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Seasonal Succession of Planktonic Copepods in Bight Environments of Northeastern Taiwan

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Chi Chou, Li-Chun Tseng, Ching-Hsiewn Ou, Qing-Chao Chen, and Jiang-Shiou Hwang (2012) Seasonal succession of planktonic copepods in bight environments of northeastern Taiwan. *Zoological Studies* **51**(8): 1380-1396. The seasonality and parameters of ocean waters have a significant influence on planktonic copepod species richness and diversity in various marine environments near and surrounding Taiwan. We conducted 6 sampling cruises in the bights of Shen-Aou Bay and Fan-Zai-Aou Bay to investigate seasonal variations in copepod communities in northeastern Taiwan from Oct. 2007 to Jan. 2009. The sample included 76 species of copepods belonging to 4 orders, 22 families, and 36 genera identified in these 2 bays in northeastern Taiwan. The most abundant species were *Temora turbinata* (with a relative abundance (RA) of 29.34%), *Paracalanus parvus* (of 21.98%), *Canthocalanus pauper* (of 7.86%), *Calanus sinicus* (of 4.00%), and *Acrocalanus gracilis* (of 3.93%). A cluster analysis showed that the copepod communities of northeastern Taiwan fluctuated with season during the study period. *Calanus sinicus* showed a significant negative correlation with seawater temperature (r = -0.434, p = 0.008) and was abundant during the period when the China Coastal Current intruded into northeastern Taiwan, indicating that it is a temperate species. In contrast, the abundances of 7 copepod species (*Acr. monachus*, *T. discaudata*, *Macrosetella gracilis*, *Corycaeus* (*Corycaeus*) *speciosus*, *Cor.* (*Farranula*) *concinna*, *Oncaea media*, and *Copilia mirabilis*) showed significant positive correlations with seawater temperature, indicating that they are subtropical and tropical species. Copepod species, the community structure, and assemblages were distinguished by seasonality based on seawater temperature. Results suggest that the planktonic copepod communities in these 2 bays of northeastern Taiwan are primarily influenced by water temperatures, with seasonal succession determined by ingress of the China Coastal Current and Kuroshio Branch Current. http://zoolstud.sinica.edu.tw/Journals/51.8/1380.pdf

Key words: Copepod, Habitat diversity, East China Sea, China Coastal Current, Kuroshio Branch Current.

Taiwan is located in the western North Pacific Ocean and is surrounded by complex water systems (Jan et al. 2002, Liang et al. 2003, Hsiao et al. 2011a 2011b, Hwang and Martens 2011, López-López et al. 2012). The Taiwan Strait is a shallow channel between the west coast of Taiwan and China; to the north, the East China Sea (ECS) connects to Japan and Korea. In southern Taiwan, the Luzon Strait connects to the Philippines and the South China Sea (SCS), and to the east is the Pacific Ocean. The marine fauna around Taiwan is highly diversified, and Shao (1998) and Hwang et al. (2006) estimated that the main group of marine species around Taiwan account for up to 10% of the world's total records.

The zooplankton communities surrounding Taiwan are heavily influenced by various environmental factors, including the characteristics of water masses (Huang 1983, Hwang et al. 2004b 2006 2010b, Dur et al. 2007, Tseng et al. 2008b

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*To whom correspondence and reprint requests should be addressed. Tel: 886-935289642. Fax: 886-2-24629464. E-mail:jshwang@mail.ntou.edu.tw c e 2011b c 2012 2013, Lan et al. 2009, Hwang and Martens 2011), and monsoons (Hwang et al. 2004b 2006 2010b, Dur et al. 2007, Tseng et al. 2008c, Chang et al. 2010, Hwang and Martens 2011, Dahms et al. 2012). Northern Taiwan has a typical subtropical climate, with a northeasterly (NE) monsoon period during winter and spring (Sept. to Mar.) and a southwesterly (SW) monsoon period during summer and autumn (Apr. to Aug.). The China Coastal Current (CCC) brings cold water masses from the Bohai Sea and Yellow Sea to northern Taiwan during the NE monsoon period. Two warm water masses flow to northern Taiwan during the SW monsoon period: the Kuroshio Current (KC) in eastern Taiwan (Chu 1974, Hsiao et al. 2011a, Kâ and Hwang 2011) and the Taiwan Strait Current in western Taiwan (Jan et al. 2002). These complex conditions create diverse habitats and provide various environments for marine biota. Zooplankton play important roles in energy transfer from lower to upper trophic levels (Nybakken 1993, Hwang et al. 2004a, Hwang and Martens 2011, Sanoamuang and Hwang 2011). Among zooplankton, copepods are the dominant assemblage in marine ecosystems worldwide (Zheng and Li 1989, Uye et al. 1996, Hwang et al. 2004a, Tseng et al. 2008b 2011b 2012, Hwang and Martens 2011, Sanoamuang and Hwang 2011). Thus, feeding patterns and fecal pellets of copepods are important factors in the carbon flux of marine environments (Hwang et al. 1998 2004a, Tseng et al. 2008d 2009, Patonai et al. 2011, Hwang and Martens 2011). The distribution and abundance of food items and how copepods obtain their prey have been major topics in copepod research. Because of their sensitivity to water conditions such as food supply, water temperature, and salinity, some copepod species have long been employed as indicators of different water masses (Hwang and Wong 2005, Dur et al. 2007, Tseng et al. 2008c 2011c).

Over the past 2 decades, researchers have investigated the influences of copepod seasonality and monsoon seasons on various Taiwanese waters: the ECS (Shih and Chiu 1998, Lan et al. 2004, Hwang and Wong 2005, Hwang et al. 1998 2006 2009, Tseng et al. 2008f 2011b c), Taiwan Strait (Lo et al. 2004a, Tseng et al. 2008b c d, Lan et al. 2009), SCS (Hwang et al. 2007 2010a, Tseng et al. 2008a 2011a, Chang et al. 2010), and KC (Hsiao et al. 2004 2011a, Kâ and Hwang 2011). Shih and Young (1995) reviewed copepod species in and around Taiwanese waters and found a high number of approximately 325 species. Previous studies on this topic were conducted in upwelling areas (Lo et al. 2004b), estuarine areas (Hwang et al. 2006 2009, Dur et al. 2007, Dahms et al. 2012), coastal areas (Hwang et al. 1998, Lo et al. 2004a, Tseng et al. 2008c 2011c), areas adjacent to nuclear power plants (NPPs; Hwang et al. 2004b, Tseng et al. 2011c), outfall areas (Tseng et al. 2008b), harbors (Chien 2003, Chang and Fang 2004), embayment environments (Chang et al. 2010), hydrothermal vents (Kâ and Hwang 2011), and lagoons (Hsu et al. 2008). However, relatively few studies have investigated copepod communities in bay environments around Taiwan.

In this study, we (1) investigated how interactions of waters between the CCC and KC influence the abundance and composition of copepod communities in bight environments of northeastern Taiwanese waters; (2) show copepod community succession between different seasons, and (3) identify indicator species for environmental monitoring of coastal areas of northeastern Taiwan.

MATERIALS AND METHODS

Study area

Six sampling stations were established to investigate the seasonal succession of copepod abundances and the community composition in bight environments. Stations included 1 in Shen-Aou Bay and 5 stations in Fan-Zai-Aou Bay of northeastern Taiwanese coastal waters located around the southern edge of the ECS in the vicinity of Keelung City, at 25°07'-25°09'N and 121°48'-121°50'E (Table 1, Fig. 1).

Field sampling

Samples were collected from Oct. 2007 to Mar. 2009. At all stations, copepod samples were collected using surface net tows (at 0-5 m) with a standard North Pacific zooplankton net (i.e., with a mouth diameter of 45 cm and mesh size of 333 μm; Kaohsiung City, Taiwan), with a Hydrobios flow meter (HydroBios, Germany) mounted at the center of the net opening. Samples were immediately preserved in 5% buffered seawater formaldehyde on board. Salinity and temperature were measured prior to towing the plankton net.

Identification and measurement of zooplankton

In the laboratory, samples were split using a Folsom splitter until the subsample contained approximately 500 specimens. Adult copepods were sorted and identified to the species level using keys of Chen and Zhang (1965), Chen et al. (1974), and Chihara and Murano (1997). The number of individuals (ind.) in each major copepod group was recorded (as ind./m^3).

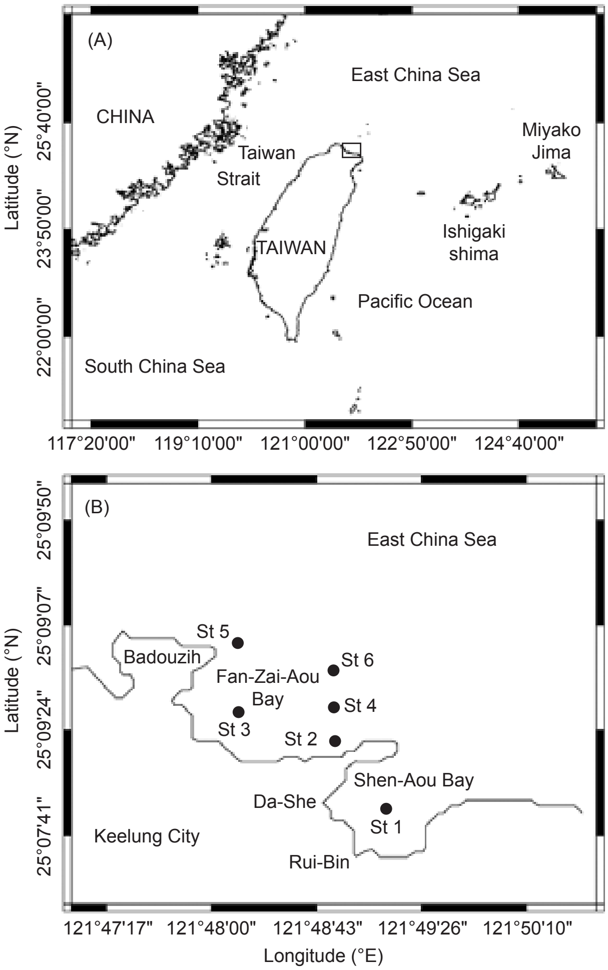

Fig. 1. Map of the study area (A) and location of sampling stations (B) in bays of northeastern Taiwan during the period from Oct. 2007 to Jan. 2009.

Table 1. Sampling stations and their locations in Shen-Aou and Fan-Zai-Aou Bay of northeastern Taiwan

Station	Latitude (°N)	Longitude (°E)
St 1	25°7.44'	121°49.18'
St 2	25°8.15'	121°49.27'
St 3	25°8.70'	121°48.45'
St 4	25°8.14'	121°49.33'
St 5	25°8.43'	121°48.24'
St 6	25°8.22'	121°49.30'

Statistical analyses

We used a Bray-Curtis cluster analysis to evaluate similarity patterns of copepod distributions at both temporal and spatial scales. In total, 23 dominant copepod species among all 36 samples with a relative abundance exceeding 0.5% (comprising 92.76% of all copepods) were used in the analyses. The significance level of the difference between copepod assemblages was determined using the similarity analysis program of the Plymouth Routine In Multivariate Ecological Research (PRIMER, vers. IV; Clarke and Warwick 1994) software package. The functional test of Box and Cox (1964) was used to avoid bias in calculating abundances of copepod species. All data on copepod abundances were transformed before the similarity analysis. The value (λ) of power transformation was 0.82, and therefore $\log(x + 1)$ was applied to logarithmically transform individual densities of all samples.

Copepod species in each cluster were further identified using the indicator value index (IndVal) proposed by Dufrêne and Legendre (1997). This index is obtained by multiplying the product of 2 independently computed values by 100:

$$IndVal(j, s) = 100SP(j, s)FI(j, s); \ldots\ldots\ldots\ldots\ldots\ (1)$$

where $SP(j, s)$ is the specificity and $FI(j, s)$ is the fidelity of a species (s) toward a group of samples (j). These values were calculated by

$$SP(j, s) = \frac{NI(j, s)}{\Sigma NI(s)} \text{ and } FI(j, s) = \frac{NS(j, s)}{\Sigma NS(s)}; \ldots\ (2)$$

where $NI(j, s)$ is the mean abundance of species s across samples pertaining to j, $\Sigma NI(s)$ is the sum of the mean abundances of species s within the various groups in the partition, $NS(j, s)$ is the number of samples in j in which species s is present, and $\Sigma NS(s)$ is the total number of samples in that group. The specificity of a species for a group is greatest for a species found only in a particular group, whereas the fidelity of a species to a group is greatest if the species is present in all groups considered. This study calculated IndVal indices based on a selection of only those $SP(j, s)$ values that exceeded 5% in each cluster. To compare copepod assemblages throughout the sampling period, an analysis of indicator species was applied to each sampling cruise.

The Shannon-Wiener diversity index was used to check the species diversity, and Pielou's evenness index was used to measure the relative abundance of species at each station. The abundance data of 6 different cruises were treated as replicates for the temporal analyses. This study adopted one- and two-way analyses of variance (ANOVAs) with Tukey's post-hoc honest significant difference (HSD) test to identify differences in copepod abundances among seasons and stations. Pearson's product moment correlation was used to estimate relationships of copepod abundance with temperature and salinity.

RESULTS

Weather and the hydrologic structure

We used sea surface temperature (SST) satellite images (obtained from National Oceanic and Atmospheric Administration, NOAA) taken between Jan. and Dec. of 2008 to show interactions of various water masses in and around the study area (Fig. 2). Cold water masses of the CCC affected the study area from early Sept. to Apr. during periods when the NE monsoon prevailed. Warm water masses of the KC intruded into the study area from the northeastern part of Taiwan and the warm waters of the Taiwan Strait Current intruded from the northwestern part of Taiwan during periods when the SW monsoon prevailed.

Figure 3 shows average seawater temperatures (Fig. 3A) and salinities (Fig. 3B) during each sampling period. Temperature variations show a clear seasonal shift, with lower seawater temperatures recorded from Oct. to Feb., and increasing temperatures from Apr. until a peak in July. During the sampling periods, the lowest seawater temperature was recorded in Feb. 2009 (17.70 ± 0.13°C) (mean ± standard error), whereas the highest was recorded in July 2008 (28.64 ± 0.14°C) (Fig. 3A). Salinity was stable because there was no stream or river discharge at the sampling sites. Average salinity values ranged from 33.72 ± 0.60 (Oct. 2007) to 35.87 ± 0.29 (Jan. 2008) (Fig. 3B). Based on a temperature-salinity (T-S) plot of the CCC and KC water masses, relationships of seawater temperature with salinity during the 6 sampling cruises showed that dynamic environments existed at the study sites (Fig. 3C). Reference sources for the CCC and KC water properties were obtained during the cruise of *Ocean Research Vessel I*, CR-618. The T-S plot shows characteristics of water masses in both the estuary of the Yangtze River (30°30'N; 123°10'E) and the KC area (25°10'N; 123°10'E) in summer (Fig. 3C). From Jan. 2008 to Feb. 2009, lower seawater temperatures and salinities were recorded because the CCC brought cold water from the coastal area of northern China into the study area. In contrast, seawater characteristics

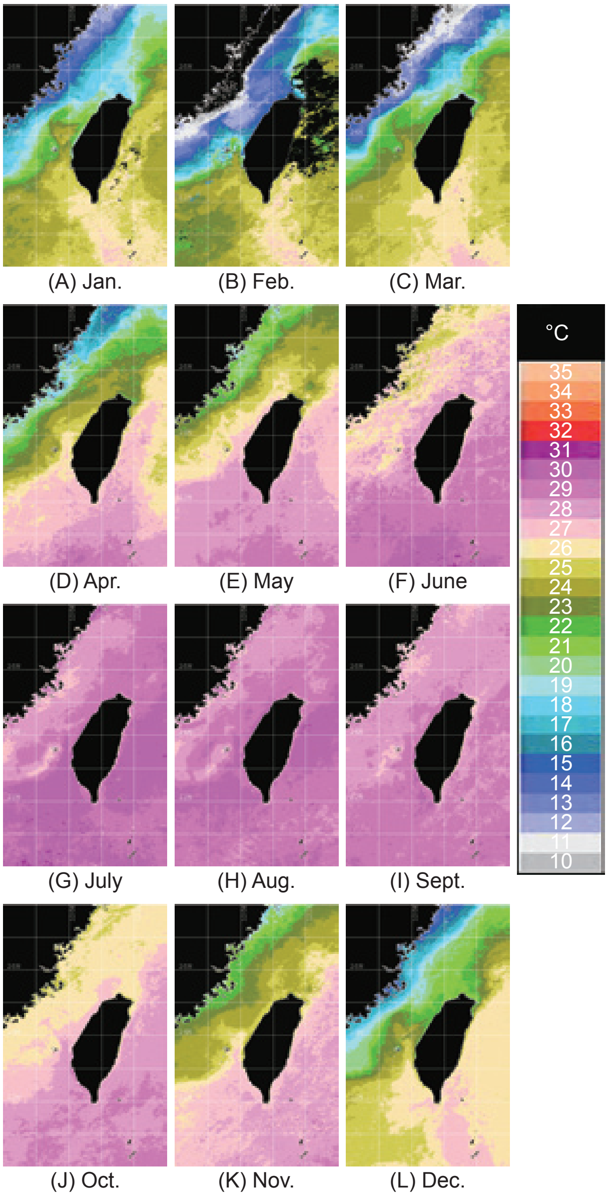
(A) Jan. (B) Feb. (C) Mar.
(D) Apr. (E) May (F) June
(G) July (H) Aug. (I) Sept.
(J) Oct. (K) Nov. (L) Dec.

Fig. 2. Satellite images of monthly-averaged information derived from AVHRR for sea surface temperatures (SSTs). Images were selected from Jan. (A) to Dec. (L) of 2008.

of the study area in July 2008 showed that the main KC had higher temperatures and salinities. The properties of the water masses during Oct. 2007 and Apr. 2008 were comparable to those of the KC with lower temperatures. In Oct. 2008, the water masses surrounding northern Taiwan were characterized by mixed properties of the CCC and KC (Fig. 3C).

Copepod community structure

We analyzed 36 samples taken on 6 research cruises in 2 bights of northeastern Taiwan from Oct. 2007 to Feb. 2009. The samples included 78 copepod species (including 2 species only identified to the genus level) belonging to 4 orders, 22 families, and 36 genera (Table 2). Figure 4 shows time series values of the average (mean

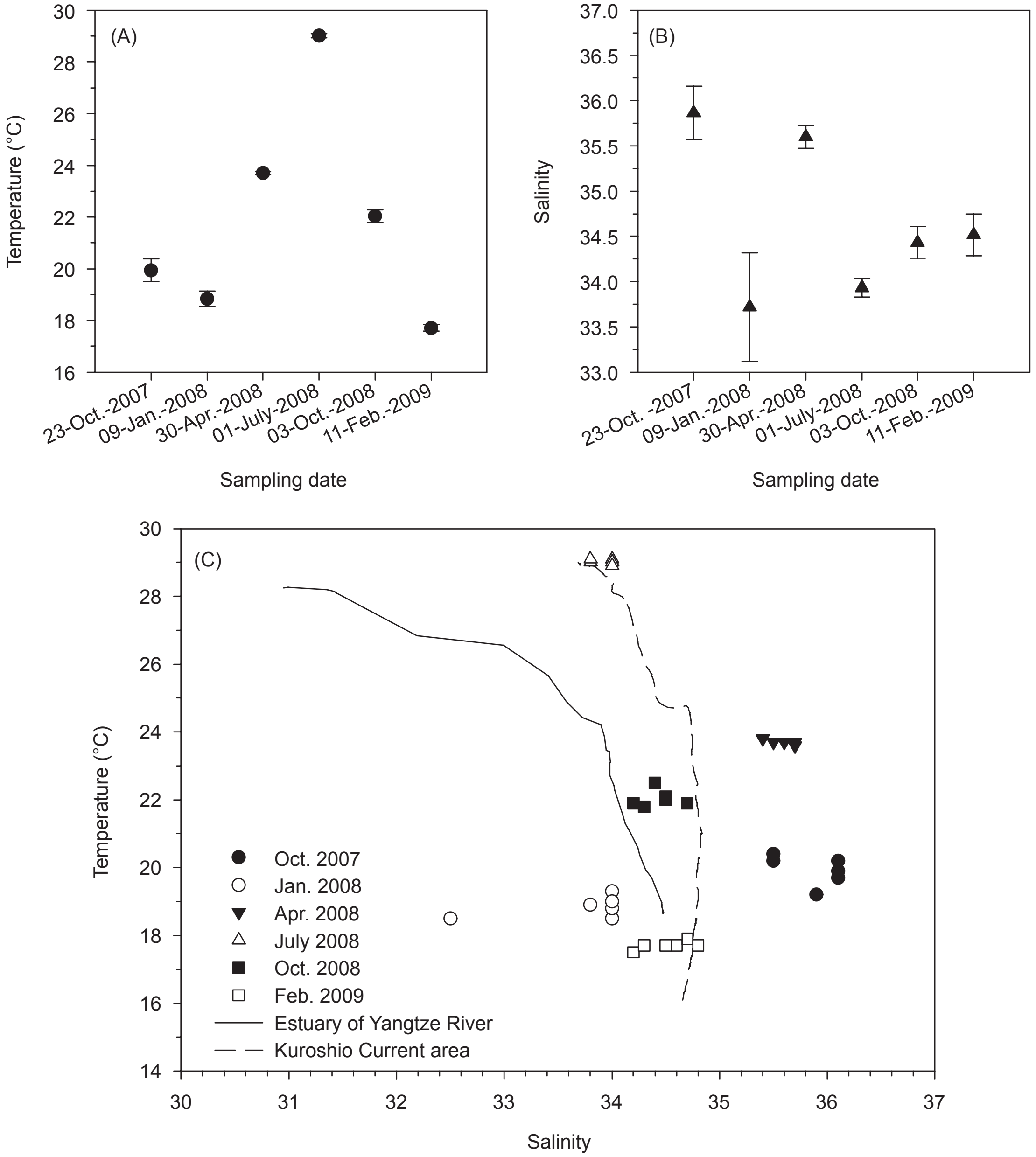

Fig. 3. Average temperature (A) and salinity (B) during each sampling cruise. The temperature vs. salinity (T-S) diagram shows the distribution of averaged values of 6 cruises during the study period. Two T-S curves of the estuary of the Yangtze River (30°30'N; 122°52'E) and the Kuroshio Current area (25°10'N; 123°10'E) were recorded from cruise OR1 618 on 15-29 July 2001 (C).

Table 2. Average density (individuals/m^3), number of species identified (number/sample), indices of Shannon-Wiener diversity, species richness and Pielou's evenness, total filtered water volume, relative abundance (RA, %), and occurrence ratio (OR, %) recorded from each cruise for all samples. Copepod species in boldface indicate that their abundances had RA values exceeding 0.5%, and these were used for the Bray-Curtis cluster analysis

	Sampling time						All samples		
	Oct. 2007	Jan. 2008	Apr. 2008	July 2008	Oct. 2008	Feb. 2009	Total	RA (%)	OR (%)
Copepod density (mean ± standard deviation)	322.63 ± 383.24	59.35 ± 17.48	67.6 ± 103.64	133.09 ± 124.08	76.08 ± 34.06	81.09 ± 39.73	123.31 ± 184.12		
Number of species identified	21.00 ± 2.53	16 .00 ± 2.19	16.33 ± 3.56	18.17 ± 5.19	17.17 ± 2.71	25.17 ± 6.52	18.97 ± 5.01		
Shannon-Wiener diversity index	2.12 ± 0.38	1.42 ± 0.47	1.81 ± 0.61	2.25 ± 0.78	2.08 ± 0.68	2.33 ± 0.52	2.00 ± 0.63		
Species richness index	4.08 ± 0.96	3.73 ± 0.67	4.51 ± 1.32	3.96 ± 1.46	3.84 ± 0.65	5.63 ± 1.39	4.29 ± 1.23		
Pielou's evenness index	0.69 ± 0.1	0.51 ± 0.15	0.65 ± 0.21	0.77 ± 0.22	0.73 ± 0.23	0.72 ± 0.12	0.68 ± 0.19		
Total filtered water volume (m^3)	178.69	376.74	192.04	94.14	177.49	250.21	1269.31		
Scientific classification									
Order Calanoida									
ACARTIIDAE									
***Acartia* (*Plantacartia*) *negligens* Dana 1849**	**1.65**	**0.06**	**0.53**	**1.23**	**2.45**	**0.44**	**1.06 ± 2.12**	**0.86**	**50.00**
AETIDEIDAE									
Aetideus giesbrechti Cleve 1904	-	-	-	0.20	-	-	0.03 ± 0.2	0.03	2.78
CALANIDAE									
***Calanus sinicus* Brodsky 1965**	**1.04**	-	**0.12**	**0.20**	-	**28.27**	**4.94 ± 12.35**	**4.00**	**25.00**
***Canthocalanus pauper* (Giesbrecht) 1888**	**14.42**	**0.75**	**0.58**	**35.32**	**3.44**	**3.64**	**9.69 ± 33.95**	**7.86**	**86.11**
***Cosmocalanus darwini* (Lubbock) 1860**	**0.20**	**0.49**	**-**	**2.27**	**0.31**	**2.78**	**1.01 ± 2.2**	**0.82**	**38.89**
Mesocalanus tenuicornis (Dana) 1863	-	-	-	-	-	0.17	0.03 ± 0.12	0.02	5.56
Nannocalanus minor (Claus) 1863	-	-	-	-	-	0.16	0.03 ± 0.16	0.02	2.78
***Undinula vulgaris* (Dana) 1849**	**6.70**	**0.07**	**0.21**	**2.88**	**1.33**	**0.26**	**1.91 ± 4.64**	**1.55**	**61.11**
CALOCALANIDAE									
Calocalanus pavo (Dana) 1849	1.51	-	0.06	1.39	-	-	0.49 ± 1.66	0.40	16.67
Calocalanus plumulosus (Claus) 1863	-	-	-	-	0.09	0.09	0.03 ± 0.12	0.02	5.56
CANDACIIDAE									
Candacia bradyi A. Scott 1902	-	-	-	-	0.12	0.05	0.03 ± 0.13	0.02	5.56
Candacia ethiopica (Dana) 1849	0.34	-	-	-	-	-	0.06 ± 0.24	0.05	5.56
Candacia pachydactyla (Dana) 1849	-	-	-	-	-	0.10	0.02 ± 0.1	0.01	2.78
Paracandacia truncata (Dana) 1849	-	0.34	-	0.20	-	-	0.09 ± 0.24	0.07	16.67
CENTROPAGIDAE									
Centropages calaninus (Dana) 1849	0.09	-	0.13	-	-	0.13	0.06 ± 0.18	0.05	11.11
Centropages furcatus (Dana) 1849	-	-	-	-	0.23	-	0.04 ± 0.16	0.03	5.56
Centropages gracilis (Dana) 1849	-	-	-	-	0.14	0.08	0.04 ± 0.16	0.03	5.56
Centropages orsini Giesbrecht 1889	0.29	-	0.18	-	-	-	0.08 ± 0.27	0.06	8.33
CLAUSOCALANIDAE									
***Clausocalanus arcuicornis* (Dana) 1849**	**5.36**	-	**0.25**	-	**5.03**	**2.71**	**2.23 ± 4.12**	**1.81**	**44.44**
***Clausocalanus furcatus* (Brady) 1883**	**9.12**	**0.22**	**0.66**	**3.29**	**0.73**	**0.51**	**2.42 ± 4.25**	**1.96**	**72.22**
Clausocalanus mastigophorus (Claus) 1863	1.80	0.28	-	-	-	1.12	0.53 ± 1.85	0.43	19.44
EUCALANIDAE									
Pareucalanus attenuatus (Dana) 1849	-	-	0.09	-	0.28	0.36	0.12 ± 0.34	0.10	16.67
Rhincalanus nasutus Giesbrecht 1888	-	0.07	-	-	-	0.33	0.07 ± 0.26	0.05	8.33
Rhincalanus rostrifrons (Dana) 1852	1.74	0.25	0.05	-	-	0.70	0.46 ± 1.53	0.37	30.56
Subeucalanus crassus (Giesbrecht) 1888	**4.26**	**0.20**	-	-	**0.38**	**0.47**	**0.88 ± 3.14**	**0.72**	**33.33**
***Subeucalanus subcrassus* (Giesbrecht) 1888**	**5.48**	**0.27**	**2.46**	**3.95**	**3.23**	**0.37**	**2.63 ± 3.18**	**2.13**	**83.33**
Subeucalanus subtenuis (Giesbrecht) 1888	-	-	0.12	-	-	0.09	0.03 ± 0.15	0.03	5.56
EUCHAETIDAE									
Euchaeta concinna (Dana) 1849	-	1.18	0.19	-	0.49	0.16	0.34 ± 0.77	0.27	27.78
Euchaeta plana Mori 1937	-	0.27	-	-	-	1.08	0.23 ± 0.75	0.18	19.44
Euchaeta rimana Bradford 1973	-	-	-	-	0.41	-	0.07 ± 0.41	0.06	2.78
Euchaeta sp.	0.11	-	-	-	-	-	0.02 ± 0.11	0.01	2.78
HETERORHABDIDAE									
Heterorhabdus papilliger (Claus) 1863	-	-	-	-	-	0.10	0.02 ± 0.1	0.01	2.78
LUCICUTIIDAE									
Lucicutia flavicornis (Claus) 1863	0.39	0.18	-	-	-	0.39	0.16 ± 0.44	0.13	19.44
METRIDINIDAE									
Pleuromamma gracilis (Claus) 1863	-	0.06	-	-	-	0.13	0.03 ± 0.11	0.03	8.33
PARACALANIDAE									
***Acrocalanus gibber* Giesbrecht 1888**	-	-	-	-	9.57	-	1.6 ± 5.47	1.29	13.89

Table 2. (continued)

	Sampling time						All samples		
	Oct. 2007	Jan. 2008	Apr. 2008	July 2008	Oct. 2008	Feb. 2009	Total	RA (%)	OR (%)
Copepod density (mean ± standard deviation)	322.63 ± 383.24	59.35 ± 17.48	67.6 ± 103.64	133.09 ± 124.08	76.08 ± 34.06	81.09 ± 39.73	123.31 ± 184.12		
Number of species identified	21.00 ± 2.53	16 .00 ± 2.19	16.33 ± 3.56	18.17 ± 5.19	17.17 ± 2.71	25.17 ± 6.52	18.97 ± 5.01		
Shannon-Wiener diversity index	2.12 ± 0.38	1.42 ± 0.47	1.81 ± 0.61	2.25 ± 0.78	2.08 ± 0.68	2.33 ± 0.52	2.00 ± 0.63		
Species richness index	4.08 ± 0.96	3.73 ± 0.67	4.51 ± 1.32	3.96 ± 1.46	3.84 ± 0.65	5.63 ± 1.39	4.29 ± 1.23		
Pielou's evenness index	0.69 ± 0.1	0.51 ± 0.15	0.65 ± 0.21	0.77 ± 0.22	0.73 ± 0.23	0.72 ± 0.12	0.68 ± 0.19		
Total filtered water volume (m^3)	178.69	376.74	192.04	94.14	177.49	250.21	1269.31		
Scientific classification									
***Acrocalanus gracilis* Giesbrecht 1888**	**9.27**	**8.60**	**0.56**	**4.65**	**3.43**	**2.58**	**4.85 ± 8.39**	**3.93**	**91.67**
Acrocalanus monachus Giesbrecht 1888	-	-	0.04	0.51	-	-	0.09 ± 0.38	0.07	8.33
Bestiolina sinica (Shen & Lee) 1966	-	-	-	0.34	-	-	0.06 ± 0.34	0.05	2.78
***Paracalanus nanus* Sars 1907**	**7.09**	-	-	-	**0.34**	-	**1.24 ± 4.92**	**1.00**	**16.67**
***Paracalanus parvus* (Claus) 1863**	**54.08**	**34.69**	**45.49**	**8.05**	**13.62**	**6.67**	**27.1 ± 44.6**	**21.98**	**97.22**
Parvocalanus crassirostris (Dahl) 1893	-	-	-	0.34	-	-	0.06 ± 0.34	0.05	2.78
PONTELLIDAE									
***Calanopia elliptica* (Dana) 1849**	**5.97**	-	-	**0.20**	**0.12**	-	**1.05 ± 5.58**	**0.85**	**13.89**
Labidocera acuta (Dana) 1849	1.75	-	0.11	0.20	0.71	-	0.46 ± 1.57	0.37	22.22
Labidocera bipinnata Tanaka 1936	-	-	-	-	0.14	-	0.02 ± 0.14	0.02	2.78
Labidocera euchaeta Giesbrecht 1889	1.04	-	-	0.20	-	0.15	0.23 ± 1.05	0.19	11.11
Labidocera kroeyeri (Brady) 1883	1.51	-	-	-	-	-	0.25 ± 1.51	0.20	2.78
Labidocera minuta Giesbrecht 1889	-	0.05	0.05	-	1.13	-	0.21 ± 0.66	0.17	16.67
Pontella chierchiae Giesbrecht 1889	-	-	-	-	0.11	-	0.02 ± 0.11	0.01	2.78
Pontella fera Dana 1849	0.11	-	-	0.16	0.12	-	0.06 ± 0.22	0.05	8.33
Pontellina plumata (Dana) 1849	1.51	-	-	0.37	-	-	0.31 ± 1.52	0.25	8.33
SCOLECITHRICIDAE									
Scolecithricella sp.	-	-	-	-	-	0.80	0.13 ± 0.42	0.11	11.11
Scolecithrix danae (Lubbock) 1856	1.04	-	0.11	0.16	0.12	-	0.24 ± 1.05	0.19	13.89
TEMORIDAE									
***Temora discaudata* (Giesbrecht) 1889**	**2.25**	**0.12**	**0.80**	**3.36**	**0.28**	**0.17**	**1.16 ± 2.28**	**0.94**	**52.78**
***Temora turbinata* (Dana) 1849**	**136.69**	**6.22**	**10.92**	**40.03**	**22.28**	**0.90**	**36.17 ± 92.84**	**29.34**	**88.89**
Order Cyclopoida									
OITHONIDAE									
Oithona fallax Farran 1913	-	-	-	-	-	1.83	0.31 ± 1.1	0.25	11.11
Oithona setigera (Dana) 1849	0.78	-	-	0.74	0.62	0.09	0.37 ± 0.59	0.30	33.33
Oithona similis Claus 1866	-	0.34	0.47	-	-	1.59	0.4 ± 0.96	0.32	30.56
Order Harpacticoida									
ECTINOSOMATIDAE									
Microsetella norvegica (Boeck) 1846	-	-	-	0.68	-	-	0.11 ± 0.68	0.09	2.78
MIRACIIDAE									
Macrosetella gracilis (Dana) 1847	-	0.06	-	0.72	0.27	-	0.17 ± 0.56	0.14	11.11
Order Poecilostomatoida									
CORYCAEIDAE									
Corycaeus (*Corycaeus*) *crassiusculus* Dana 1849	-	-	-	-	-	0.09	0.02 ± 0.09	0.01	2.78
Corycaeus (*C.*) *speciosus* Dana 1849	0.11	-	0.16	0.88	-	0.26	0.23 ± 0.56	0.19	22.22
***Corycaeus* (*Ditrichocorycaeus*) *affinis* McMurrich 1916**	**4.39**	**1.38**	**0.15**	-	**0.69**	**0.44**	**1.18 ± 2.05**	**0.95**	**52.78**
Corycaeus (*D.*) *andrewsi* Farran 1911	-	-	0.09	-	0.13	1.36	0.26 ± 0.89	0.21	13.89
***Corycaeus* (*D.*) *dahli* Tanaka 1957**	**0.39**	**0.65**	**0.92**	**1.08**	**1.08**	**0.24**	**0.73 ± 1.22**	**0.59**	**58.33**
***Corycaeus* (*D.*) *erythraeus* Cleve 1901**	**9.57**	**0.47**	**0.05**	-	-	**1.25**	**1.89 ± 7.56**	**1.53**	**41.67**
Corycaeus (*Farranula*) *concinna* (Dana) 1847	-	-	-	1.27	-	0.16	0.24 ± 0.87	0.19	11.11
***Corycaeus* (*F.*) *gibbula* Giesbrecht 1891**	**16.96**	**0.13**	**0.59**	**2.45**	**0.09**	**3.20**	**3.91 ± 13.56**	**3.17**	**66.67**
Corycaeus (*Onychocorycaeus*) *agilis* Dana 1849	0.78	-	-	0.70	-	0.62	0.35 ± 0.65	0.28	27.78
Corycaeus (*O.*) *catus* F. Dahl 1894	0.56	0.11	0.32	-	-	0.60	0.26 ± 0.48	0.21	33.33
Corycaeus (*O.*) *giesbrechti* F. Dahl 1894	0.20	0.04	0.05	-	-	0.05	0.06 ± 0.21	0.05	11.11
Corycaeus (*O.*) *pacificus* M. Dahl 1912	-	-	0.05	-	-	-	0.01 ± 0.05	0.01	2.78
Corycaeus (*Urocorycaeus*) *lautus* Dana 1849	-	0.30	0.10	0.20	-	0.16	0.13 ± 0.35	0.10	16.67
ONCAEIDAE									
Oncaea conifera Giesbrecht 1891	1.51	-	-	-	0.12	0.24	0.31 ± 1.52	0.25	8.33
***Oncaea media* Giesbrecht 1891**	**1.24**	**0.10**	**0.21**	**4.03**	**1.36**	**0.57**	**1.25 ± 2.16**	**1.01**	**55.56**
***Oncaea minuta* Giesbrecht 1892**	**7.84**	**1.40**	**0.34**	**8.35**	**0.58**	**7.76**	**4.38 ± 7.35**	**3.55**	**86.11**
***Oncaea venusta* Philippi 1843**	-	-	**0.38**	**1.21**	**0.52**	**4.60**	**1.12 ± 2.9**	**0.91**	**38.89**
SAPPHIRINIDAE									
Copilia mirabilis Dana 1849	-	-	-	1.28	-	-	0.21 ± 0.58	0.17	13.89
Copilia quadrata Dana 1852	1.51	-	-	-	-	-	0.25 ± 1.51	0.20	2.78

± standard deviation) copepod abundance and species richness (A), and indices of richness, evenness, and diversity (B) recorded over 6 seasonal periods. Table 2 shows species-specific abundances in each season, relative abundances (%), and occurrence frequencies (%). Data from 6 cruises showed the highest copepod abundances in Oct. 2007 (322.63 ± 383.24 ind./m^3) followed by July 2008 (133.09 ± 124.08 ind./m^3), whereas the lowest copepod density (59.35 ± 17.48 ind./m^3) and copepod species richness (16.00 ± 2.19 species/station) were recorded in Jan. 2008 (Fig. 4A). The highest recorded number of copepod species (25.17 ± 6.52 species/station), and indices of richness (5.63 ± 1.39) and diversity (2.33 ± 0.52) occurred in Feb. 2009 (Fig. 4B). The richness index ranged from 3.73 ± 0.67 in Jan. 2008 to 5.63 ± 1.39 in Feb. 2009. Similarly, the Shannon-Wiener diversity index ranged from 1.42 ± 0.47 in Jan. 2008 to 2.33 ± 0.52 in Feb. 2009. Pielou's evenness index ranged from 0.51 ± 0.15 in Jan. 2008 to 0.77 ± 0.22 in July 2008 (Fig. 4B). Interactions between water masses of the CCC and KC in northern Taiwan coastal areas indicated that the cold water mass of the CCC (Jan. 2008) most affected the copepod communities during the winter season.

Integrating all of the samples demonstrated 5 highly abundant species: *Temora turbinata* (with a relative abundance (RA) of 29.34%), *Paracalanus parvus* (of 21.98%), *Canthocalanus pauper* (of 7.86%), *Calanus sinicus* (of 4.00%), and *Acrocalanus gracilis* (of 3.93%). In terms of the frequency of occurrence, the following 6 species occurred in more than 80% of the samples; *Par. parvus* (with an occurrence ratio (OR) of 97.22%), *Acr. gracilis* (of 91.67%), *T. turbinata* (of 88.89%), *Can. pauper* (of 86.11%), *Oncaea minuta* (of 86.11%), and *Subeucalanus subcrassus* (of 83.33%) (Table 2). The 6 sampling cruises identified 13 species: *Acartia* (*P.*) *negligens*, *Can. pauper*, *Undinula vulgaris*, *Centropages furcatus*, *Sub. subcrassus*, *Acr. gracilis*, *Par. parvus*, *T. discaudata*, *T. turbinata*, *Corycaeus* (*D.*) *dahlia*, *Cor.* (*F.*) *gibbula*, *Onc. media*, and *Onc. minuta*.

Figure 5 shows the rank abundance (%) analysis of copepod compositions in bights of northeastern Taiwan during the 6 sampling cruises. Patterns of the rank abundance curves were relatively similar for most sampling cruises, but the highest species number was recorded on the Feb. 2009 cruise. More species with a relative abundance of < 0.1% were identified on the Oct. 2007 cruise than in other sampling periods. The relative rank abundances of the top 5 dominant copepod species among each season showed an obvious seasonal succession (Fig. 6). The calanoid *Par. parvus* was the dominant species

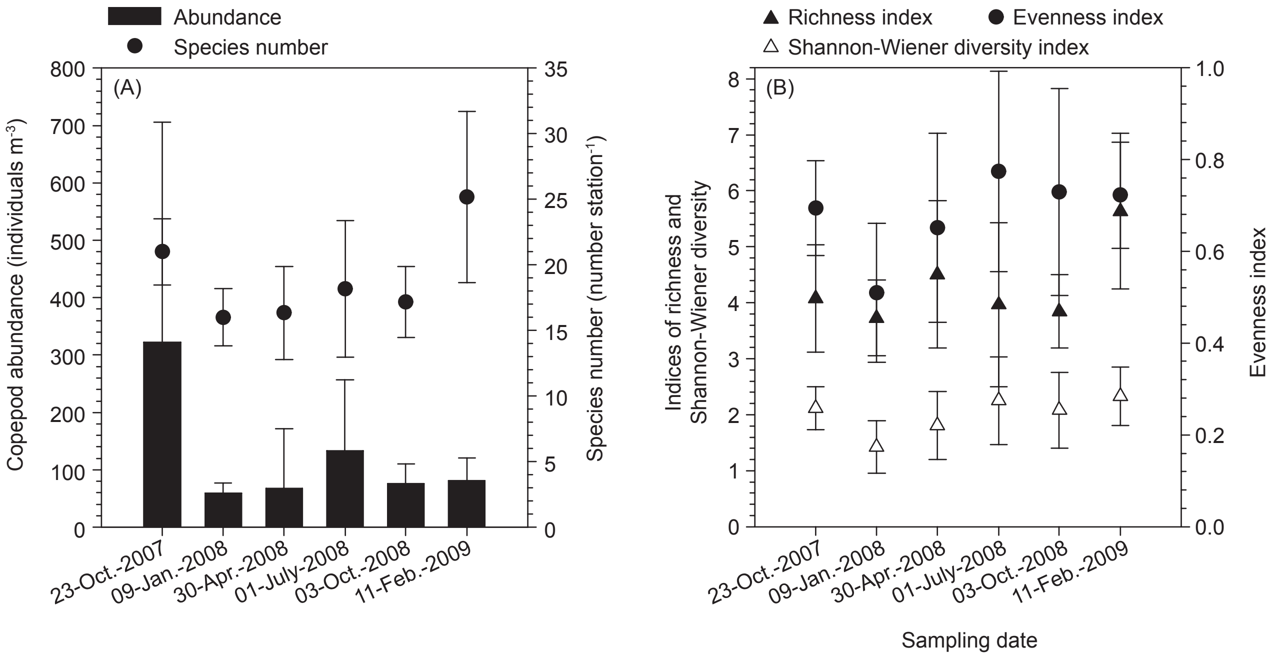

Fig. 4. Variations in the average (mean ± standard deviation) copepod abundance, species number (A), richness index, Shannon-Wiener diversity index, and Pielou's evenness index (B) recorded from samples of each sampling cruise during the investigation period.

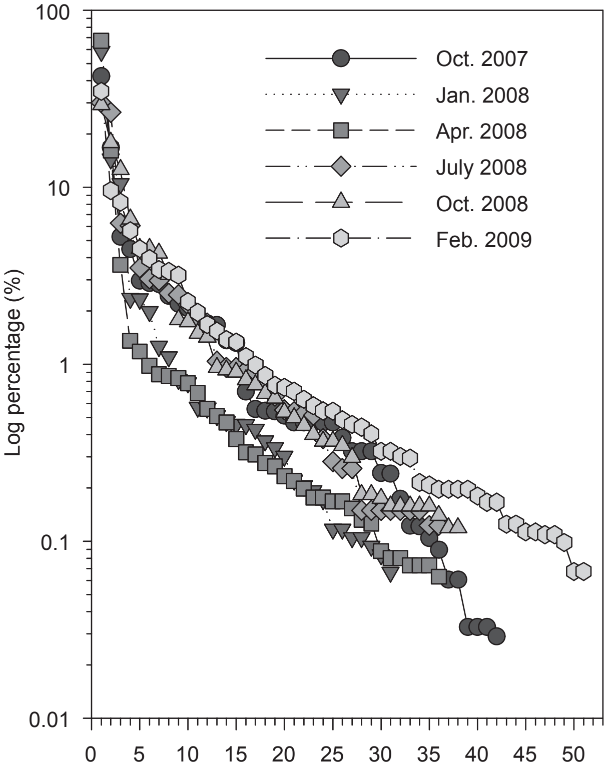

Fig. 5. Rank abundance diagrams of planktonic copepods sampled on 6 cruises during the investigation period. The Y-axis (percentage) is given at a log 10 scale.

observed during all cruises in the study area. The highest recorded proportion of *Par. parvus* was during Apr. 2008 (67.29%), followed by Jan. 2008 (58.45%). The 2nd dominant species, *T. turbinata*, was commonly found in 5 sampling cruises except in Feb. 2009. The calanoid species *Acr. gracilis* and *Can. pauper* appeared in high proportions during the study period. *Calanus sinicus* is an indicator species of the northern ECS, with a high proportion (34.87%) in Feb. 2009. Some opportunistic dominant species included *Clausocalanus arcuicornis*, *Cor.* (*D.*) *affinis*, *Cor.* (*D.*) *dahlia*, *Cor.* (*D.*) *erythraeus*, *Cor.* (*F.*) *gibbula*, *Onc. minuta*, *Onc. venusta*, *Par. parvus*, *Sub. subcrassus*, and *T. discaudata*. The dynamic structure of these copepod communities indicated that their succession is highly temporal.

The copepod community analysis based on Bray-Curtis similarities showed seasonal variations in the community structure (Fig. 7). Table 3 provides information on the copepod composition and distribution for the 36 samples taken on 6 sampling cruises. At the highest grouping level, 2 samples (stations 1 and 3) with higher abundances of copepods collected in Oct. 2007 were separated into group IA (Fig. 7). The 3 major copepod species of group IA were *T. turbinata* (with an IndVal of 50.72%), *Par. parvus* (of 13.56%), and

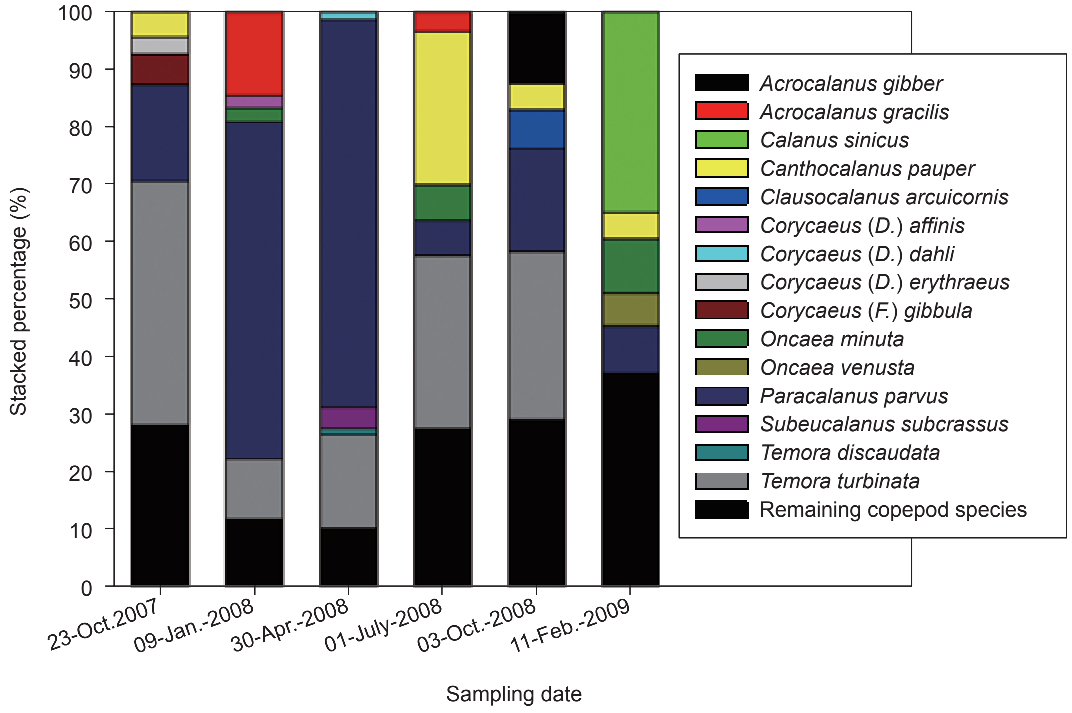

Fig. 6. Relative abundances of the 5 most abundant copepod species found on 6 different sampling cruises.

Cor. (*F.*) *gibbula* (of 6.16%) (Table 3). The 2nd hierarchical level separated samples collected in Feb. 2009 (group IIA). Samples in group IIA were characterized by the dominance of *Cal. sinicus* (with an IndVal of 41.67%), *Onc. minuta* (of 11.43%), and *Par. parvus* (of 9.83%), indicating

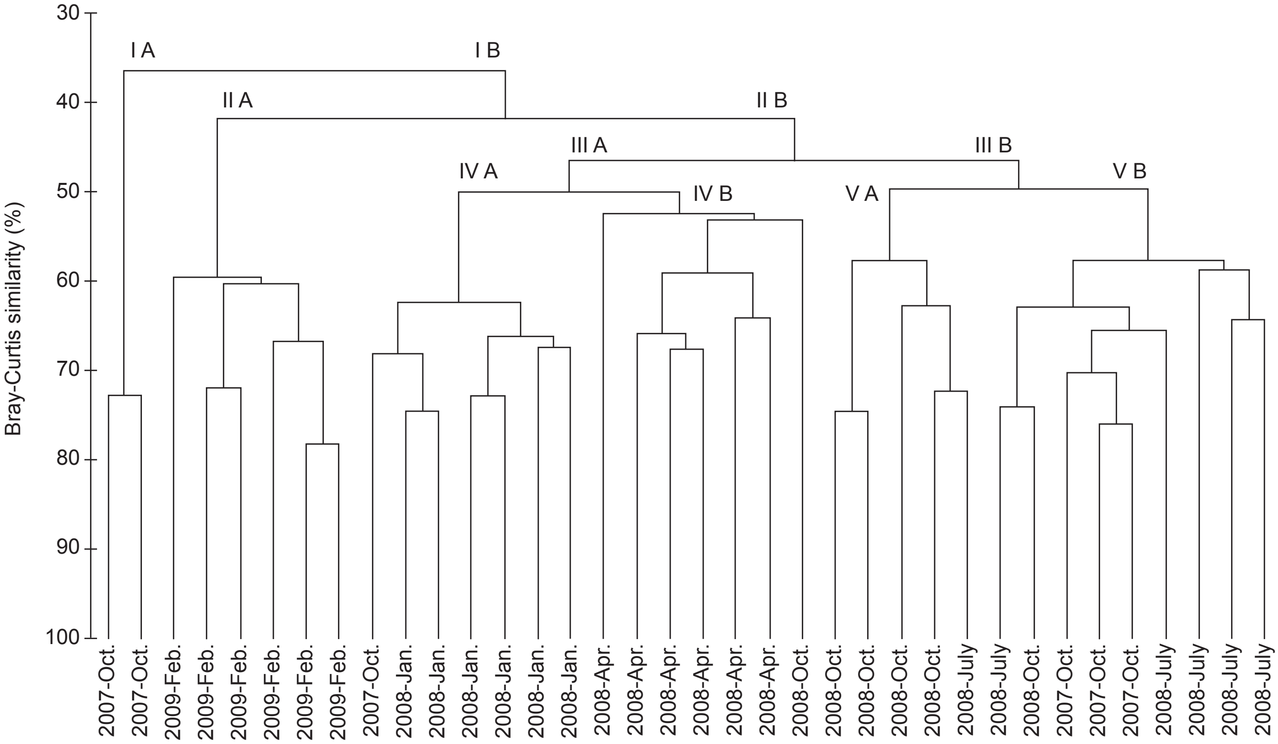

Fig. 7. Clustering dendrogram of different samples using Bray-Curtis similarity of 23 dominant copepod species (comprising 92.76% of the total copepods) during 6 sampling cruises.

Table 3. Indicator species and index values (%) of each copepod species with a value exceeding 3% for each cluster identified by the Bray-Curtis cluster analysis (Fig. 7)

	Cluster group					
Indicator species	I A	II A	IV A	IV B	V A	V B
Acrocalanus gibber					17.70	
Acrocalanus gracilis		3.17	13.76		6.43	3.96
Calanus sinicus		41.67				
Canthocalanus pauper	4.63	5.37			5.73	16.99
Clausocalanus arcuicornis					6.55	
Clausocalanus furcatus						3.68
Corycaeus (*D.*) *erythraeus*	3.37					
Corycaeus (*F.*) *gibbula*	6.16	4.72				
Cosmocalanus darwini		3.41				
Oncaea minuta		11.43				5.84
Oncaea venusta		5.65				
Paracalanus parvus	13.56	9.83	62.29	54.20	28.14	12.41
Subeucalanus subcrassus					7.47	3.36
Temora turbinata	50.72		9.45	33.23	6.07	27.55
Undinula vulgaris					3.46	
Cumulative contribution (%)	78.45	85.26	85.50	87.43	81.55	73.79

that the CCC had intruded into the study area. The 3rd hierarchical level separated samples by periods of winter and spring (samples of Jan. 2008 and Apr. 2008, group IIIA) and summer to autumn (samples of Oct. 2007 and July 2008, group IIIB).

Group IIIA was restricted to a differential community pattern of copepod species composition in winter (Jan. 2008, group IVA) and spring (Apr. 2008, group IVB), which were samples collected during the NE monsoon season (Fig. 7). In group IVA, *Par. parvus* (with an IndVal of 62.29%) was followed by *Acr. gracilis* (of 13.76%) and *T. turbinata* (of 9.45%). Group IVB showed 2 dominant species, *Par. parvus* (of 54.20%) and *T. turbinata* (of 33.23%), in spring. Hierarchical level IIIB separated most autumn samples collected in 2008 (stations 2-4, and 6 of Oct. 2008 and D6 of July 2008, group VA), in which the 3 dominant copepod species of group VA were *Par. parvus* (with an IndVal of 28.14%), *Acr. gibber* (of 17.70%), and *Cla. arcuicornis* (of 6.55%). The remaining samples collected during Oct. 2007 and July 2008 had similar communities and were accommodated into a single group (stations 4-6 of Oct. 2007, stations 1-5 of July 2008, and station 5 of Oct. 2008, group VB) and were dominated by *T. turbinata* (with an IndVal of 27.55%), *Can. pauper* (of 16.99%), and *Par. parvus* (of 12.41%) (Table 3).

Statistical analysis

Multiple comparisons of mean values among the 4 sampling seasons were conducted with a one-way ANOVA followed by the Tukey's test (Fig. 8). The abundance of *Cal. sinicus* in winter was significantly higher than that in spring ($p = 0.022$) (Fig. 8A), whereas the abundance of *Cla. arcuicornis* was significantly higher in autumn than in summer ($p = 0.036$) (Fig. 8B). *Clausocalanus furcatus* was significantly more abundant in autumn than in winter ($p = 0.034$) (Fig. 8C). The abundance of *Sub. subcrassus* in autumn was significantly higher than that in winter (Fig. 8D). The abundance of *Acr. monachus* in summer was significantly higher than those in winter ($p = 0.027$) and autumn ($p = 0.027$) (Fig. 8E). The abundance of *T. discaudata* in summer was significantly higher than that in winter ($p = 0.021$) (Fig. 8F). The abundance of *Oithona setigera* in autumn was significantly higher than in winter ($p = 0.016$) and spring ($p = 0.041$); and higher in summer than in winter ($p = 0.046$) (Fig. 8G). The abundance of *Cor.* (*C.*) *speciosus* in summer was significantly higher than those in autumn ($p = 0.011$) and winter ($p = 0.024$) (Fig. 8H). The abundance of *Cor.* (*D.*) *affinis* in autumn was significantly higher than that in summer ($p = 0.045$) (Fig. 8I). The abundance of *Cor.* (*F.*) *concinna* in summer was significantly higher than those in spring ($p = 0.033$), autumn ($p = 0.011$), and winter ($p = 0.019$) (Fig. 8J). The abundance of *Onc. media* in summer was significantly higher than those in spring ($p = 0.004$), autumn ($p = 0.001$), and winter ($p = 0.02$) (Fig. 8K). The copepod *Copilia mirabilis* was only found during summer, with significantly higher abundances than during the other 3 seasons ($p < 0.001$) (Fig. 8L).

Among all identified copepods, the abundance of the calanoid *Cal. sinicus* was negatively correlated with seawater temperature ($r = -0.434$, $p = 0.008$). In contrast, 7 species showed significant positive changes in their abundances with increasing seawater temperature (Table 4): *Acr. monachus*, *T. discaudata*, *Macrosetella gracilis*, *Cor.* (*C.*) *speciosus*, *Cor.* (*F.*) *concinna*, *Onc. media*, and *Cop. mirabilis*. The abundances of 5 copepod species showed a positive correlation with seawater salinity ($p < 0.05$, Table 5): *Candacia ethiopica*, *Cen. orsini*, *Cla. furcatus*, *Cor.* (*D.*) *affinis*, and *Cor.* (*O.*) *catus*.

The two-way ANOVA demonstrated that the effects of season, station, and their interactions on numbers of species, abundances, and indices of richness, evenness, and Shannon-Wiener diversity were not significant ($p > 0.05$). These results indicate that the water parameters of both bights are stable and evenly distributed.

DISCUSSION

In this study, we investigated temporal and spatial variations in copepod assemblages on 6 sampling cruises. Results of the two-way ANOVA showed that the bight environments were stable. The indices of richness, evenness, and species diversity, and the total abundance of copepods did not significantly differ among the sampling cruises or stations (Fig. 8). The scale of distances between sampling stations was small, and the bights belong to semi-enclosed environments, minimizing spatial variations. The embayments provided a consistent, stable environment for copepod communities at all sampling stations. Hwang et al. (2004b) studied the copepod assemblages in waters adjacent to NPPs in northern coastal areas of Taiwan and found a higher abundance and diversity of copepods in

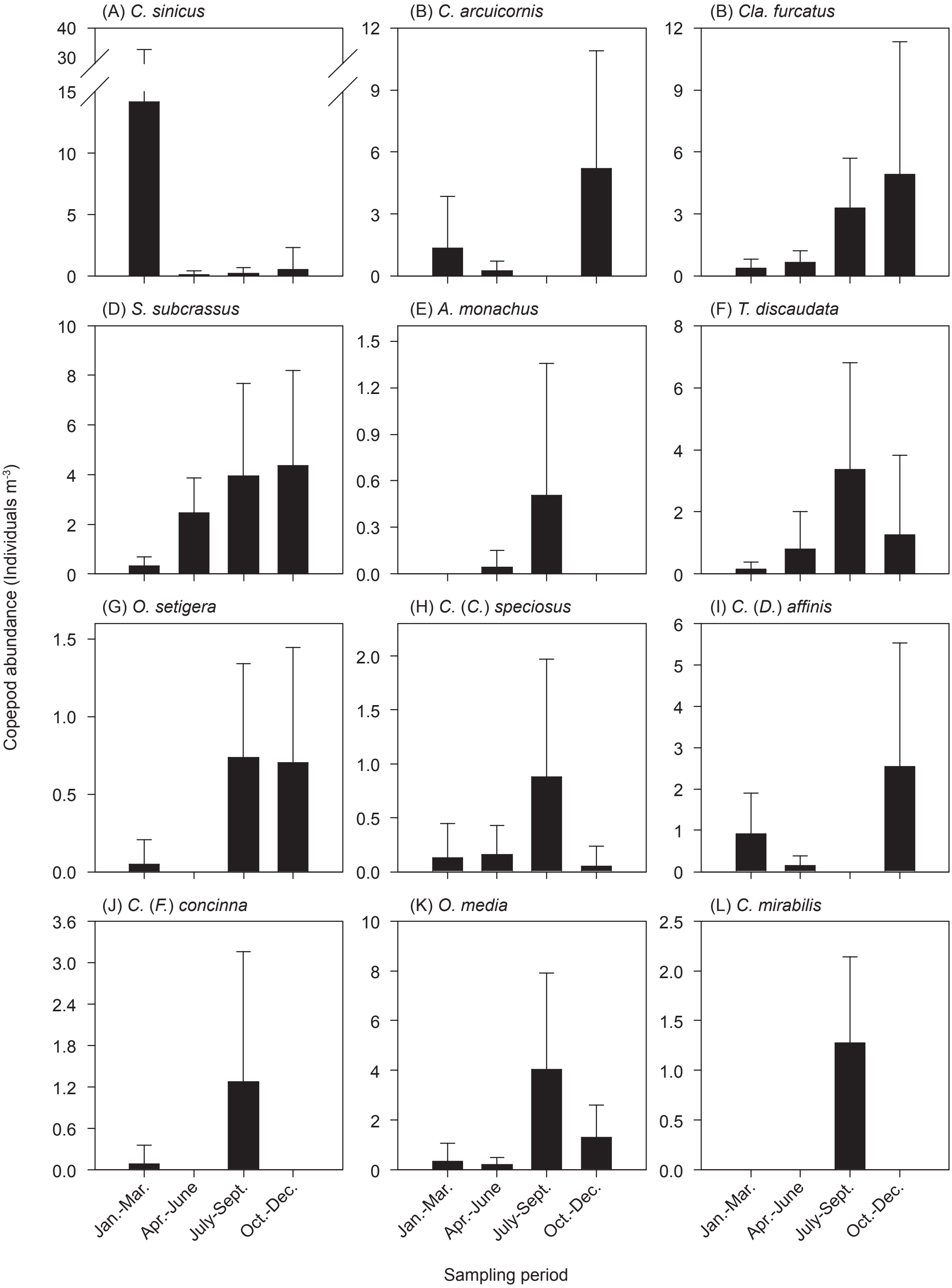

Fig. 8. Abundance (individuals (ind.)/m^3) of different zooplankton groups among 4 sampling seasons using a one-way ANOVA followed by Tukey's test showing significant differences: *Calanus sinicus* (A), *Clausocalanus arcuicornis* (B), *Cla. furcatus* (C), *Subeucalanus subcrassus* (D), *Acrocalanus monachus* (E), *Temora discaudata* (F), *Oithona setigera* (G), *Corycaeus* (*C.*) *speciosus* (H), *Cor.* (*D.*) *affinis* (I), *Cor.* (*F.*) *concinna* (J), *Oncaea media* (K), and *Copilia mirabilis* (L).

environments close to NPP-II. Hu (2004) showed that currents moved slowly close to areas around NPP-II, and this provided a stable environment. Chang and Fang (2004) recorded higher abundances of *Aca. erythraea* and *Par. parvus* in the harbor area than in non-harbor areas, indicating that both species preferred more-stable environments. Tseng et al. (2011c) found higher densities of the copepods *T. discaudata* and *T. turbinata* close to NPP-II than to NPP-I. This can be explained by the extension of a land-tip near NPP-II that forms a bay-like environment, creating stable conditions. Previous studies demonstrated that copepods may prefer the stability of such environments (Chang and Fang 2004, Hu 2004, Hwang et al. 2004b, Tseng et al. 2011c).

The highest total copepod abundance (322.63 ± 383.24 ind./m^3) was recorded during the Oct. 2007 cruise, and showed a large difference compared to the total abundance of copepods in Oct. 2008 (76.08 ± 34.06 ind./m^3). The average density of total copepods in Oct. 2007 was approximately 4.2-times higher than that in Oct. 2008. Based on weather events recorded by the Central Weather Bureau, Ministry of Transportation and Communications (Taipei, Taiwan), this study did not show significant differences in water parameters such as temperature, salinity, and precipitation in Oct. during the 2 sampling years. The strong Typhoon Krosa from the Pacific Ocean passed northeast of Taiwan on 6 Oct. 2007, following its direct impact on northern Taiwan. This typhoon brought heavy precipitation, and its strong winds mixed the water masses from the surface with water masses from deeper zones. López-López et al. (2012) reported that this typhoon effected the jellyfish population off northern Taiwan and indicated that a stable environment is preferred by planktonic creatures. The present study showed that a bight provides a more-stable environment than open-water areas. This may also be the reason for the higher copepod density in Oct. 2007. However, a typhoon also increases the efficiency of deep- and surface-water mixing, increasing nutrient levels and enhancing primary production in the euphotic zone (Lin et al. 2003). This increase in primary production supports a higher production and growth rate of copepods (Jónasdóttir and Kiørboe 1996, Amarasinghe et al. 1997, Jones et al. 2002). Previous studies suggested that a higher copepod density in Oct. 2007 compared to Oct. 2008 might have been an indirect result of the typhoon.

This study was conducted in semi-enclosed environments, and the top 5 dominant copepod species were *T. turbinata*, *Par. parvus*, *Can. pauper*, *Cal. sinicus*, and *Acr. gracilis*. Chien (2003) found that *Par. parvus*, *T. turbinata*, *Onc. venusta*, *Par. aculeatus*, and *Onc. media* were the 5 predominant copepods in Bi-Sha Harbor in northern Taiwan, and Chang and Fang (2004) observed that *T. turbinata*, *Aca. erythraea*, *Par. parvus*, *Par. aculeatus*, and *Pseudodiaptomus marinus* were the 5 most abundant copepods in Kaohsiung Harbor in southern Taiwan. Hsu et al. (2008) found that the copepods *Parvocalanus crassirostris*, *Bestiolina amoyensis*, *Oit. oculata*, *Aca. sinjiensis*, *Acartia* sp., and *T. turbinata* were predominant in a lagoon (Dapeng Bay) in southwestern Taiwan. Differences in copepod assemblage abundances among these studies may have been caused by spatial variations (Hwang et al. 2007, Tseng et al. 2013), water mass characteristics (Hwang et al. 2006 2009, Dur et al. 2007, Tseng et al. 2008c 2012), or the mesh size of the sampling nets (Tseng et al. 2011a). According to previous studies, *T. turbinata* is the predominant

Table 4. Results of copepod abundances with a significant correlation with seawater temperatures according to Pearson's correlation analysis

Species	*r*-value	*p*-value
Calanus sinicus	- 0.434	0.008 (**)
Acrocalanus monachus	0.445	0.007 (**)
Temora discaudata	0.409	0.013 (*)
Macrosetella gracilis	0.400	0.016 (*)
Corycaeus (*C.*) *speciosus*	0.428	0.009 (**)
Corycaeus (*F.*) *concinna*	0.435	0.008 (**)
Oncaea media	0.513	0.001 (**)
Copilia mirabilis	0.702	< 0.001 (**)

*$p < 0.05$ (2-tailed); **$p < 0.01$ (2-tailed).

Table 5. Results of copepod abundances with a significant correlation with salinities according to Pearson's correlation analysis

Species	*r*-value	*p*-value
Candacia ethiopica	0.402	0.015 (*)
Centropages orsini	0.407	0.014 (*)
Clausocalanus furcatus	0.342	0.041 (*)
Corycaeus (*D.*) *affinis*	0.373	0.025 (*)
Corycaeus (*O.*) *catus*	0.378	0.023 (*)

*$p < 0.05$ (2-tailed); **$p < 0.01$ (2-tailed).

calanoid commonly found among different semi-enclosed environments in Taiwan. Shih and Young (1995) reported that this species was recorded from the northern Bo-Hai Sea, Yellow Sea, and ECS up to the southern SCS and is one of the dominant species in the western Pacific Ocean. This species typically lives in temperate to tropical waters. Many studies reported that this species is an indicator of warm water masses (Hwang et al. 2006 2009, Dur et al. 2007, Tseng et al. 2008c 2011c), and their populations fluctuate with seasonal succession. Lan et al. (2009) suggested that this species is an indicator of the KC water mass. Copepod communities vary in coastal areas of northern (Hsieh et al. 2004, Hwang et al. 2004b 2006 2009, Lan et al. 2004, Tseng et al. 2008c 2012) and southern Taiwan (Lo et al. 2004a, Chang et al. 2010), where *T*. *turbinata* is the most abundant and dominant species. This study confirmed that *T*. *turbinata* is also an important species in northeastern Taiwan, and can be used in assessing ecological impacts on coastal areas.

The 2nd most abundant copepod in this study was *Par. parvus*, a pelagic species that is widely distributed in coastal areas of the world's oceans (Kouwenberg and Boxshall 2012). Previous studies suggested that *Par*. *parvus* prefers lower-temperature water masses (Peterson et al. 2002, Hsieh et al. 2004). Lan et al. (2009) found that the abundance of *Par*. *parvus* was significantly higher in spring than in summer and early winter in the middle of the Taiwan Strait. Hsu et al. (2008) indicated that the abundance of *Par. parvus* decreased when seawater temperatures exceeded 30°C. When the southwesterly monsoon prevails, the Kuroshio Branch Current (KBC) brings warm waters into the southern part of the Taiwan Strait. Dur et al. (2007) also reported that this species is dominant in northwestern Taiwan when temperatures are low. The present study confirms this hypothesis in northeastern Taiwan, which is influenced by a northeasterly monsoon.

The 3rd most abundant copepod was *Can. pauper*, a typical tropical species (Liao et al. 2006) and an indicator species of the KC (Lan et al. 2009). This species appeared in all samples. The abundance of *Can. pauper* was low in winter and spring, and increased up to 26.54% in summer (July 2008). During the NE monsoon season, proportions of *Can. pauper* among total copepods decreased in autumn (4.52%) and winter (4.49%). This clearly shows that the *Can. pauper* population is strongly affected by the characteristics of northeastern Taiwanese waters.

The satellite images used in this study showed that surface water temperatures of northern Taiwan decreased in Sept. 2008 (Fig. 2I). The CCC reached northern Taiwan and flowed into the Taiwan Strait in Dec. 2008 (Fig. 2L). When the CCC entered the Taiwan Strait, it blocked warm water masses of the KBC of southwestern Taiwan (Fig. 2L-C) (Jan et al. 2002, Tseng et al. 2008b c). Planktonic copepods recorded from northern Taiwan belong to temperate-water species. *Calanus sinicus* was significantly more abundant in spring (Jan.-Mar.) than during the other 3 seasons ($p < 0.05$, one-way ANOVA). This shows that *Cal*. *sinicus* is an indicator species of the ECS and cold water masses (Shih et al. 2000, Hwang and Wong 2005, Tseng et al. 2008c 2012). In the monsoon transition periods in winter and spring, the CCC transported *Cal*. *sinicus* from the ECS coastal area of China to northeastern Taiwan and the Taiwan Strait, even reaching waters of Hong Kong (Hwang and Wong 2005). Several studies reported that this species is more abundant in coastal areas of Taiwan in winter and spring (Hsieh and Chiu 2002, Hwang et al. 2004b 2006, Hwang and Wong 2005, Tseng et al. 2008c, Lan et al. 2009). Dur et al. (2007) reported that *Cal*. *sinicus* was the most abundant species, with a high occurrence rate in the estuarine area of the Danshuei River in northwestern Taiwan. This study confirmed this view, indicating that *Cal*. *sinicus* was most abundant in Feb. 2009, at which time, the lowest surface water temperatures were recorded. Pearson's correlation results demonstrated that the abundance of *Cal*. *sinicus* was significantly negatively correlated with water temperature. These results confirm previous reports that *Cal*. *sinicus* prefers lower-temperature water masses.

This study also showed a lower density (1.19 ind./m^3) of *Cal*. *sinicus* in the July 2008 sample, disagreeing with previous research conducted in northern coastal areas of Taiwan (Hwang et al. 2004b 2006, Dur et al. 2007, Tseng et al. 2008c). Those studies indicated that *Cal*. *sinicus* was not found in surface waters during the period of July-Sept. when water temperatures were high. However, this species appeared in the present study during summer periods, indicating that a bight environment may provide stable, low-temperature conditions at the bottom of the water column for the survival of *Cal*. *sinicus* in waters of this habitat in northern Taiwan. Hwang and Wong (2005) reported that the population of *Cal. sinicus* may migrate to the bottom of the water column where temperatures are lower. The present study provides a clue for the potential habitat of *Cal. sinicus* in the summer in the southern ECS.

Abundances of *Acr. gracilis* increased in Jan. 2008 and July 2008. This species was reported in upwelling waters of northern Taiwan (Shih et al. 2000), the southeastern area of the ECS (Liao et al. 2006), an estuarine area of northwestern Taiwan (Dur et al. 2007), and harbors in southern Taiwan (Chang and Fang 2004). Lan et al. (2009) reported that *Acr*. *gracilis* is typically a tropical species. This species appeared in all samples, but its abundances showed no significant correlation with water temperature.

The present study identified the copepod *Acr. gibber* as a tropical indicator species. This species was previously recorded from the Taiwan Strait (Hsieh and Chiu 2002, Lo et al. 2004a), the southeastern ECS (Liao et al. 2006), the southern ECS (Tseng et al. 2012), the southern SCS (Hwang et al. 2007), and from waters of the KBC (Chen 1992, Lo et al. 2001) in summer. In the northern Taiwan Strait area, *Acr*. *gibber* appeared in spring and autumn, with a significantly higher abundance during autumn (Dur et al. 2007). In waters of northwestern Taiwan, Tseng et al. (2008c) reported the disappearance of *Acr*. *gibber* when the cold water mass of the CCC entered the Taiwan Strait. During winter periods in harbors of southern Taiwan, water temperatures were higher than 24°C, and the relative abundance of *Acr*. *gibber* was < 2% (Chang and Fang 2004). *Acrocalanus gibber* had a higher abundance in the Oct. 2008 sample (12.58%). This result differed from those of Tseng et al. (2008c) and Dur et al. (2007), who reported that this species was dominant in warm waters in northwestern coastal areas of Taiwan and the northern Taiwan Strait, indicating habitat variations.

This study could demonstrate no significant differences in the indices of richness, evenness, or diversity of species, or total copepod abundances among the 6 sampling cruises or stations in the 2 bights (Fig. 8). Contrary to results of the indices and total abundances, seasonal successions of copepod species, the community structure, and assemblages significantly differed among sampling cruises (Fig. 6, Table 2). Previous studies showed that copepod assemblages change based on water-mass interactions in northwestern Taiwan (Tseng et al. 2008c 2011c), in the southwestern ECS (Dur et al. 2007, Hwang et al. 2006 2009), and in northern Taiwan (Chien 2003, Hwang et al. 2004b). The present study confirmed the seasonal succession of copepod assemblages in coastal areas of northern Taiwan, including embayment environments. In southern Taiwan, Chang et al. (2010) recognized a clear succession of copepod assemblages in an embayment environment during the NE and SW monsoonal transitions. Results of this study confirm that the copepod communities develop a clear seasonal succession in bight environments of northeastern Taiwan (Figs. 5, 6). In addition, the present study demonstrated that 13 copepod species can serve as indicator species for environmental monitoring of water conditions. These results provide useful information on copepod assemblages in bay habitats of northeastern Taiwan.

In conclusion, this study presents 2 main results: (1) a bay environment provides a well-protected and stable environment, leading to no significant differences in temporal or spatial distributions of planktonic copepods during the investigation period in northeastern Taiwan; and (2) species compositions and assemblages of copepods exhibited seasonal successional trends because of the influence of different water masses: the CCC and KBC.

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