RESEARCH

Open Access

Distinct difference of littoral rotifer community structure in two mangrove wetlands of Qi'ao Island, Pearl River estuary, China

Nan Wei¹ and Run-Lin Xu^{2*}

Abstract

Background: Less study was focused on the ecological community of littoral rotifers than on pelagic area worldwide. Moreover, rotifers were overlooked mostly due to the improper sampling methods and lack of experienced taxonomists for ecological researches, and the diversity and role of estuarine rotifers in ecological systems were underestimated severely.

Results: A long-term investigation of the littoral rotifer in a shallow mangrove swamp (MS) and a tidal creek (TC) of Qi'ao Island, the Pearl River estuary of southern China, revealed significant differences of the community structure at different sites and in different seasons. Ninety-four monogonont rotifers were detected in total. The average abundance of rotifer at MS (97.0 individuals/L) was lower than that at TC (140.8 individuals/L), but all average diversity indexes at MS were higher than those at TC. The main species at MS were *Colurella* sp.1, *Encentrum marinum, Colurella adriatica, Synchaeta cf. kitina, Synchaeta* sp., and *Cephalodella cf. innersi*, whereas they were *Synchaeta cf. kitina* and *Brachionus angularis* at TC. The rotifer community was correlated with the salinity and total nitrogen group most at MS, while temperature contributed most at TC.

Conclusions: This study revealed higher diversity and abundance of littoral rotifers at the two close mangrove wetlands of Qi'ao Island compared to other studies. Different kinds of biotopes at the two sites displayed significant difference of the community structure, which was mainly due to the abundance of different main species present at the two sites. The peculiar environment of MS created an unusual rotifer community which had more marine species with higher abundance mostly in winter.

Keywords: Littoral rotifer; Abundance; Diversity; Community structure; Stenohaline; Mangrove wetlands

Background

Littoral zones of aquatic systems tend to have higher biodiversity and community structure which are dissimilar to that of the open water. Notably, about 75% of rotifer species occur in littoral zones (Duggan 2001; Smith 2001). However, knowledge of the diversity and biology of animals in littoral zones is still less than that of the pelagic area (Lemly and Dimmick 1982; Maia-Barbosa et al. 2008; Thorp and Covich 2010), especially in brackishwater estuaries (Rougier et al. 2005; Zhou et al. 2009).

Mesozooplankton, mostly copepods, usually are the most dominant components of zooplankton in estuarine

Full list of author information is available at the end of the article



environments (e.g., Tan et al. 2004; Li et al. 2006). Glo-



© 2014 Wei and Xu; licensee Springer. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/2.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly credited.

^{*} Correspondence: xurunlin_1960@yahoo.com

²School of Life Sciences, Sun Yat-sen University, Guangzhou, Guangdong 510275, China

Habitat	Sampling area	Methods	Species number	Average abundance ^a (individuals/L)	Sites	Sampling effort (times; dates)	References
Littoral	Pearl River estuary, China	Utermöhl (1931)	94	118.9 (0 ~ 2,050)	2	48; Jan 2007 to Dec 2010	This study
	Pearl River estuary, China	64 µm	21	-	39	1; Mar to Apr 2009	Zhang et al. (2012)
Open waters	Pearl River estuary, China	169 µm	2	-	31/21	2; Jul 1999; Jan 2000	Tan et al. (2004)
	Pearl River estuary, China	64 and 112 µm	8	<10	8	3; Aug 2006	Gao et al. (2008a)
	Pearl River estuary, China	64 and 112 μm	28	<10	8	3; Aug 2006; Nov 2006; Feb 2007	Gao et al. (2008b)
	Pearl River estuary, China	112 µm	12	-	2	3; Nov 2006; Feb; May; Aug 2007	Gao et al. (2010)
	Pearl River estuary, China	20 µm	69	18.3 (0~199)	3	Semimonthly; Jul 2009 to Jan 2010	Hou (2011)
	Yangtze River Estuary, China	64 µm	103	15.6 (0 ~ 2,500)	39	4; May 1988 to Jul 1990	Han and Hu (1995)
	Yangtze River estuary, China	64 µm	24	<0.2 (0~9.3)	24	1; Sept 1966	Wang et al. 1999
	Yangtze River estuary, China	Utermöhl (1931)	65	185.7 (0~600)	14	2; Sept 2005; Apr 2006	Hu et al. (2008)
	Lagos Harbour and Badagry Creek, Nigeria	55 µm	51	-	10	Monthly; Oct 1986 to Sept 1987	Egborge (1994)
	Elbe estuary, Germany	30 µm	77	about 800 (0 ~ 2,048)	8	Weekly; Mar 1995 to Jul 1995	Holst et al. (1998)
	Kaw River estuary, French Guiana	40 µm	108	about 135 (0 ~ 750)	3	2; Jun 1999; Nov 2001	Rougier et al. (2005)
	Schelde estuary, Belgium	50 µm	52	(0 ~ 2,500)	16	Monthly; Feb 2002 to Dec 2002	Azémar et al. (2010)
	Mossoró River estuary, Brazil	60 µm	16	about 9.8	3	Monthly; Oct 2006 to Sept 2007	Medeiros et al. (2010)

Tabl	e 1 9	Spec	ies nur	nber	and	average	abunc	dance o	of roti	fers (on Q	li'ao	Island	l in	comparison	with	othe	r studi	ies
												-							

^aAverage abundance was calculated in all investigated samples; some of the data are approximate values.

identification in this study, Utermöhl's method (Utermöhl 1931) and the widely accepted taxonomy system of Wallace et al. (2006) and Segers (2007, 2011) were used.

Few papers investigated rotifer communities in estuarine areas worldwide (e.g., Egborge 1994; Holst et al. 1998; Rougier et al. 2005; Azémar et al. 2010). Additionally, so far, only one paper reported on rotifer community in mangrove forest habitats (e.g., Rougier et al. 2005). The same situation holds in China as well. There was no exclusive paper on littoral rotifer of estuaries. Only one recent ecological paper of zooplankton included littoral rotifer (e.g., Zhang et al. 2012). Researches on zooplankton covering rotifers mainly focused on open water areas (e.g., Tan et al. 2004; Gao et al. 2008a, 2008b, 2010; Hou 2011).

This study aimed to better understand the spatial and temporal characteristics of the littoral rotifer communities in two kinds of wetlands: shallow mangrove swamp and tidal creek. They are dominant aquatic ecological systems in the mangrove forest of Qi'ao Island, Pearl River estuary.

Methods

Study sites

The sampling sites (Figure 1) are situated in Qi'ao-Dan'gan Provincial Mangrove Nature Reserve (113° $36' \sim 113^{\circ} 39'$ E, 22° $23' \sim 22^{\circ} 27'$ N) on Qi'ao Island, west side of the Pearl River estuary, Guangdong province. Two close sites (about 300 m) were selected in the littoral zone of shallow mangrove swamp (MS) wetlands and tidal creek (TC) wetlands, respectively. The two different wetlands are the main kinds of aquatic ecological system in the mangrove forest of Qi'ao Island. The mangrove swamp (Figure 1) was semi-closed with a variation in water depth of 0 to 60 cm, mostly about 20 cm, but dried three times on the sampling days of May 2007, June 2007, and April 2009. Mostly, it was stagnant, but it could be inundated by high tides. It was covered with dominant mangrove trees Kandelia candel and some understory plant of Acanthus ilicifolius. The tidal creek, an open water body connecting to the Pearl River estuary in the mangrove forest (Figure 1), was influenced by tides with a variation in water depth of 50 to 250 cm. It was dominated by emergent *Phragmites communis* and mangrove trees Kandelia candel in the intertidal zone.

Field sampling

Littoral rotifer samples of the two sites were taken monthly, from January 2007 to December 2010. One semi-automatic plexiglass water sampler, with a volume of 2.5 L (Beijing Purity Instrument Co., Beijing, China), was used for the quantitative sampling. The distance from the



shore was about 2 m. Each sample was metered 5 L water, so the samples from MS or TC needed to be collected randomly at least twice or more depending on the depth of water. Then, the samples were transferred to unified plastic kettles and fixed immediately by adding 40% formaldehyde up to a final concentration of 4%. Fixed samples were concentrated to 50 mL for quantitative counting by using a siphon tube to remove the supernatant fluid after more than 48 h of sedimentation (Utermöhl 1931). Qualitative samples were collected with 30- and 64- μ m nets.

Duplicated samples were taken bimonthly for abiotic parameter analyses following the methods specified for oceanographic survey of China (State Oceanic Administration People's Republic of China 2007). Salinity (S), temperature (T), total phosphorus (TP), and total nitrogen (TN) were analyzed.

Species identification and statistics analysis

Monogonont rotifers were identified into species mainly according to Wallace et al. (2006), Segers (2007, 2011), and Koste (1978). Bdelloid rotifers were hard to identify with fixed specimens which were only enumerated. Animals were selected and examined with a Nikon Eclipse E800 microscope (Nikon Co., Tokyo, Japan). A 1-mL plankton counting chamber was used for enumerating. At least five subsamples were examined until a minimum of 200 individuals per sample was reached, in order to minimize subsampling errors and reduce the coefficient of variation to a maximum of 10% (Omori and Ikeda 1984).

Statistical analyses for the rotifer community, including ANOSIM (analysis of similarity), BEST/BIOENV (best match between biota and environment), CLUSTER (hierarchical clustering), MDS (non-metric multi-dimensional scaling), SIMPER (similarity percentages), and REALTE for serial shift and cyclic variation check within a year or within the investigation period, were conducted by PRIMER 5.0 following Clarke and Gorley (2006). Community abundance data for similarity matrices were square-root transformed and then constructed by the Bray-Curtis similarity method. Abiotic data (salinity, temperature, total phosphorus, and total nitrogen) were normalized, and similarity matrices were constructed by using the Euclidean distance similarity measure. Diversity indexes of rotifer at the two wetlands were expressed with Margalef's species richness index (*D*), Shannon diversity index (*H'*, base-e logarithm), and Pielou's evenness (*J'*). CCA (canonical correspondence analysis) analyses between the main species (square-root transformed) at MS and TC and abiotic parameters (normalized) were performed by CANOCO 4.5 (Monte Carlo permutation tests, number of permutations = 999, *P* < 0.1%). Abundance figures were constructed by SigmaPlot 11.0.

Results

Abiotic parameters

The abiotic parameters of salinity (Figure 2A) and temperature (Figure 2B) analyzed in this study had minor discrepancies between the two sampling sites at the same months and fluctuated regularly with months. The average salinity was a little higher at MS (9.08) than at TC (8.04), while the temperature was a little higher at TC (24.2°C) than at MS (23.6°C). In contrast, total nitrogen (Figure 2C) and total phosphorus (Figure 2D) had slightly larger discrepancies and fluctuated irregularly. The average total phosphorus was a little higher at MS (0.187 mg/L) than at TC (0.164 mg/L), whereas for total nitrogen, it was a little higher at TC (1.592 mg/L) than at MS (1.449 mg/L).

Species composition, abundance, and diversity indexes

Ninety-four species belonging to 25 genera of monogonont rotifers (Table 2, Figure 3) were recorded at the two sampling sites in total. Additionally, 3 published new species and 16 new records of China were found in this survey

(Table 2), and some other new materials need to be further determined. Almost the same species number was found at the two sites; there were 68 species at MS and 67 species at TC, and 27 unique species appeared in MS and 26 in TC. At MS, the dominant rotifer genera in species diversity were *Brachionus, Colurella, Encentrum, Synchaeta* and *Lecane* with 10, 7, 7, 6, and 6 species, respectively, whereas at TC, they were *Brachionus, Lecane, Synchaeta*, and *Polyarthra* with 14, 9, 7, and 5 species (Figure 3).

Variations in rotifer abundance, including monogononta and bdelloida at the two sampling sites, are shown in Figure 4. The average abundance was much higher at TC than at MS (Table 3), and the average abundance of separate years followed the order of 2007 > 2008 > 2009 > 2010 (129.9, 128.8, 95.2, and 39.7 individuals/L) at MS and 2009 > 2007 > 2010 > 2008 (202.0, 181.2, 120.5, and 59.6 individuals/L) at TC. The highest abundance at MS was recorded in November 2008, while it appeared in June 2007 at TC (Figure 4).

The main species of the two sites - *Colurella* sp.1, *Encentrum marinum, Colurella adriatica, Synchaeta cf. kitina, Synchaeta* sp., and *Cephalodella cf. innersi* at MS, and *Synchaeta cf. kitina* and *Brachionus angularis* at TC - are presented in Figure 5 with their variations in



Table 2 Rotifer species and their ecological characteristics recorded in the two sampling sites of Qi'ao Island

Species	Sam	pling	Ecological characteristics	(Continued)		
	MS TC			Encentrum (Pseudenc		
Bdelloid spp.				Encentrum sp. 3		
Anuraeopsis coelata de Beauchamp, 1932		+	Haloxenous	Encentrum sp. 4		
Asplanchna brightwellii Gosse, 1850	+	+	Haloxenous	Epiphanes macroura (B		
Beauchampiella eudactylota (Gosse, 1886)	+		Haloxenous	<i>Euchlanis dilatata</i> Ehr		
Brachionus angularis Gosse, 1851	+	+	Euryhaline	<i>Filinia branchiata</i> (Rou		
Brachionus budapestinensis Daday, 1885		+	Haloxenous	<i>Filinia longiseta</i> (Ehrer		
Brachionus calvciflorus Pallas, 1766	+	+	Eurvhaline	Filinia novaezealandia		
Brachionus caudatus Barrois & Daday, 1894	+	+	Haloxenous	Hexarthra fennica (Lev		
Brachionus dimidiatus Bryce, 1931 ^a		+	Euryhaline	Hexarthra intermedia		
Brachionus diversicornis (Daday, 1883)	+		Haloxenous	Hexarthra mira (Huds		
Brachionus falcatus Zacharias, 1898	+	+	Haloxenous	Hexarthra oxyuris (Ser		
Brachionus ibericus Ciros-Peréz, Gómez &	+	+	Stenohaline	Itura cf. deridderae Se		
Serra, 2001				Keratella cochlearis (G		
Brachionus murphyl Sudzuki, 1989		+	Haloxenous	<i>Keratella procurva</i> (Th		
Brachionus nilsoni Anistrom, 1940	+	+	Haloxenous	<i>Keratella tropica</i> (Apst		
Brachionus plicatilis Muller, 1786	+	+	Stenonaline	<i>Lecane baimaii</i> Sanoa		
Brachionus quadridentatus Hermann, 1783		+	Eurynaline	Savatenalinton, 1999		
Brachionus rotundiformis Ischugunoff, 1921	+	+	Stenohaline	<i>Lecane bulla</i> (Gosse, 1		
Brachionus rubens Ehrenberg, 1838		+	Euryhaline	Lecane closterocerca (
Brachionus urceolaris Müller, 1773	+	+	Euryhaline	Lecane donneri Cheng		
Cephalodella catellina (Müller, 1786)		+	Euryhaline	Lecane arandis (Murra		
<i>Cephalodella cf. gibba</i> (Ehrenberg, 1830)	+	+	Euryhaline	Lecane bamata (Stoke		
Cephalodella cf. innesi Myers, 1924	+	+	Euryhaline?	Lecane hastata (Murra		
Cephalodella cf. misgurnus Wulfert, 1937	+		Haloxenous?			
Cephalodella sp.1		+				
Cephalodella sp.2	+			Lecane puriciaia (Nui		
Colurella adriatica Ehrenberg, 1831	+	+	Euryhaline	Lecare pyritorritis (Dad		
<i>Colurella anodonta</i> Carlin, 1939 ^a		+	Euryhaline	Lecane quaariaentata		
Colurella colurus (Ehrenberg, 1830)	+		Euryhaline	Lecane stenroosi (ivieis		
<i>Colurella psammophila</i> Segers & Chittapun, 2001 ^a	+		Haloxenous	Lepadella acuminata Lepadella patella (Mül		
<i>Colurella sanoamuangae</i> Chittapun, Pholpunthin & Segers, 1999 ^a	+	+	Haloxenous	<i>Lepadella</i> sp.		
Colurella uncinata bicuspidata (Ehrenberg, 1832)	+		Euryhaline	Lindia sp. Notholca sp.		
Colurella sp. 1	+	+	Euryhaline?	Paradicranophorus sin		
Colurella sp. 2	+		,	Platyias quadricornis (
Encentrum marinum (Dujardin, 1841)	+	+	Euryhaline	Polyarthra dolichopter		
Encentrum longidens Donner, 1943 ^a	+	+	, Haloxenous	Polyarthra indica Sege		
Encentrum wiszniewskii Wulfert. 1939 ^a	+		Haloxenous	Polyarthra vulgaris Ca		
Encentrum cf. limicola Otto. 1936	+		Stenohaline	Polyarthra sp. 1		
Encentrum (Isoencentrum) sp. 1	+		Stenohaline	Polyarthra sp. 2		
Encontraini (sochechauni) sp. 1	r -		Sterioriumie			

Table 2 Rotifer species and their ecological characteristicsrecorded in the two sampling sites of Qi'ao Island(Continued)

Encentrum (Pseudencentrum) sp. 2		+	Stenohaline
Encentrum sp. 3	+		
Encentrum sp. 4	+		
Epiphanes macroura (Barrois & Daday, 1894)		+	Euryhaline
<i>Euchlanis dilatata</i> Ehrenberg, 1832	+		Euryhaline
Filinia branchiata (Rousselet, 1901)	+	+	Haloxenous
<i>Filinia longiseta</i> (Ehrenberg, 1834)	+	+	Euryhaline
<i>Filinia novaezealandiae</i> Shiel & Sanoamuang, 1993	+	+	Haloxenous
Hexarthra fennica (Levander, 1892)	+	+	Stenohaline
<i>Hexarthra intermedia</i> (Wiszniewski, 1929)	+	+	Euryhaline
<i>Hexarthra mira</i> (Hudson, 1871)		+	Euryhaline
<i>Hexarthra oxyuris</i> (Sernov, 1903) ^a		+	Stenohaline
ltura cf. deridderae Segers, 1993		+	
Keratella cochlearis (Gosse, 1851)		+	Euryhaline
<i>Keratella procurva</i> (Thorpe, 1891)		+	Haloxenous
<i>Keratella tropica</i> (Apstein, 1907)	+	+	Euryhaline
<i>Lecane baimaii</i> Sanoamuang & Savatenalinton, 1999 ^a	+		Euryhaline
Lecane bulla (Gosse, 1851)	+	+	Euryhaline
Lecane closterocerca (Schmarda, 1859)		+	Euryhaline
<i>Lecane donneri</i> Chengalath & Mulamoottil, 1974ª		+	Euryhaline
Lecane grandis (Murray, 1913)		+	Stenohaline
<i>Lecane hamata</i> (Stokes, 1896)	+		Haloxenous
Lecane hastata (Murray, 1913)	+		Euryhaline
Lecane luna (Müller, 1776)		+	Euryhaline
Lecane punctata (Murray, 1913)		+	Euryhaline
Lecane pyriformis (Daday, 1905)		+	Haloxenous
<i>Lecane quadridentata</i> (Ehrenberg, 1830)	+	+	Euryhaline
Lecane stenroosi (Meissner, 1908)	+	+	Euryhaline
<i>Lepadella acuminata</i> (Ehrenberg, 1834)	+		Euryhaline
<i>Lepadella patella</i> (Müller, 1773)	+	+	Euryhaline
<i>Lepadella</i> sp.	+		
Lindia sp.	+		
Notholca sp.	+	+	Stenohaline
Paradicranophorus sinus De Smet, 2003ª	+		Stenohaline
Platyias quadricornis (Ehrenberg, 1832)	+	+	
Polyarthra dolichoptera Idelson, 1925		+	Euryhaline
Polyarthra indica Segers & Babu, 1999ª	+	+	Haloxenous
Polyarthra vulgaris Carlin, 1943	+	+	Euryhaline
Polyarthra sp. 1	+	+	Haloxenous
Polyarthra sp. 2	+	+	Haloxenous

Table 2 Rotifer species and their ecological characteristics recorded in the two sampling sites of Qi'ao Island (Continued)

<i>Proales similis</i> de Beauchamp, 1907 ^a	+	+	Stenohaline
Resticula melandocus (Gosse, 1887)	+		Euryhaline
Synchaeta arcifera Xu, 1998	+	+	Stenohaline
<i>Synchaeta bicornis</i> Smith, 1904 ^a	+	+	Stenohaline
Synchaeta elsteri Hauer, 1963ª	+	+	Stenohaline
Synchaeta cf. kitina Rousselet, 1902	+	+	Euryhaline
<i>Synchaeta oblonga</i> Ehrenberg, 1832	+	+	Euryhaline
Synchaeta stylata Wierzejski, 1893		+	Euryhaline
<i>Synchaeta vorax</i> Rousselet, 1902ª		+	Stenohaline
Synchaeta sp.	+		Stenohaline
<i>Testudinella patina</i> (Hermann, 1783)	+		Euryhaline
<i>Testudinella pseudobscura</i> Wei, De Smet & Xu, 2011 ^b		+	Stenohaline
<i>Testudinella quadilobata</i> Wei, De Smet & Xu, 2011 ^b	+		Stenohaline
<i>Testudinella zhujiangensis</i> Wei, De Smet & Xu, 2010 ^b	+	+	Stenohaline
Trichocerca marina (Daday, 1890)	+		Stenohaline
Trichocerca pusilla (Jennings, 1903)	+	+	Euryhaline
Trichocerca sp.	+		

MS, mangrove swamp site; TC, tidal creek site. ^aNew rotifer records of China; ^bPublished new rotifer species found in this survey; +, species occurred in the sampling site.

abundance. The species were defined by the average abundance of the species with a cumulative contribution of more than 80% to the average Bray-Curtis similarity between all pairs of samples in the specific community (Clarke and Gorley 2006).

Species number (S), Margalef's species richness index (D), Shannon diversity index (H'), and Pielou's evenness

 $\left(J'\right)$ at MS were all higher than those at TC on average (Table 3).

Site difference and temporal variation of community structure

The results of ANOSIM routine for testing dissimilarity between the sampling sites revealed that the rotifer communities were significant different (R = 0.346, P < 0.1%), and the analysis of CLUSTER (Figure 6) and MDS (Figure 7) also had similar results. Table 4 shows the average abundance of the main species (SIMPER) which added together contributed more than 50% to the dissimilarity of the rotifer communities between the two sites, and the two most dominant species at MS and TC, *Colurella* sp. 1 and *Synchaeta cf. kitina*, contributed up to 24.84% together.

There were four distinct groupings (A, B, C, D) on the dendogram (Figure 6) divided by a similarity of 35%, which were made up with most of lower temperature and higher salinity months of MS in group A, most of higher temperature and lower salinity months of MS in group B, most of lower temperature and higher salinity months of TC in group C, and most of higher temperature and lower salinity months of TC and few months of MS in group D. Additionally, group D had a tendency for two clusters (Figure 6D), viz., most months of 2007 and 2008 in group D tended to cluster together, while all months of 2009 and 2010 of group D were in another branch. Four rotifer communities were found for the relevant groupings, including Encentrum marinum-Colurella adriatica-Synchaeta sp.-Colurella sp.1-Encentrum sp.1 (community A), Colurella sp.1-Synchaeta cf. kitina (community B), S. cf. kitina (community C), and Brachionus angularis-C. adriatica-Brachionus rotundiformis-S. cf. kitina-Keratella tropica-Synchaeta oblonga-Filinia novaezealandiae-Polyarthra





indica-Filinia longiseta (community D). The communities were represented by the main species of each community, in order of decreasing importance, and their average abundance added together contributed more than 80% to the community.

Since the communities were significantly different between the two sites, the temporal changes were analyzed separately. Seasonal community structure varied significantly at the two sampling sites (MS: R = 0.311, P < 0.1%; TC: R = 0.202, 0.1% < P < 5%), while no significant annual change was found (P > 5%) (two-way ANOSIM). Annual cyclic change (RELATE) of the communities could be observed in 3 years at MS (2008: $\rho = 0.359$, 0.1% < P < 5%; 2009: $\rho = 0.325$, 0.1% < P < 5%; 2010: $\rho = 0.421$, P < 0.1%), whereas it was only detected in 2007 and 2008 at TC (2007: $\rho = 0.581$, P < 0.1%; 2008: $\rho = 0.503$; P < 0.1%). For serial shift of rotifer communities (RELATE), only 2007 had a serial shift of the faunal communities at MS ($\rho = 0.403$, 0.1% < P < 5%) and 2008 at TC ($\rho = 0.396$, 0.1% < P < 5%), respectively.

BEST/BIOENV analysis of the correlation between rotifer communities and abiotic parameters of the two sampling sites revealed that the higher significant correlation recorded at TC was found only with temperature (R = 0.417). While at MS, the group salinity and total nitrogen together correlated with the communities most (R = 0.246), of which salinity contributed most (R = 0.237).

The correlation between main species (species weight range > 10%) and environmental factors at the two sites

is shown in Figure 8. For MS, about half of the main species situated at the bottom left area of the plot, mostly stenohaline and few euryhaline species (Table 2), were associated with high salinity. The other half of the main species, located at the right side, were correlated with high temperature. Besides, one peculiar rare ben-thic species, *Ecentrum longidens*, was correlated with total nitrogen greatly. For TC, overwhelming majority of the main species arranged at the left side of the plot, mostly planktonic euryhaline or haloxenous species (Table 2), were correlated with high temperature.

Variations in abundance of the most dominant species, which were *Colurella* sp.1 at MS and *Synchaeta cf. kitina* at TC, significantly correlated with total nitrogen (R = 0.722, P < 0.1%) and salinity (R = 0.476, P < 0.1%), temperature (R = -0.509, P < 0.1%), respectively. The next dominant species at MS, *Encentrum marinum*, also correlated with salinity (R = 0.476, P < 0.1%) and temperature (R = -0.509, P < 0.1%) significantly, which were in accordance with the equations shown in Figure 9.

Discussion

Species composition, diversity, and abundance

Since the sampling methods of the estuarine studies were not consistent, almost all the consulted studies of China were prone to overlook small-sized rotifers because of the improper methods and few papers considering littoral rotifers (Table 1); the discussion based on comparisons in this

Table 3 Average abundance and diversity indexes of rotifer communities at two sampling sites in mangrove wetlands of Qi'ao Island

	Average abundance (individuals/L)	S	D	J'	H'
MS	97.0 (1 ~ 742)	6.3 (1 ~ 20)	1.30 (0.00 ~ 3.80)	0.63 (1.19 ~ 0.99)	1.18 (0.00 ~ 2.61)
TC	140.8 (1 ~ 1,636)	5.9 (1 ~ 21)	1.18 (0.00 ~ 3.40)	0.55 (0.02 ~ 1.00)	0.95 (0.00 ~ 2.32)

MS, mangrove swamp site; TC, tidal creek site; S, species number; D, Margalef's species richness index; J', Pielou's evenness index; H',: Shannon diversity index (base-e logarithm).



article was limited but may allow for a general grading of the present results.

The number of rotifer species was much higher than that of the few previous studies which covered rotifers in the Pearl River estuary (maximum 69 species: Tan et al. 2004; Gao et al. 2008a, 2008b, 2010; Hou 2011; Zhang et al. 2012) (Table 1). None of the papers reported any strictly marine species. However, in this study, more than 20 species were recorded (Table 2) according to Fontaneto et al. (2006, 2008) and the measured salinity of their habitats. The average rotifer abundance was more than 20 times higher than the zooplankton reports from Gao et al.





(2008a, 2008b) on the eight outlets of the river (Table 1). When compared with the rotifer data well-documented in the Yangtze River estuary, China, the number of rotifer species (only monogonont rotifers) and abundance in this study were mostly higher too (maximum 103 species: Han and Hu 1995; Wang et al. 1999; Hu et al. 2008). For comparison to some estuaries out of China, the results were similar, especially on strictly haline species (e.g., Egborge 1994; Holst et al. 1998; Lam-Hoai et al. 2006; Rougier et al. 2005; Azémar et al. 2010).

Rotifers in the littoral zone of the two wetlands on Qi'ao Island in the Pearl River estuary had significantly high species diversity and abundance. It may mainly result from (1) suitable sampling methods applied for 4-year-long repeated sampling, (2) widely accepted taxonomy system and up-to-date authoritative references used, and (3) greater environmental heterogeneity and

Table 4 Differences of the main species in average abundance between the two sampling sites

Species	Average (individ	e abundance uals/L)	Contribution (%)		
	MS	тс			
Synchaeta cf. kitina	2.7	37.9	15.31		
Colurella sp.1	9.5	0.3	9.53		
Colurella adriatica	4.3	0.2	7.87		
Encentrum marinum	9.5	0.3	5.75		
Brachionus angularis	3.1	30.7	5.55		
Synchaeta sp.	6.1	0.0	3.19		
Brachionus rotundiformis	0.4	8.1	2.73		
Keratella tropica	0.2	7.4	2.33		

MS, mangrove swamp site; TC, tidal creek site.

wider spectrum of ecological niches in the littoral zone which may bring higher species richness compared to pelagic area (Lemly and Dimmick 1982; Maia-Barbosa et al. 2008).

Site difference and temporal variation of community structure

It was indicated that the differences of the communities between the two sites are mainly caused by the abundance of different main species present at the two sites (Table 4). All of the main species of MS - *Colurella* sp.1, *Encentrum marinum, Colurella adriatica*, and *Synchaeta* sp. (Figure 5) - had at least more than 20 times higher average abundance than those at TC, while the main species of TC - *Synchaeta cf. kitina, Brachionus angularis* (Figure 5), *Keratella tropica*, and *Brachionus rotundiformis* - all presented more than 10 times higher average abundance than those at MS.

Great dissimilarity of the rotifer community detected between MS and TC indicated different biotopes for rotifers (Figures 6 and 7). The MS wetlands, where the depth of the water was no more than 60 cm, mostly about 20 cm with a small water area, were more likely to be occupied by a benthic community in most cases. It can be verified by the ecological characters of the main species present at MS. The most dominant species -Colurella sp.1, Encentrum marinum, and Colurella adriatica (together contributed to the community >70%) belong to benthic genera (Koste 1978), and the rest of the main species (Figures 5 and 8) mostly are benthic or periphytic living animals, and only few pelagic. Whereas, in the case of TC with much deeper water, definitely a planktonic community, most of the main species (Figure 8) are planktonic, especially the overwhelming



dominant species *Synchaeta cf. kitina* (contribution = 70.94%). It was probably the main reason contributing to the difference of community structure between the two sites.

Both the BEST/BIOENV and CCA analysis had similar results that salinity and/or temperature were/was the primary decisive factors affecting the community structure in this study. It was similar to many other estuary aquatic systems. For instance, the abundance of planktonic rotifers was positively correlated with temperature and negatively correlated with salinity at Medaomen, one outfall of the Pearl River estuary (Hou 2011), and Huangpu site in upstream of the Pearl River estuary (Wang et al. 2009). Azémar et al. (2010) also found that salinity was the main spatial structuring factor for the Schelde River estuarine rotifer community.

Physiological tolerances of organisms prescribe the environment where survival and reproduction are possible



(Thorp and Covich 2010). For rotifers, although they have a very wide tolerance range, certainly the differences of dependence on temperature and salinity exist among separate species (Berzins and Pejler 1989; Fontaneto et al. 2006). For example, the species of Encentrum marinum, Notholca sp., Synchaeta sp., and Paradicranophorus sinus at MS mostly are present in winter with preference for high salinity and low temperature (Figures 8 and 9), while the Filinia and Polyarthra species were only found in summer, with preference for low salinity and high temperature (Figures 8 and 9). The alternation of the main species in abundance (Figure 5) influenced by the factors partly results in the temporal succession among the communities of each site (Figure 6). So the variations of abiotic factors might be one of the most important factors to shape the rotifer community structure of Qi'ao Island in the Pearl River estuary temporally; especially, salinity and temperature with strong temporal regularity (Figure 2) significantly correlated with rotifer abundances, particularly with the abundances of the main species (Figures 8 and 9).

The peculiar environment of MS created an unusual situation that the most important abiotic factors detected, temperature and salinity, had an opposite effect on the littoral rotifer communities between MS and TC (Figure 8). It mainly resulted from the fact that the most abundant species *Synchaeta cf. kitina* at TC (Figures 5, 8, and 9) was negatively correlated with salinity and positively correlated with temperature, whereas the majority of the most abundant species at MS - *Encentrum marinum, Colurella adriatica, Synchaeta cf. kitina, Synchaeta* sp., and *Cephalodella cf. innersi* (Figures 5, 8, and 9) - were positively correlated with salinity and negatively correlated with temperature.

The rational explanation for this unusual situation at MS may be as follows: with a low amount of evaporation in winter and being uneasily influenced by tides in dry season which resulted in a relatively stable environment with high salinity at MS, it tended to hold high diversity and abundance of marine species, such as *Encentrum marinum, Paradicranophorus sinus,* and *Synchaeta* sp. (Figures 4 and 5), while in summer it became unstable because of the frequent tide actions in rainy seasons and greater evaporation with high temperature, and it inclined to have a low species diversity and abundance (Figure 4). This was verified by the distinct temporal differentiation between community A with higher abundance of more marine species and community B with more euryhaline species (Figures 5 and 6).

Conclusions

This study revealed high diversity and abundance of littoral rotifers at the two close mangrove wetlands of Qi'ao Island in the Pearl River estuary, China. The great community structure differences detected between the two sites mainly resulted from the abundance of different main species present at the two sites, which indicated different kinds of biotopes between the two sites. Community structure varied greatly at all sites seasonally, but there was no significant yearly change. The rotifer communities were correlated with the salinity and total nitrogen group mostly at MS, while temperature contributed mostly at TC.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

RLX designed the study. NW carried out the sampling, analyzed the data, and finalized the manuscript. Both authors read and approved the final manuscript.

Acknowledgements

Sincere thanks go to some students of Sun Yat-sen University without whom the field sampling would not have been possible, especially Xin Ye, Jin-qiu Chen, and Jia-wen Xu. This work was supported by National Natural Science Foundation of China (U0633002).

Author details

¹Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Guangzhou, Guangdong 510380, China. ²School of Life Sciences, Sun Yat-sen University, Guangzhou, Guangdong 510275, China.

Received: 12 October 2013 Accepted: 27 May 2014 Published online: 25 June 2014

References

- Azémar F, Maris T, Mialet B, Segers H, Van Damme S, Meire P, Tackx M (2010) Rotifers in the Schelde estuary (Belgium): a test of taxonomic relevance. J Plankton Res 00:1–17
- Berzins B, Pejler B (1989) Rotifer occurrence in relation to temperature. Hydrobiologia 175:223–231
- Bottrell HH, Duncan A, Gliwicz ZM, Grygierek E, Herzig A, Hillbricht-Ilkowska A, Kurasawa H, Larsson P, Weglenska T (1976) A review of some problems in zooplankton production studies. Norw J Zool 24:319–456
- Chick JH, Levchuk AP, Medley KA, Havel JH (2010) Underestimation of rotifer abundance a much greater problem than previously appreciated. Limnol Oceanogr Meth 8:79–87
- Clarke KR, Gorley RN (2006) PRIMER v6: user manual/tutorial. PRIMER-E Ltd, Plymouth, UK
- Dolan JR, Gallegos CL (1991) Trophic coupling of rotifers, microflagellates, and bacteria during fall months in the Rhode River Estuary. Mar Ecol Prog Ser 77:147–156
- Dolan JR, Gallegos CL (1992) Trophic role of planktonic rotifers in the Rhode River Estuary, spring–summer 1991. Mar Ecol Prog Ser 85:187–199
- Duggan IC (2001) The ecology of periphytic rotifers. Hydrobiologia 446(447):139–148
- Egborge ABM (1994) Salinity and the distribution of rotifers in the Lagos Harbour–Badagry Creek system, Nigeria. Hydrobiologia 272:95–104
- Fontaneto D, De Smet WH, Ricci C (2006) Rotifers in saltwater environments, re-evaluation of an inconspicuous taxon. J Mar Biol Assoc U K 86:623–656
- Fontaneto D, De Smet WH, Melone G (2008) Identification key to the genera of marine rotifers worldwide. Meiofauna Marina 16:75–99
- Fontaneto D, Barbosa AM, Segers H, Pautasso M (2012) The 'rotiferologist' effect and other global correlates of species richness in monogonont rotifers. Ecography 35:174–182
- Gao Y, Lai ZN, Wang C, Pang SX, Wei TL, Xie WP, Yang WL (2008a) Community characteristics of zooplankton in Pearl River Estuary in summer of 2006. S China Fish Sci 4:10–15 (in Chinese)
- Gao Y, Lai ZN, Wang C, Pang SX, Wei TL, Xie WP, Yang WL (2008b) Distributing characteristics of zooplankton in Pearl River Estuary. J Fishery Sci China 15:260–268 (in Chinese)

- Gao Y, Lai ZN, Pang SX, Wei TL, Wang C, Yang WL (2010) Comparison of zooplankton communities in Hutiaomen and Yamen of Huangrnao Sea. Ecologic Sci 29:121–126 (in Chinese)
- Han DJ, Hu JX (1995) A survey of the rotifers from Yizhen to Chongmin of Yangtze River. Chinese J Zool 30:1–8 (in Chinese)
- Holst H, Zimmermann H, Kausch H, Koste W (1998) Temporal and spatial dynamics of planktonic rotifers in the Elbe Estuary during spring. Estuar Coast Shelf S 47:261–273
- Hou L (2011) Community characteristics of rotifers in Guangzhou segment of the Pearl River and Modaomen Estuary. Jinan University, Guangzhou, China, p 125 (in Chinese)
- Hu JX, Zheng JX, Fang YH, Peng Q (2008) Impact of water transfer project on rotifer in Yangtze River estuary. Environmental Science and Technology 31:39–42 (in Chinese)
- Koste W (1978) Rotatoria, Die Rädertiere Mitteleuropas 2 vols. Borntraeger, Berlin, p 673, 234 plates
- Lam-Hoai T, Guiral D, Rougier C (2006) Seasonal change of community structure and size spectra of zooplankton in the Kaw River estuary (French Guiana). Estuar Coast Shelf S 68:47–61
- Lemly AD, Dimmick JF (1982) Structure and dynamics of zooplankton communities in the littoral zone of some North Carolina lakes. Hydrobiologia 88:299–307
- Li KZ, Yin JQ, Huang LM, Tan YH (2006) Spatial and temporal variations of mesozooplankton in the Pearl River estuary, China. Estuar Coast Shelf S 67:543–552
- Maia-Barbosa PM, Peixoto RS, Guimarães AS (2008) Zooplankton in littoral waters of a tropical lake: a revisited biodiversity. Braz J Biol Supplement 68:1069–1078
- Medeiros AMA, Barbosa JEL, Medeiros PR, Rocha RM, Silva LF (2010) Salinity and freshwater discharge determine rotifer distribution at the Mossoro River Estuary (Semiarid Region of Brazil). Braz J Biol 70(3):551–557
- Omori M, Ikeda T (1984) Methods in marine zooplankton ecology. John Wiley, New York
- Rougier C, Pourriot R, Lam-Hoai T, Guiral D (2005) Ecological patterns of the rotifer communities in the Kaw River estuary (French Guiana). Estuar Coast Shelf S 63:83–91
- Segers H (2007) Annotated checklist of the rotifers (Phylum Rotifera), with notes on nomenclature, taxonomy and distribution. Zootaxa 1564:1–104
- Segers H (2008) Global diversity of rotifers (Rotifera) in freshwater. Hydrobiologia 595:49–59
- Segers H (2011) Phylum Rotifera Cuvier, 1817. In: Zhang ZQ (ed) Animal biodiversity: an outline of higher-level classification and survey of taxonomic richness., Zootaxa 3148:231–233
- Smith DG (2001) Pennak's freshwater invertebrates of the United States: Porifera to Crustacea, 4th edn. John Wiley and Sons, New York
- State Oceanic Administration People's Republic of China (2007) Specifications for oceanographia survey-part 4: survey of chemical parameters in sea water. Standards Press of China, Beijing (in Chinese)
- Tan YH, Huang LM, Chen QC, Huang XP (2004) Seasonal variation in zooplankton structure and grazing impact on phytoplankton standing stock in the Pearl River Estuary, China. Cont Shelf Res 24:1949–1968
- Thorp JH, Covich AP (eds) (2010) Ecology and classification of North American freshwater invertebrates, 3rd edn. New York, Academic Press
- Tseng LC, Dahms HU, Hung JJ, Chen QC, Hwang JS (2011) Can different mesh sizes affect the results of copepod community studies? J Exp Mar Biol Ecol 398:47–55
- Utermöhl H (1931) Neue Wege in der quantitativen Erfassung des Planktons (Mit besondere Bericksichtigung des Ultraplankton). Zwecke und Ziele der Internationalen Vereinigung für theoretische und angewandte Limnologie 5:567–595
- Wallace RL, Snell TW, Ricci C (2006) Rotifera. In: Segers H, Dumont HJF (eds) Biology, ecology and systematics, vol 1, 2nd edn, Guides to the identification of the microinvertebrates of the continental waters of the world, volume 23. Ghent, Belgium and Backhuys Academic Publishing, The Hague, The Netherlands, p 299, Kenobi productions
- Wang JQ, Yuan Q, Chen YQ (1999) A preliminary study on the species diversity of estuarine community of rotifer in the Changjiang estuary. J Fishery Sci China 6:10–14 (in Chinese)
- Wang Q, Yang YF, Chen JF (2009) Impact of environment on the spatio-temporal distribution of rotifers in the tidal Guangzhou segment of the Pearl River estuary, China. Int Rev Hydrobiol 94:688–705

- Zhang HG, Cui BS, Zhang ZM, Fan XY (2012) Species diversity and distribution for zooplankton in the intertidal wetlands of the Pearl River estuary, China. Procedia Environmental Sciences 13:2383–2393
- Zhou SC, Jin BS, Guo L, Qin HM, Chu TJ, Wu JH (2009) Spatial distribution of zooplankton in the intertidal marsh creeks of the Yangtze River Estuary, China. Estuar Coast Shelf S 85:399–406

doi:10.1186/s40555-014-0030-6

Cite this article as: Wei and Xu: Distinct difference of littoral rotifer community structure in two mangrove wetlands of Qi'ao Island, Pearl River estuary, China. *Zoological Studies* 2014 **53**:30.

Submit your manuscript to a SpringerOpen[®] journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Immediate publication on acceptance
- Open access: articles freely available online
- ► High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at > springeropen.com