve of species richness at study sites in 3 types of sand: A) very fine sand (<125 µm); B) fine sand (125 - 250 µm); C) medium sand (>250 µm).

psammon habitat was significantly related to water pH, TDS, TN, TP and conductivity ($P = 0.031$), with 44.53% of total variance being attributed to these environmental variables. A total of 79.64% of the cumulative variance in species was explained by the first two CCA axes, yet only the first one was statistically significant at a level of 10% ($P = 0.077$). This gradient was likely to be defined mainly by TP and TDS (scores were 0.88 and 0.66, respectively ($P<0.1$)) even though TN and conductivity also established strong correlations. Meanwhile, the second ordination axis was strongly related to the water pH ($P = 0.01$). Regarding the distribution of *Lecane*, *L. papuana* and *L. closterocerca* were likely to be more abundant in higher TP and TDS conditions while the density of *L. luna* was considerably enhanced by high pH value.

Discussions

Other than taxonomic studies, research on *Lecane* group is relatively scarce with two typical publications investigating the biogeography and ecology of *Lecane* (Pejler and Bērziņš, 1994; Segers, 1996) even though *Lecane* was often mentioned as an important part of rotifer communities in many studies. Our work was one of the first studies focusing on the *Lecane* community in psammon habitat and its relationship to some abiotic factors. In Vietnam, Trinh-Dang et al. (2015) reported 89 taxa of rotifers in psammon habitat in Thua Thien Hue Province in which *Lecane* contributed 42 taxa. Our investigation focused solely on this genus reported a number of 50 species in the Central Coast of Vietnam, higher than the previous record by 8 species. In our list, 35 taxa were similar to those in Thua Thien Hue and 4 taxa were new records for Vietnam.

Sand grain structure is considered as one of important factors structuring psammon communities (Arov, 1990; Ejsmont-Karabin, 2004). According to Giere (2009), sand grain size characterizes psammon habitat as it directly determines spatial and structural conditions, and thus indirectly determines the physical and chemical characteristics. Arov (1990) suggested that larger rotifer species tend to inhabit sand with bigger grain size while smaller species occur more frequently in sand with smaller grain sizes. Such relationship was not observed in the study on psammon rotifers in Polish natural and artificial lakes (Bielańska-Grajner, 2005), yet it was partly supported by Ejsmont-Karabin (2004) who reported a positive significant correlation between the rotifer numbers and the share of grain size fraction 0.25-1.00 mm. In our study, the occurrence of *Lecane* species was different among 3 grain-size groups despite an indifference in the biodiversity level. Very fine sand

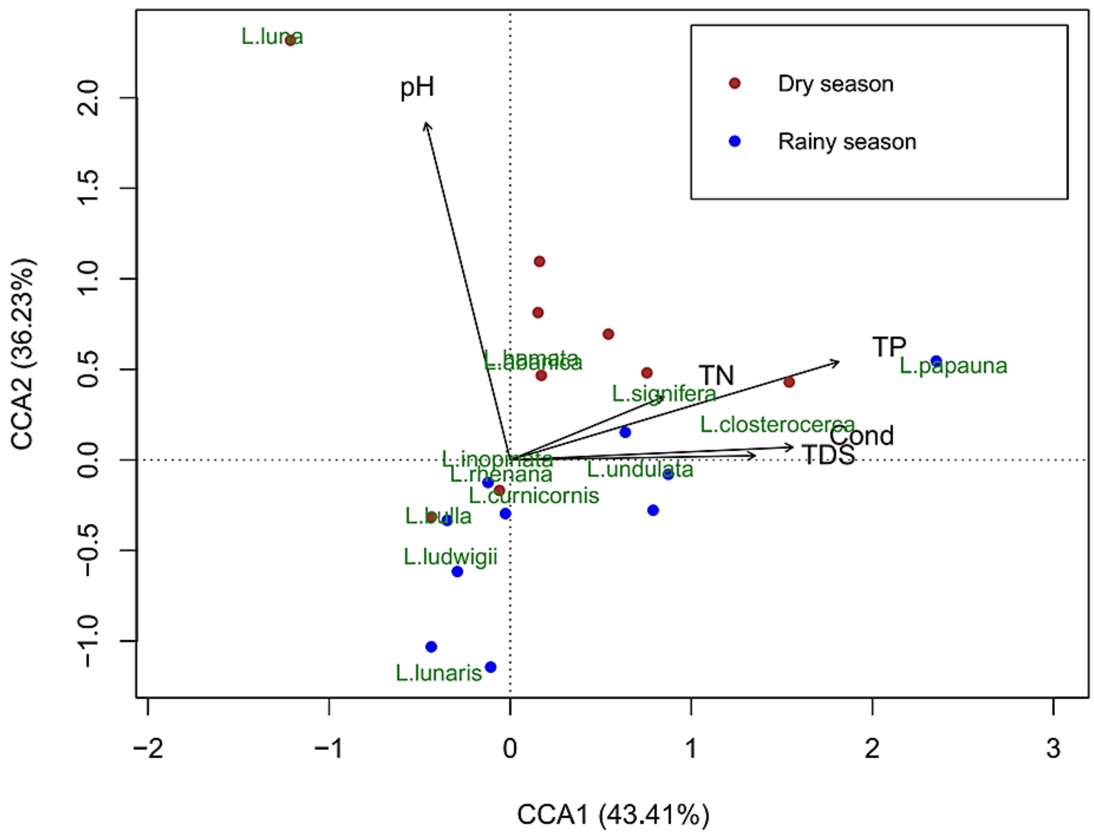

Figure 5. A triplot of species scores, site scores, and environmental variables.

seemed to provide a less favorable condition for *Lecane* as the number of species found in this type of sand was much lower compared to the two other groups. *Lecane doryssa* was identified as one of the most restricted species by fine sand. Meanwhile, *L. bulla* and *L. hamata* seem to be well-adapted to a wide range of sand-size as their high densities were found in all samples. Nevertheless, Ejsmont-Karabin (2004) suggested that the body-size of rotifers was not a significant factor defining the preference to different size classes of sand grains. Her results showed that large sand grains (250-1000 µm) were favorable to all three size groups of rotifers whereas larger or smaller classes were not preferred.

Rotifers inhabiting psammic habitats have to experience an extremely unstable environment which is strongly impacted by various physical and chemical factors outside the sand (Schmid-Araya, 1998) such as wave exposure, the quantity of organic matter, sand grain morphometry, amount of pore water, water pH, temperature, and oxygen (Pennak, 1940; Neel, 1948; Ruttner-Kolisko, 1953; Evans, 1982). Our result indicated a clear difference in water characteristics of temporary pools in the studied area between two seasons. A general decrease in values of all parameters in the rainy season could be explained by the dilution of rainwater. As a result, these changes were very likely to alternate the psammic *Lecane* communities' structure and composition.

Correlation between the trophic state of the water body and community structure of planktonic rotifers has been investigated in many studies (as overviewed in Ejsmont-Karabin, 2012). However, the relationship between the water trophy and psammic rotifers, especially the Lecanids, has not been examined in detail yet. Myers (1936) suggested that beaches of lakes with the higher trophy are likely to have higher numbers of psammon rotifers. The results of a study conducted by Ejsmont-Karabin (2003) in 18 Polish lakes showed that psammobionts were more abundant in lakes with the lower trophy while psammoxenes dominated the beaches of nutrient-rich lakes.

Moreover, the density of psammon rotifers was reported to significantly correlate with the concentration of chlorophyll a, pheophytin, total and mineral phosphorus (Ejsmont-Karabin, 2006). Our results were generally in agreement with these findings. TP and TDS were significantly influential to the distribution of the most common *Lecane* species found in our study. Besides, TN and conductivity also showed a relative correlation though was not significant. Moreover, our study found that *L. signifera*, *L. closterocerca* and *L. papuana* tended to present in hygropsammic zones at higher levels of nutrients concentration, TDS and salinity in water.

pH is not only an important factor influencing the distribution of planktonic rotifers (Edmondson, 1944) but also may play a critical role in structuring psammic rotifers communities (Wiszniewski, 1936). Our CCA analysis results were well in agreement with this statement as pH established a high correlation with the second ordination axis, which could explain 36.23% variation in Lecanids distribution. For example, *L. luna* showed a high preference for an alkaline environment whereas lower pH conditions seem to favour the growth of *L. lunaris*, *L. ludwigii*, and *L. bulla*. This is comparable to the study result conducted by Bērziņš and Pejler (1987), which showed that *L. luna* prefers pH from 6.5-9 while *L. lunaris* is able to tolerate a wider pH range from 4-9.5. However, it is noticeable that aside from morphological traits, functional adaptations, such as moving and feeding behaviors of rotifers should be taken into account in understanding rotifers' habitat selections (Arov, 1990). Besides, competition and predation might also play a role in the distribution of rotifers (Green, 1987).

Conclusion

A total of 50 species of *Lecane* in psammic habitats of the Central Coast Vietnam was recorded, in which 4 species are new to Vietnam. Psammonxenes group composed the largest part of the *Lecane* community with a proportion of 82%. Regarding relations to environmental conditions, Lecane species showed a minor preference for fine and medium grain-size sand over a very fine type though the diversity of these groups is comparable. Canonical correspondence analysis revealed the statistically significant influences of some environmental factors, specifically pH, TP, and TDS, on the distribution of some commonly-found lecanids in psammon. More intense studies are required to deepen the knowledge about the diversity of *Lecane* communities, and also of rotifers in general, and to fully understand their ecological importance in psammic habitat.

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