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Biodiversity of Planktonic Copepods in the Lanyang River (Northeastern Taiwan), a Typical Watershed of Oceania

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Hans-Uwe Dahms, Li-Chun Tseng, Shih-Hui Hsiao, Qing-Chao Chen, Bong-Rae Kim, and Jiang-Shiou Hwang (2012) Biodiversity of planktonic copepods in the Lanyang River (northeastern Taiwan), a typical watershed of Oceania. *Zoological Studies* **51**(2): 160-174. To evaluate the environmental status of a typical Oceania watershed in Taiwan, zooplankton samples were collected bimonthly along the Lanyang River (NE Taiwan) at 9 different stations including 1 estuarine and 8 freshwater stations during 10 sampling campaigns from June 2004 to Dec. 2005. Upstream stations showed lower chlorophyll *a* and temperature values than downstream stations; the highest chlorophyll *a* concentration was found in the estuary at all times. We identified 21 copepod species, belonging to 4 orders, 12 families, and 20 genera in total. Eleven species were recorded only once among all samples. The Calanoida was restricted to samples from the estuary. The Poecilostomatoida was only recorded from the estuary and the Lanyang Bridge station. The Harpacticoida was only recorded from the estuary, Lanyang Bridge, and Tsu-Keng River stations. At 2 mid-section stations, no copepods were found. The upstream station showed lower abundance, species number, species richness, and evenness and diversity indices than the downstream and estuarine stations. The estuarine station provided the highest copepod abundance (3410.05 individuals/m^3) and species number (12 species/station) in Aug. 2004 when the waters showed the highest salinities (37 psu), indicating the marine origin of the diverse biota. Among all samples, there were no significant differences in the abundance, number of species, or indices of richness, evenness, and diversity among sampling months. In contrast, our analysis clearly showed a succession in abundance and species composition among sampling months. At the estuarine station, copepod abundances were significantly positive correlated with salinity (r = 0.880, p = 0.001). Numbers of species were significantly positive correlated with chlorophyll *a* (r = 0.790, p = 0.007), salinity (r = 0.780, p = 0.008), and copepod abundance (r = 0.785, p = 0.007). Copepod abundances were mainly affected by intruding seawater, but there was no interaction with the month of sampling. http://zoolstud.sinica.edu.tw/Journals/51.2/160.pdf

Key words: Riverine zooplankton, River ecology, Estuary, Copepod mesozooplankton, Plankton communities.

When compared to the open ocean, coastal and estuarine ecosystems may be smaller, in terms of area and volume, but the amount of organic carbon exported to the deep ocean through the coastal fringe (1.7×10^{15} tons C/yr) can reach nearly that of the entire oceanic realm (13.2×10^{15} tons C/yr) (Bienfang and Ziemann 1992, Carlsson et al. 1995). Coastal tropical environments are of particular importance in this respect (Nittrouer et al. 1995). Increasing attention has been given to small mountainous rivers with drainage areas of < 10,000 km^2. These smaller but numerous rivers could collectively be very important in transporting sediments and particulate

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organic carbon to the ocean (Hsu et al. 1998). Many of these rivers are present on islands of the western Pacific, collectively called Oceania (Kao and Liu 1996 1997). On Oceania islands, such as Taiwan, high precipitation, steep slopes, small basin areas, and frequent flood events can induce high erosion rates (Carry et al. 2002). These natural characteristics make watersheds much more vulnerable to anthropogenic perturbations (Cearreta et al. 2000) such as exacerbation of erosion induced by human perturbations in the Lanyang River (Kao and Liu 2002).

Rivers provide a unique gradation of environments: from pristine waters to a mix of riverine and seawater in their estuaries. Considering the high resilience of the estuarine portion of rivers, analyses of zooplankton community assemblages along riverine, estuarine, and marine sections of a river mouth are warranted to understand the main determinants of zooplankton communities in estuaries (Thor et al. 2005, Hwang et al. 2000 2006 2009b 2010).

The Lanyang River is a typical watershed on an Oceania island and is used as an example in the present study. Shiah et al. (1996) differentiated 3 types of waters in the estuary of the Lanyang River: river-mouth water, marine seawater, and mixed water. Amounts of precipitation in the drainage basin and estuary of the Lanyang River are influenced by a shift in seasonal currents. These are driven by the northward flow of the Kuroshio Current along eastern Taiwan year round and during winter by the northeasterly monsoon (Jan et al. 2002, Lee and Chao 2003, Liang et al. 2003, Liu et al. 2003, Hwang et al. 2006, Tseng et al. 2008b, Hsieh et al. 2011). Although being the largest tidal river in northeastern Taiwan, comparatively few biological and hydrological investigations have been undertaken in the Lanyang River and its estuary. For example, there is no information available about zooplankton in general or copepod community structures, and particularly about their dynamics. To determine the ecological health of a river, such as the Lanyang River, an assessment study needs to sample a variety of physicochemical and biological parameters. Studies at higher levels of organization are important to understand environmental stressors on ecologically relevant endpoints such as community diversity. Thus, organism-level responses are important in assessing the health of aquatic systems and their recovery after a disturbance. Establishment of relationships between stressors and biological responses serve as the basis of management decisions and environmental remediation practices.

Copepods are claimed to be numerically the most abundant metazoans (Schminke 2007, Chang et al. 2010, Hwang et al. 2004 2010, Kâ and Hwang 2011) and play a central role in the transfer of carbon from producers to higher trophic levels in most aquatic ecosystems (Jerling and Wooldridge 1995). Copepods are the primary consumers of phytoplankton and are the main prey items of larval and juvenile fishes that link pelagic food webs (Tseng et al. 2008a 2009, Vandromme et al. 2010, Wu et al. 2010). Copepods are used as indicator species for waters of different qualities and origins (Bonnet and Frid 2004, Hwang and Wong 2005, Thor et al. 2005, Hwang et al. 2006 2009a 2010). Understanding the copepod fraction of the mesozooplankton is thus meaningful to fundamental ecology and applied environmental monitoring (Chullasorn et al. 2009 2011, Hwang et al. 2009b). This also holds for the management and protection of biological resources of other riverine watersheds worldwide and in Oceania.

In the present paper, we investigated planktonic copepod assemblages in the freshwater and estuarine portions of the Lanyang River in order to understand the major determinants such as temperature, salinity, chlorophyll (Chl) *a*, and copepod abundances and distributions in a typical smaller watershed of a subtropical Oceania island.

MATERIALS AND METHODS

Study site

The Lanyang River is a comparatively small watershed in Taiwan but the largest in northeastern Taiwan (Fig. 1). It originates at an elevation of 3535 m and runs for only 73 km. It is on average 0.5 km wide with a comparatively small drainage basin area of 820 km^2 (Kao 1996). The main channel flowing northeasterly, is affected by high precipitation, and has a steep slope (with a mean gradient of 1: 21) (Kao 1996). The river mouth is shallow (< 2 m deep) and narrow. The annual precipitation in this watershed ranged 2000-5000 mm for the past 50 yr, with an average of about 3000 mm (Kao and Liu 2002). This amount is high as an average value on a global scale, but typical for Oceania islands. The lithology and climatic conditions are homogeneous in the watershed. The basement rock of the Lanyang River watershed is composed mainly of Tertiary argillite-slate and metasandstone (Ho 1975). There are 2 gauge stations along the main channel of the river. Gauge 1 is located above the tidal zone at the river mouth. Gauge 2 is located in the upper part at an elevation of 450 m. The drainage areas above G1 and G2 are 820 and 273 km^2, respectively. There were 2 massive road construction events in the study area in the past 50 yr which were the major anthropogenic disturbances in the watershed and which also allowed farming disturbances on otherwise steep slopes. Vegetable plantations were developed along the riverbeds and banks of the main stem as high as 1250 m in elevation. There is little domestic effluent in the upper and midstream sections, but heavy discharges in the estuary of the Lanyang River. Most disturbances are due to agricultural activities in upstream areas and a quarry in the midstream portion.

Zooplankton and water sample collection

Based on preliminary surveys of salinity and copepod distributions, 9 stations were set up at 24°27'41"-24°43'01"N and 121°24'12"-121°49'31"E along the Lanyang River in order to cover most of the range of environmental conditions. These stations are grouped in 3 areas and include fresh waters and brackish waters in the estuarine river mouth (Fig. 1, Table 1). The largest distance between the Gah-Siang (GS) Bridge and the coast is about 73.00 km. There is a drastic decrease

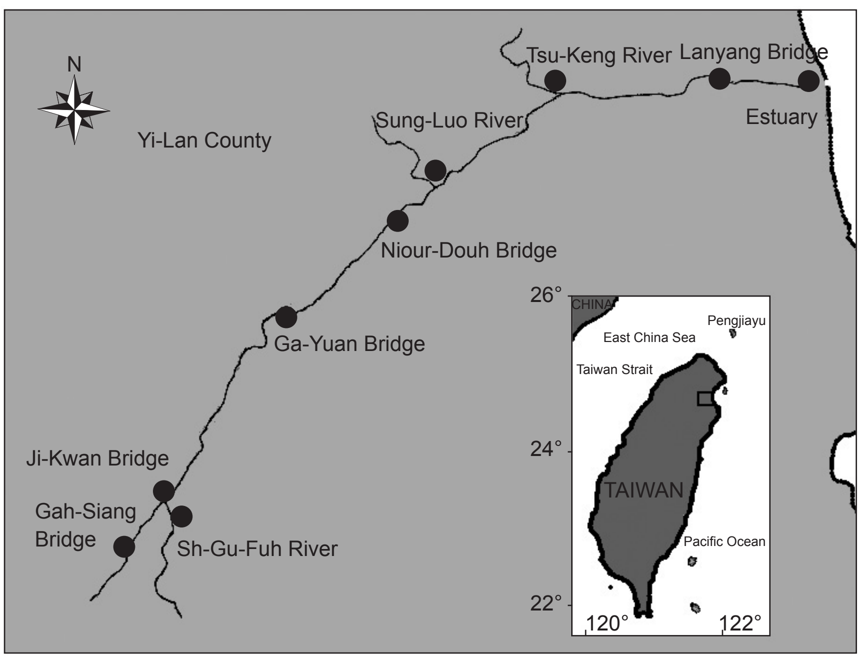

Fig. 1. Sampling stations along the Lanyang River in northeastern Taiwan.

Table 1. Station name, abbreviation, code, elevation, and distance to the coast

Location	Abbreviation	Code for station	Elevation (m)	Distance to coast (km)
Gah-Siang Bridge	GS Bridge	A	1534	73.00
Sh-Gu-Fuh River	SGF River	B	948	67.43
Ji-Kwan Bridge	JK Bridge	C	808	65.08
Ga-Yuan Bridge	GY Bridge	D	376	47.10
Niour-Douh Bridge	ND Bridge	E	209	35.11
Sung-Luo River	SL River	F	189	28.69
Tsu-Keng River	TK River	G	90	17.55
Lanyang Bridge	LY Bridge	H	2	6.21
Estuary	Estuary	I	1	0.10

in elevation from 1534 to 90 m between the GS Bridge and Tsu-Keng (TK) River stations. The Sung-Luo (SL) River and TK River stations are located where these streams merge with the Lanyang River. Whereas 7 upper stations belong to the freshwater zone, the 2 stations of Lanyang (LY) Bridge and the estuary are influenced by seawater. Waters at the LY Bridge station are less affected by seawater as they are somewhat farther from the coast.

Stations were sampled every 2nd month during 10 sampling periods from June 2004 to Dec. 2005. Tows were performed from a boat at the estuary station and by foot at the river stations. Since the channel of the Lanyang River is shallow and narrow, boats cannot navigate in the middle and upstream sections. Zooplankton samples were obtained by towing a modified North Pacific (NORPAC) zooplankton net (with a mouth diameter of 45 cm, a mesh size of 100 μm, and a length of 180 cm with a Hydrobios flow meter (Germany) mounted at the center of the net mouth) horizontally for 10 min at the surface at all stations (Hwang et al. 2007). Zooplankton were preserved in a buffered 5% formalin-seawater solution for later sorting, identification, and counting in the laboratory.

Water temperature and salinity were measured with a mercury thermometer and refractometer (S-100, Tanaka Sanjiro Co.,Ltd., Japan), respectively. Water samples at 1 m in depth were collected with Niskin bottles to determine Chl *a* concentrations using the fluorometric method of Parsons et al. (1984). Other parameters like precipitation, nutrient and organic loadings were not measured but were taken from the literature (Kao and Liu 1996 1997).

Copepod enumeration and identification

In the laboratory, zooplankton samples were subsampled with a Folsom splitter. Procedures for species identification and counting were similar to those described by Hwang et al. (1998 2006). Adult copepods in the subsamples were identified and counted under a stereomicroscope. Species were identified according to keys and references by Chen and Zhang (1965), Chen et al. (1974), Shih and Young (1995), and Chihara and Murano (1997). Freshwater copepods were identified according to Dussart and Defaye (2006) and Einsle (1996) if not indicated otherwise.

Data analysis

Copepod community structures were analyzed using the Plymouth Routine In Multivariate Ecology Research (PRIMER) computer package (Version IV; Clarke and Warwick 1994). In order to reduce the higher heteroscedasticity observed in the abundance data for major taxa, a transformation power (λ = 0.983) was generated by regression coefficients, that were simultaneously estimated using a method of maximizing the log-likelihood function (Box and Cox 1964). Copepod abundance data were log (X + 1)-transformed before clustering, using the matrix of abundances composed of samples and species. Similarity coefficients between samples were computed using the Bray-Curtis similarity and clustering strategy of flexible links. Three stations (Ji-Kuan (JK) ridge, Ga-Yuan (GY) Bridge, and Niour-Douh (ND) Bridge) were not considered in the cluster analysis since they contained no copepods. For correlations between abiotic factors and zooplankton abundances, Pearson's product moment correlation coefficients were calculated with the SPSS computer package (Chicago, IL, USA). The Mann-Whitney *U*-test was applied to compare spatial and seasonal differences in surface-water temperatures. A one-way analysis of variance (ANOVA) was applied to reveal differences in abundances, numbers of species, and indices of richness, evenness, and diversity among sampling months. The Shannon-Wiener diversity index (Weaver and Shannon 1949) together with the richness index and Pielou's evenness index (Pielou 1966) were applied to estimate the copepod community composition.

RESULTS

Overview of the Lanyang River

Hydrographic parameters, Chl *a*, and salinity

We recorded high surface temperatures from June to Dec. in both years 2004 and 2005. Stations along the upper stream showed lower Chl *a* (0.84 ± 0.25 μg/L) and temperature (19.4 ± 4.45°C) values than the downstream stations (2.35 ± 1.90 μg/L for Chl *a* and 25.5 ± 4.11°C for temperature) (Fig. 2). The estuarine station always had higher concentrations of Chl *a* (Fig. 2A).

Spatial differences in surface water temperature were not significant, but seasonal differences

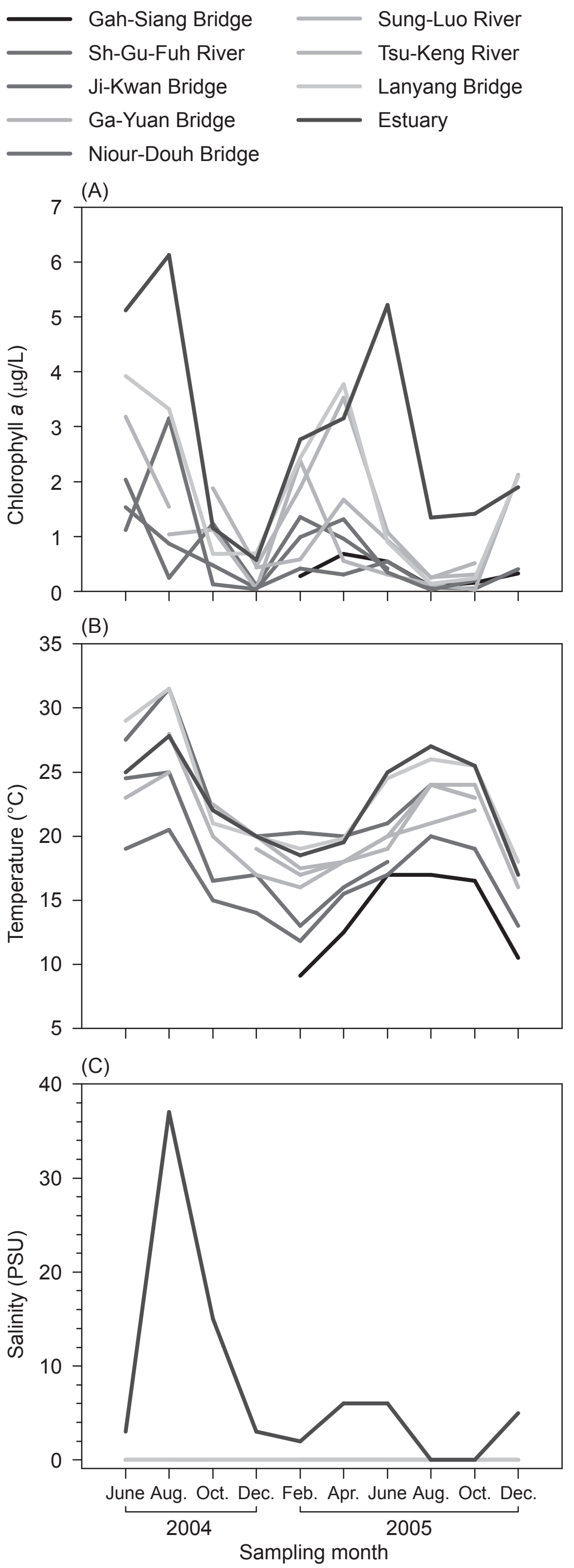

Fig. 2. Chlorophyll *a* (A), water temperature (B), and salinity (C) in each sampling month at each sampling station. Only the estuary station exhibited salinities of > 0 psu.

in temperature were significant ($p < 0.05$; Mann-Whitney *U*-test), with the lowest temperature of 9.1°C recorded in Feb. 2005 (GS Bridge station) and the highest temperature of 31.5°C in Aug. 2004 (ND Bridge and LY Bridge stations) (Fig. 2B). All sampling stations, except the estuarine one, had freshwater conditions throughout the study period, with salinities of 0 psu at all times (Fig. 2C). A plume-ward progressive increase in salinity was obvious in the estuary. The value recorded off the estuary station showed remarkable changes from 0 (i.e., fresh water) to 37 psu, with an average of 9.58 psu, indicating a variable influence of riverine freshwater outflow near the surface from upstream and of near-bottom intrusion of saline water from the ocean. The salinity was 37.0 psu when seawater intruded the estuary, and it was 0 psu when fresh water flushed the estuary after a heavy rainfall or during an ebb tide (Fig. 2C). All 3 hydrographic parameters showed maximum values at the estuarine station (Fig. 2A-C).

Copepod abundance and diversity

In total, 28 species and 21 genera, belonging to 12 families and 4 copepod orders were identified from the marine, estuarine, and riverine portions of the Lanyang River (Table 2). The Poecilostomatoida was only recorded at the estuarine and LY Bridge stations. At the sampling station closest to the Lanyang River mouth, *Apocyclops borneoensis* showed the highest occurrence rate (6.67%). In contrast, 11 copepod species were recorded only once among all samples (with an occurrence ratio (OR) of 1.11%). No copepods were found at the following 3 stations: JK Bridge, GY Bridge, and ND Bridge, located in the lower section of the upper 1/2 of the river (Table 2).

In terms of both diversity and abundance, copepods were the most dominant component of the zooplankton in all samplings. Among all zooplankton, cyclopoid copepods were most prominent, in terms of both diversity and density at most sampling stations throughout the investigation period. The number of calanoids was highest in the estuary. The Poecilostomatoida was only found in the estuary. From all samples, results showed that copepod abundances at the estuarine station were significantly affected by the intrusion of seawater. Freshwater copepods were represented by 1 calanoid species of *Mongolodiaptomus birulai* and 9 cyclopoid species of *Acanthocyclops* sp., *Apocyclops borneoensis*, *Cyclopina* sp., *Cyclops*

Table 2. Abundance (mean ± S.D. individuals (ind.)/m^3), relative abundance (RA, %), and occurrence rate (OR, %) of copepods (ind./m^3) at recorded stations. A, GS Bridge; B, SGF River; C, JK River; D, GY Bridge; E, ND Bridge; F, SL River; G, TK River; H, LY Bridge; **I**, estuary

Species	Recorded station	Mean ± S.D. (ind./m^3)	RA (%)	OR (%)
Calanoida				
Acartiidae				
Acartia (*Odontacartia*) *erythraea* Giesbrecht 1889	I	184	3.808	1.11
Acartia (*Plantacartia*) *negligens* Dana 1849	I	2.48 ± 2.15	0.103	2.22
Centropagidae				
Sinocalanus sp.	I	0.4	0.008	1.11
Sinocalanus tenellus (Kikuchi) 1928	I	0.68	0.014	1.11
Diaptomidae				
Mongolodiaptomus birulai (Rylov) 1922	I	0.68	0.014	1.11
Eucalanidae				
Subeucalanus subcrassus (Giesbrecht) 1888	I	13.14	0.272	1.11
Paracalanidae				
Acrocalanus gracilis Giesbrecht 1888	I	15.37 ± 3.15	0.636	2.22
Paracalanus aculeatus Giesbrecht 1888	I	3.93 ± 1.7	0.244	3.33
Parvocalanus crassirostris (Dahl) 1893	I	473.19 ± 708.37	29.379	3.33
Pseudodiaptomidae				
Pseudodiaptomus annandalei Sewell 1919	I	15.93 ± 17.04	0.989	3.33
Pseudodiaptomus serricaudatus (Scott T) 1894	I	365.22 ± 622.25	22.676	3.33
Temoridae				
Temora turbinata (Dana) 1849	I	93.1 ± 128.56	3.854	2.22
Cyclopoida				
Cyclopidae				
Acanthocyclops sp.	H	0.75 ± 1.06	0.031	1.11
Apocyclops borneoensis Lindberg 1954	A, B, H, I	36.81 ± 47.42	4.570	6.67
Cyclops sp.	A, H, I	30.79 ± 31.81	1.912	3.33
Eucyclops sp.	F, I	6.4 ± 7.38	0.265	2.22
Mesocyclops pehpeiensis Hu 1943	G, I	6.06 ± 2.12	0.251	2.22
Mesocyclops sp.	G, H, I	0.97 ± 0.82	0.060	3.33
Microcyclops sp.	A, B, H, I	6.63 ± 7.94	0.549	4.44
Thermocyclops kawamurai Kikuchi 1940	H, I	380.91 ± 514.96	15.766	2.22
Cyclopinidae				
Cyclopina sp.	I	56.98 ± 68.13	2.358	2.22
Oithona rigida Giesbrecht 1896	I	116.14 ± 133.15	4.807	2.22
Oithona similis Claus 1866	I	13.14	0.272	1.11
Harpacticoida				
Euterpinidae				
Euterpina acutifrons (Dana) 1847	I	289.15	5.984	1.11
Poecilostomatoida				
Corycaeidae				
Corycaeus (*Ditrichocorycaeus*) *erythraeus* Cleve 1901	I	13.14	0.272	1.11
Corycaeus (*D.*) *subtilis* M. Dahl 1912	H, I	20.38 ± 5.07	0.844	2.22
Corycaeus (*Farranula*) *concinna* (Dana) 1847	H	0.78	0.016	1.11
Corycaeus (*F.*) *gibbula* Giesbrecht 1891	I	2.2	0.046	1.11
Total		53.69 ± 367.2	100.0	

sp., *Eucyclops* sp., *Mesocyclops* sp., *Mesocyclops peheiensis*, *Microcyclops* sp., and *Thermocyclops kawamurai*.

The highest abundance (3410.05 ind./m^3) was recorded in Aug. 2004, followed by 745.04 ind./m^3 in Feb. 2005, and the 3rd highest record was 193.50 ind./m^3 in June 2004 at the estuarine station. Only the estuarine station showed significant differences in copepod abundances during the sampling period. Copepod abundances were < 5.0 ind./m^3 at all freshwater stations (Fig. 3A). The number of species at the 9 sampling

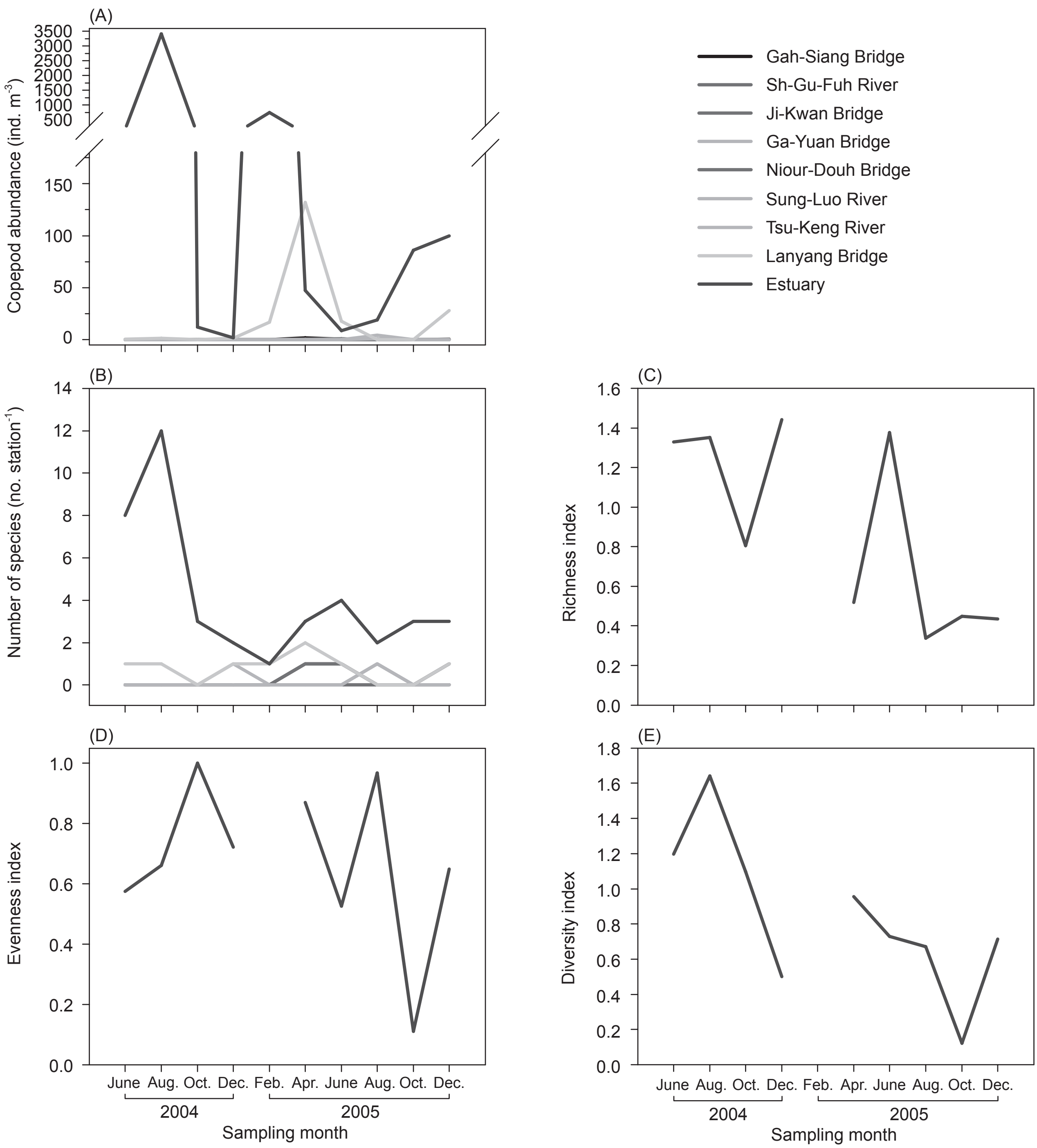

Fig. 3. Total copepod abundance (A), number of species (B), indices of richness (C), evenness (D), and Shannon-Wiener diversity (E) of each sampling month at each sampling station.

stations ranged 0-12/station. The highest species number (of 12 species/station) was recorded at the estuarine station in Aug. 2004 (Fig. 3B). The record of identified species was < 2 at the LY Bridge station. In the remaining 8 stations of the freshwater zone, the number of identified species ranged 0-1/station during the sampling period (Fig. 3B). The indices of richness (Fig. 3C), evenness (Fig. 3D), and diversity (Fig. 3E) showed high variations at the estuarine station. Indices could not be calculated at the remaining 8 sampling stations due to species numbers being < 2.

Temporal and spatial variations in the copepod community structure

As for seasonal differences, the highest record of average copepod abundances (379.06 ind./m^3) was in Aug. 2004, and the 2nd highest record was 84.65 ind./m^3 in Feb. 2005. The remaining sampling months showed values of < 25 ind./m^3 (Fig. 4A). The highest species number (13) was also recorded in Aug. 2004 (Fig. 4B), whereas the lowest record of 1 was in Feb. 2005. Most sampling months presented

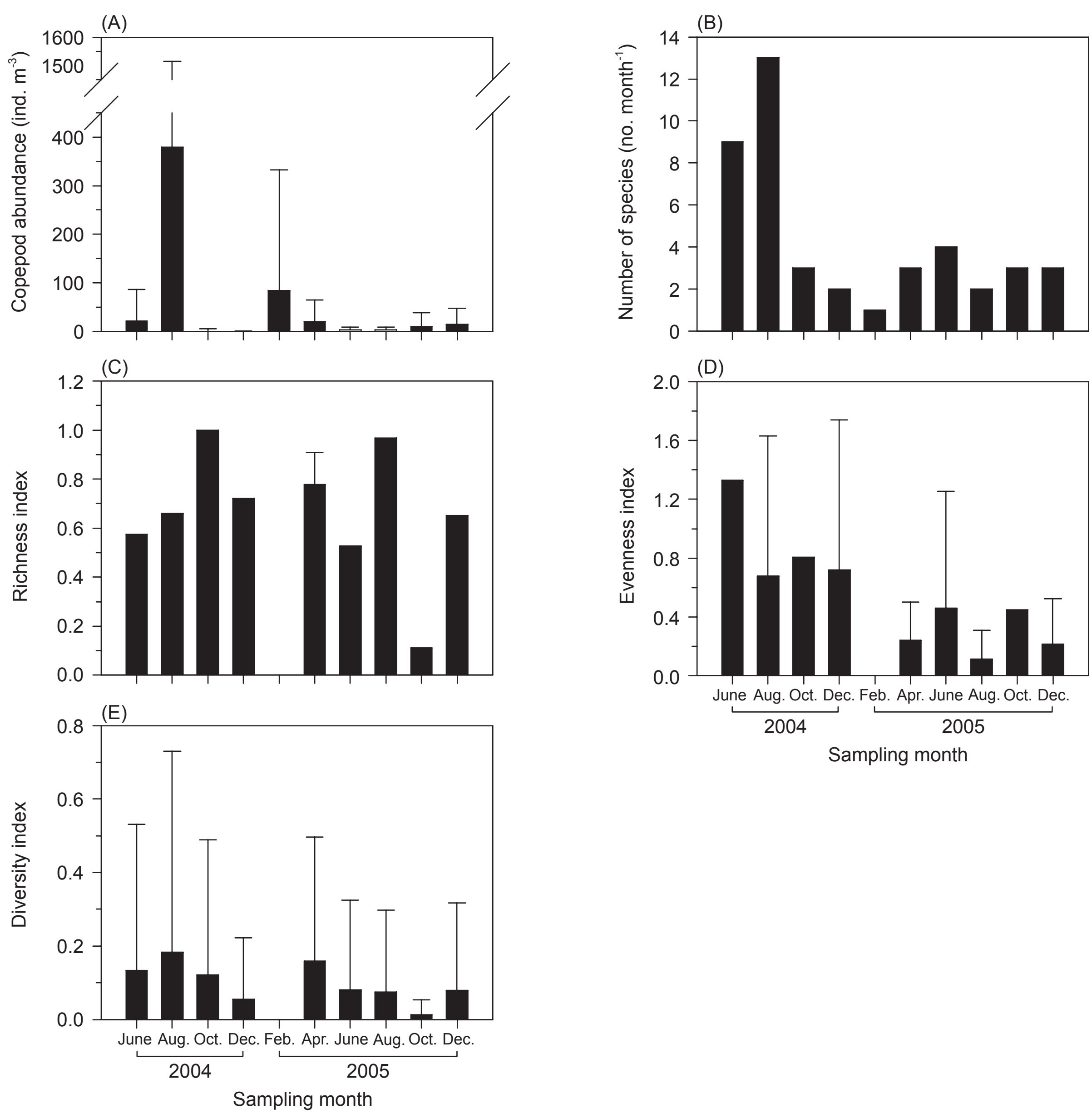

Fig. 4. Average copepod abundance (A), total copepod species number (B), indices of richness (C), evenness (D) and Shannon-Wiener diversity (E) in each sampling month.

communities with < 4 species. Indices of richness (Fig. 4C), evenness (Fig. 4D), and diversity (Fig. 4E) showed some temporal variability without a clear trend. There were no significant differences in abundance, species number, or indices of richness, evenness, and diversity of copepods among sampling months (Fig. 4, $p > 0.05$, one-way ANOVA).

When stations were compared, the highest mean abundance (462.40 ind./m^3, Fig. 5A) was found at the estuarine station. Accumulated records of copepod species provided the highest species numbers (26 species/station, Fig. 5B) at the estuarine station. The 7 upstream stations (GS Bridge, SGF River, JK Bridge, GY Bridge, ND Bridge, SL River, and TK River) showed lower values of abundance, species number, and richness, evenness, and diversity indices than the downstream stations (LY Bridge and estuarine stations) throughout the year (Fig. 5A-E).

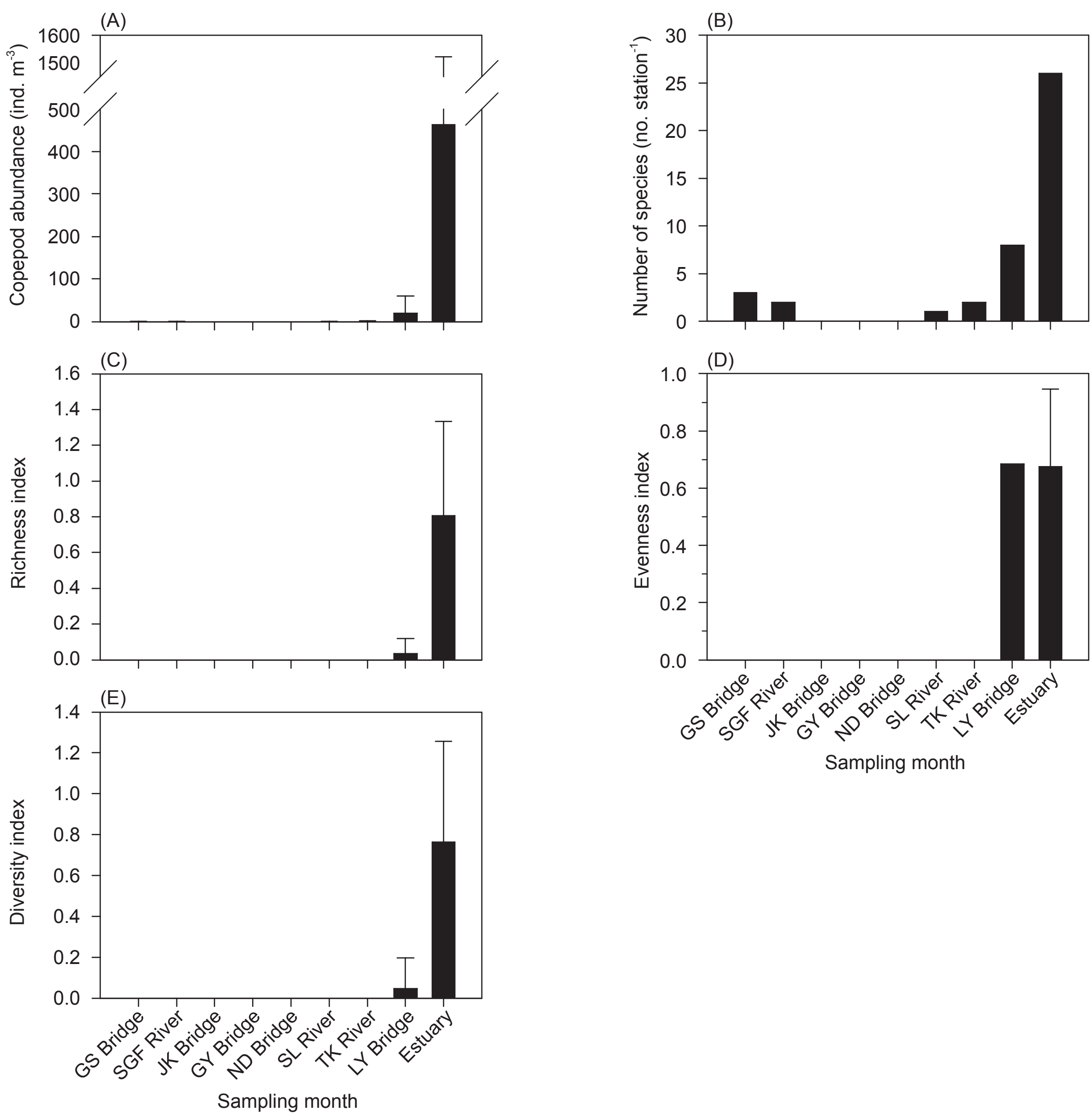

Fig. 5. Average copepod abundance (A), total copepod species number (B), indices of richness (C), evenness (D) and Shannon-Wiener diversity (E) at each sampling station.

Copepod community structure

A cluster analysis using Bray-Curtis similarities of taxonomic abundances provided 3 groups of stations: IB (SL River), IIB (TK River), IIIA (estuarine station and LY Bridge), and IIIB (SGF River and GS Bridge) (Fig. 6). Accumulations of major 75% copepods in each group according to Bray-Curtis similarity cluster results are given in table 3. The grouping results allocated downstream and upstream stations to different groups. The TK River and SL River stations were separated in single groups due to the appearance of rare species and low copepod abundances. In the upstream area of the Lanyang River, *Apocyclops borneoensis* and *Microcyclops* sp. were major species at the SGF River and GS Bridge stations. The dominant species at the SL River and TK River stations were *Eucyclops* sp. and *Mesocyclops peheiensis*, respectively. The cluster results indicated that copepod communities were affected by intruding seawater at the estuarine and LY Bridge stations (Table 3). Thus, copepod communities clearly differed in the upper, middle, and downstream areas.

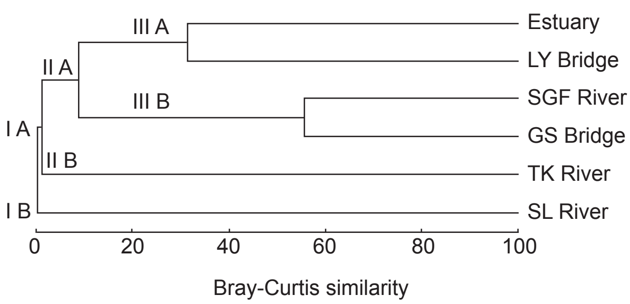

Fig. 6. Cluster analysis of Bray-Curtis similarities. Stations fell into 3 groups: IB (SL River), IIB (TK River), IIIA (estuarine station and LY Bridge), and IIIB (SGF River and GS Bridge).

Estuarine station: relationships of copepod abundance and species number with environmental factors

We found 2 peculiarities of copepod assemblages in the Lanyang River. First, there was a low abundance and low diversity in the freshwater zone. Second, seawater intrusions transported oceanic copepods to the estuarine area which raised the abundance and diversity of the copepod communities. Only the estuary station was significantly affected by seawater. Based on these results, we focused on data of the estuarine station to reveal the effects of intruding seawater (Fig. 7). The highest abundance (3410.05 ind./m^3) and species number (12 species/station) (Fig. 7A) corresponded to the highest measured salinity (37.0 psu) in the estuary (Fig. 7C). Pearson's product moment correlation analysis confirmed the positive correlation of copepod abundances with salinity (r = 0.880, p = 0.001) (Table 4). The species number was significantly positive correlated with Chl *a* (r = 0.790, p = 0.007), salinity (r = 0.780, p = 0.008), and copepod abundance (r = 0.785, p = 0.007). These results indicated that copepod assemblages at the estuarine station were strongly affected by intruding seawater which changed the hydrography and biota.

Table 3. Accumulated of major 75% copepods in each group according to the Bray-Curtis similarity cluster results

Copepod species	Group			
	IB	IIB	IIIA	IIIB
Acartia erythraea			6.70	
Apocyclops borneoensis				47.30
Eucyclops sp.	100.00			
Euterpina acutifrons			10.53	
Mesocyclops peheiensis		98.99		
Microcyclops sp.				41.21
Pavocalanus crassirostris			17.22	
Pseudodiaptomus serricaudatus			13.29	
Thermocyclops kawamurai			27.73	
Cumulative contribution (%)	100.00	98.99	75.47	88.50

DISCUSSION

Progress in understanding environmental conditions that control the distribution and abundance of riverine zooplankton and their ecological significance has lagged far behind that of lentic environments (Casper and Thorp 2007). Hydrologically dynamic rivers commonly show diverse rotifer assemblages, whereas microcrustaceans are almost always absent (Richardson 1992, Sluss et al. 2008). This is in contrast to lakes where copepods and large cladocerans most frequently dominate the system, with relative abundances often influenced by biotic (e.g., chaoborid dipteran and fish predation) and abiotic factors (e.g., inorganic turbidity)

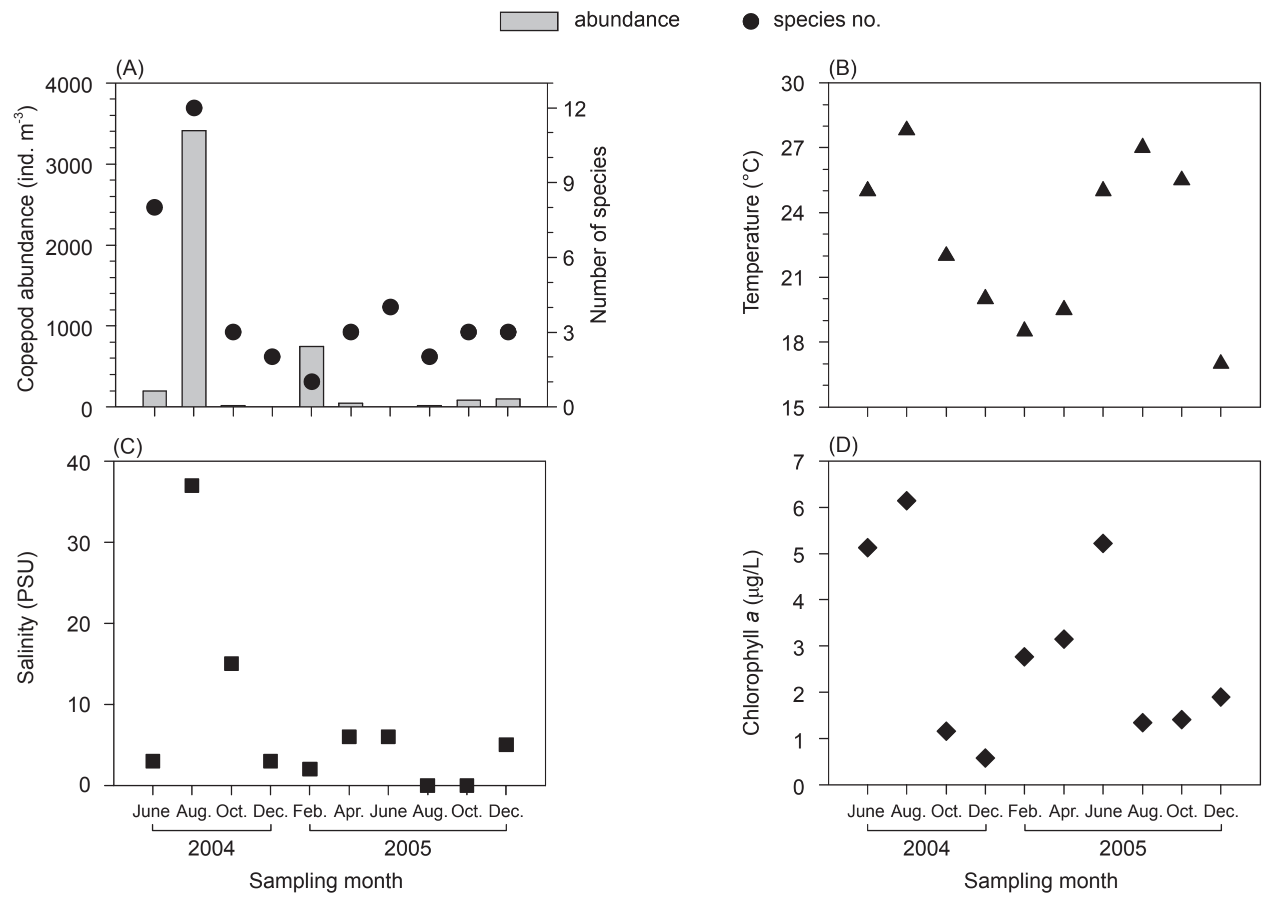

Fig. 7. Variations in copepod abundances and number of species (A), temperature (B), salinity (C), and chlorophyll *a* (D) of the estuary station in each sampling month.

Table 4. Correlation between water temperature, chlorophyll *a*, salinity, copepod abundance and species number at the estuary station during June 2004 to Dec. 2005

	Pearson correlation			
	Temperature	Chlorophyll *a*	Salinity	Abundance
Chlorophyll *a*	0.429			
Salinity	0.346	0.531		
Abundance	0.390	0.596	0.880 **	
Species number	0.575	0.790 **	0.780 **	0.785 **

** Correlation is significant at the 0.01 level (2-tailed).

(Wetzel 2001). Slack waters are suggested to be critical for sustaining a high biomass and diversity of zooplankton (Thorp and Casper 2003). Where those are lacking, and the river channel is steep and presents a high current velocity, the zooplankton is affected by turbulence and commonly shows low biomass (Sluss et al. 2008). This may also hold for the Lanyang River, particularly the 3 stations (JK Bridge, GY Bridge, and ND Bridge) in the midstream section where we found no copepods in any sampling period.

A study by Hsu et al. (2004) further explored the positive relationship between observed sediment fluxes and runoff in the Lanyang River which may also have ultimately affected the zooplankton communities and caused the lack of copepods at these stations. According to those authors, the annual sediment discharge and sediment yield of the Lanyang River are 8.0 Mt and 8154 Mt/km^2, respectively. The annual runoff is 2773 × 10^6 m^3, and transient runoff always rises sharply from the baseline level of several tens of m^3/s (with a mean rate of 62 m^3/s) to an abnormal level of thousands of m^3/s after a heavy rainfall (with an average annual rainfall of 3256 mm). Since 1949, the maximal records of daily runoff and suspended sediment concentration are 4580 m^3/s and 118 g/L, respectively (Water Resources Bureau 1997a b). Sediment discharges depend on river runoff, and a function relating the 2 parameters was established (Kao 1996).

According to Sluss et al. (2008), it is uncertain which abiotic factors control both the relative abundance of major groups and the relative size of the zooplankton community of rivers. Biological factors were addressed relatively rarely, but field surveys and *in situ* experiments suggest that competition and predation play roles in regulating river plankton at least in slack waters (Casper and Thorp 2007).

Our study demonstrated that marine zooplankton substantially contributed to the estuarine section of the Lanyang ecosystem. Here, the highest abundance (3410.05 ind./m^3) and species number (12 species/station) corresponded with the highest salinity (37.0 psu), demonstrating the marine role in shaping and maintaining the estuarine planktonic community. As mentioned, the zooplankton abundance of the Lanyang River estuarine station was significantly affected by seawater intrusions, and the number of zooplankton groups was affected by water temperature (as affected by the seasonal monsoon; see Hsieh et al. 2011). Hence, the marine compartment may determine the dynamics of the zooplankton communities in the estuary of the Lanyang River (Tan et al. 2004). The estuary of the Lanyang River is next to nearshore waters off the northeastern coast of Taiwan. Hwang et al. (1998) found that copepods represented the dominant zooplankton group along the northern coast of Taiwan.

River flow and tidal motions respectively drive the riverine and marine communities towards estuaries (Hsieh and Chiu 1997, Waniek et al. 2005, Zhang et al. 2010) and hence shape the diversity and density of estuarine communities (Waniek 2003, Froneman 2004). However, there is the possibility that resident dormant stages contribute to estuarine populations as well, once they emerge from their sedimentary depositions (Dahms and Qian 2004, Dahms et al. 2006). The biology and mesozooplankton including copepod assemblages of the East China Sea and Kuroshio Current are little known (Hsiao et al. 2004 2011), even though there was an interdisciplinary study of the Kuroshio Current (Marr 1970) and several oceanographic research programs, such as KEEP (Kuroshio-East China Sea Exchange Process) in the last decade by several research institutions and universities in Taiwan (Liu 1997, Hwang et al. 2006). In conclusion, copepod upstream assemblages were characterized by low abundances and low species diversities, whereas the estuarine station showed a high abundance and a high number of species which were correlated with intruding seawater.

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