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ORIGINAL ARTICLE

Seasonality of the copepod assemblages associated with interplay waters off northeastern Taiwan

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Abstract This study investigated copepod assemblages in the regime around Turtle Island off northern Taiwan to trace South China Sea water (SCSW) flowing northward with the Kuroshio Current. Seasonal variations of copepod assemblages demonstrated a dynamic succession of changes in copepod populations; the average abundance for total copepods ranged from 102.58 ± 53.38 in December to 1669.89 ± 1866.17 in March (individuals m^{-3}). A total of 87 copepod species representing 36 genera and 21 families were identified. Among all samples, *Temora turbinata* dominated the copepods by a relative abundance (RA) of 26.89 %, followed by *Paracalanus parvus* (RA: 22.34 %) and *Corycaeus* (*Ditrichocorycaeus*) *affinis* (RA: 12.77 %). Only the *Acrocalanus gracilis* species was recorded in all samples. Results of one-way ANOVA revealed that the number of copepod species, indices of richness, evenness, and Shannon–Wiener diversity differed significantly in five different cruises. The density of five copepod species (*Gaetanus minor*, *Calanus sinicus*, *Eucalanus elongates*, *Rhincalanus nasutus*, and *Rhincalanus rostrifrons*) exhibited a significant negative correlation with seawater temperature. In contrast, the density of *Canthocalanus pauper* and *Undinula vulgaris* was significantly positively correlated with seawater temperature. The cold-water indicator species, *C. sinicus,* recorded in samples of March and May indicated the effect of China Coast Water (CCW) on copepod communities in the study area. Furthermore, the presence of *Calanoides philippinensis* in May samples strongly indicated that the SCSW may reach the Turtle Island area. Consequently, *C. philippinensis* and *C. sinicus* can be used to trace SCSW and CCW, respectively, in the study area.

Keywords Indicator species · Copepod assemblages · Succession · East China Sea · Kuroshio Current

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Introduction

Distributions of water masses crucially affect the composition and abundance of oceanic biota around the island of Taiwan (Hwang et al. 2004, 2006, 2010; Dur et al. 2007; Tseng et al. 2008a, b, d, 2011a, c). Two crucial water masses may meet in the coastal sea off northern Taiwan. The Kuroshio Current (KC) brings the warm-water mass along the eastern coast of Taiwan, and the China Coastal Current (CCC) may transport the cold-water mass to the area during the northeast monsoon season (Jan et al. 2002). These two water types can be differentiated by a notable difference in temperature and salinity. When these two water masses meet in an area off northeastern Taiwan, their interplay creates diverse habitats with dynamic spatial and temporal variations of environmental parameters. Such a complex water system may provide diverse habitats for marine biota. Therefore, Shao (1998) estimated that approximately 10 % of marine species worldwide can be found in waters around Taiwan.

Marine creatures are sensitive to environmental changes, which may cause physical and physiological damage and/or death under extreme conditions (Peng et al. 2011; Tseng et al. 2011b; Chan et al. 2012). Most zooplankton biota are characterized by a short life span, small body size, and live their entire lives in water and are generally sensitive to hydrographic conditions (Webber et al. 2005). Thus, planktonic biota have been used as indicators to study the movement of water masses (e.g., copepods) (Hwang and Wong 2005; Hsiao et al. 2011b), water pollution (e.g., polychaeta) (Grassle and Grassle 1976; Fielman et al. 2001; Dean 2008), and water quality (e.g., crustaceans, rotifers, phytoplankton, and zooplankton,) (Gannon and Stemberger 1978; Webber et al. 2005).

In northern Taiwan, several studies indicated that the copepod *C. sinicus* is a crucial indicator species for cold-water masses derived from the Bohai Sea and the Yellow Sea (Hwang et al. 2006; Hwang and Wong 2005; Dur et al. 2007; Tseng et al. 2008b, 2012). To date, no characteristic species of copepod in the coastal sea off northern Taiwan has been reported as an indicator of South China Sea water (SCSW).

Therefore, the present study aimed to reveal: (1) the Kuroshio Current transports a characteristic species of copepod living in the South China Sea (SCS) to the study area and (2) the abundance, species richness, and composition of copepods exhibit strong seasonal succession in the study area.

Materials and methods

Study area and sampling

Samples were obtained from five sampling stations around Turtle Island off northeastern Taiwan (Fig. 1; Table 1) to investigate the succession of copepod community and search for the indicator species of copepod in water masses of East China Sea (ECS) and SCS.

The study was conducted onboard the Ocean Research Vessel II during cruises 1700, 1716, 1738, 1747, and 1756 during March, May, August, September, and December 2010. The copepod samples were collected at each station by using surface tows (0–5 m) with a standard North Pacific zooplankton net (mouth diameter of 45 cm and mesh size of 333 μm). A Hydrobios flowmeter (Germany) was mounted at the center of the net mouth. Temperature and salinity were recorded with a Seabird CTD instrument prior to collection of zooplankton samples. Zooplankton samples were preserved immediately in seawater containing 5 % buffered formaldehyde.

Identification and enumeration of zooplankton

In the laboratory, samples were split by a Folsom plankton splitter until the subsample contained less than 500 specimens. Adult copepods were sorted and identified to species level by using the keys of Chen and Zhang (1965), Chen et al. (1974), Yamaji (1996), and Chihara and Murano (1997). The total number of individuals (ind.) of each copepod taxon was recorded, and the density (ind. m^{-3}) was calculated.

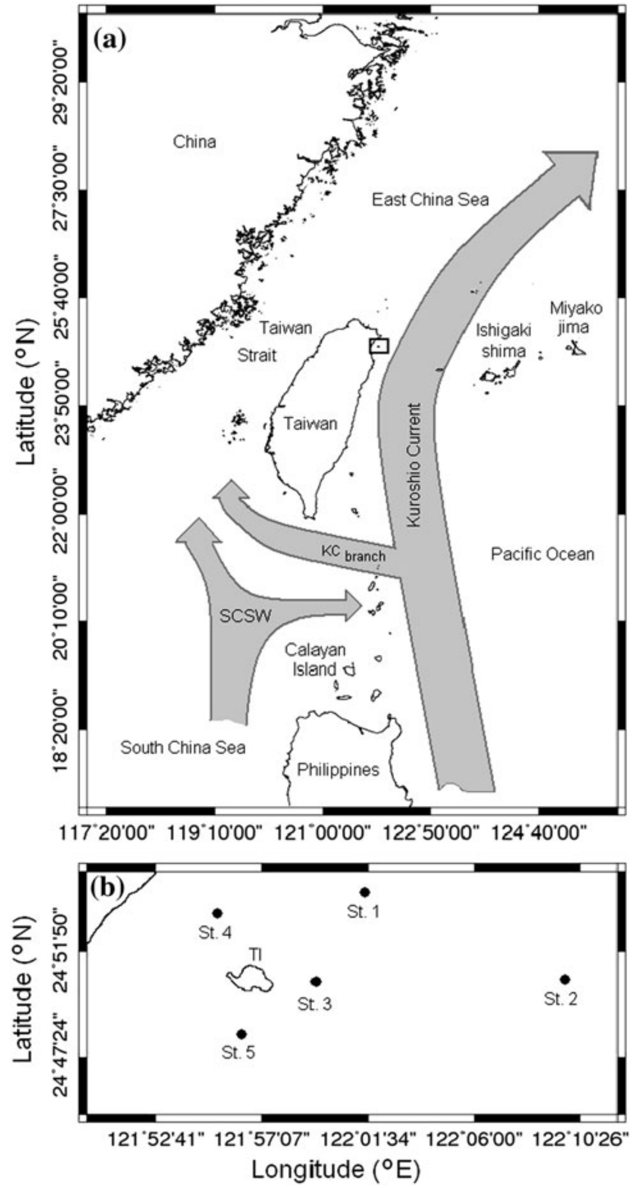

Fig. 1 Map of the study area (**a**) and sampling locations (**b**) around Turtle Island during various seasons in 2010. *KC* Kuroshio Current, *SCSW* South China Seawater, and *TI* location of Turtle Island

Statistical analyses

We analyzed the copepod community of each sample by applying the Paleontological Statistics (PAST) computer package (Hammer et al. 2001) to elucidate the temporal variations of copepod assemblages in various periods. The

Table 1 Location, sampling time, and sampling cruises of this study around Turtle Island in 2010

Station	Location		Sampling time				
	Longitude (°E)	Latitude (°N)	Mar. OR II CR 1700	May OR II CR 1716	Aug. OR II CR 1738	Sept. OR II CR 1747	Dec. OR II CR 1756
St. 1	122° 0′ 16.52″	24° 53′ 5.25″	22:07	06:09	14:42	17:24	15:34
St. 2	122° 9′ 9.50″	24° 50′ 7.63″	16:40	03:45	13:31	15:12	13:43
St. 3	121° 59′ 3.87″	24° 50′ 8.78″	00:38	07:10	15:54	10:20	16:30
St. 4	121° 55′ 14.35″	24° 52′ 5.05″	07:49	09:40	18:40	02:55	19:22
St. 5	121° 56′ 8.12″	24° 48′ 2.25″	03:45	08:30	17:00	19:32	17:33

copepod species diversity of each sample was estimated as the Shannon–Wiener diversity, and indices of Pielou's evenness and Margalef richness were applied to analyze the copepod community structure.

The abundance of copepod species of whole samples was used to calculate similarities before clustering. We used the functional test by Box and Cox (1964) for transformation of data before conducting similarity analysis to reduce the bias of considerably abundant species. The value (λ) of power transformation was 0.82. Furthermore, the data of original species abundance were subsequently transformed by using $\log_{10}(x + 1)$ to logarithmic transformation densities for all samples. The Bray–Curtis similarity (Michie 1982) was applied to measure the distance between samples and copepod community before non-metric multidimensional scaling (NMDS) analysis and cluster analysis.

The data of 25 samples included 87 species were applied with NMDS analysis to demonstrate the variation among sampling cruises. Further, cluster analysis was applied to reveal the communities of copepod species that were identified in similar water masses. Among the 25 samples, the 16 dominant copepod species with a relative abundance value of over 0.5 % (comprising 94.54 % of the total copepod) were computed by using cluster analysis to evaluate the relative similarity of distribution patterns among all samples for reducing the interference with estimating the relationship between copepod community and water temperature.

Pearson's product moment correlation was used to estimate the relationship among copepod abundance, temperature, and salinity. One-way ANOVA with post hoc Turkey's HSD (honestly significant difference) test was applied to identify differences in copepod abundance among seasons and stations.

Results

Hydrological structures

Satellite images of sea surface temperatures (SSTs) from March 2010 (Fig. 2a) to December 2010 (Fig. 2e) revealed the characteristics of interaction between CCC and KC in and around the study area. The cold-water masses of CCC influenced the study area during the prevailing periods of the northeastern monsoon (November–April). The influence of cold-water masses of CCC was stronger in March (Fig. 2a) than in May (Fig. 2b). Furthermore, the warm KC intruded to the study area during prevailing periods of the southwestern monsoon (June–October). The temperature of surface water was higher than 27 °C during August (Fig. 2c) and September (Fig. 2d). In December, the CCC appeared to flow to the study area through the northwestern part of the Taiwan Strait (Fig. 2e).

Figure 3 shows the relationship between seawater temperature and salinity for each station during five sampling cruises. During March, seawater temperatures varied significantly among sampling stations. The water properties may exist between CCW (Stations 3–5) and Kuroshio water (KW) (Stations 1–2) off northeastern Taiwan. The water properties between April and September are similar to KW. The water in August and September may have been dominated by KW, as revealed by the relatively high temperature and salinity. In December, the CCC may intrude into the study area because the water was characterized by relatively lower temperature, as shown in the T–S diagram (Fig. 3).

Copepod community structure

From the 25 samples collected from five cruises, 87 copepod species were identified from 36 genera and 21 families, including Calanoida, Cyclopoida, Harpacticoida, and Poecilostomatoida (Table 2). Figure 4 shows the variation of copepod abundance, species number (Fig. 4a), indices of species richness, Shannon–Wiener diversity, and evenness (Fig. 4b) at each sampling station. The lowest abundance of total copepod in our samples was 17.65 (ind. m^{-3}) at Station 2 in December 2010, whereas the highest abundance was 5000.84 (ind. m^{-3}) at Station 1 in March 2010 (Fig. 4a). The highest copepod abundance recorded at Station 1 in March 2010 may be attributed to KW (Fig. 3). The number of copepod species identified at each station

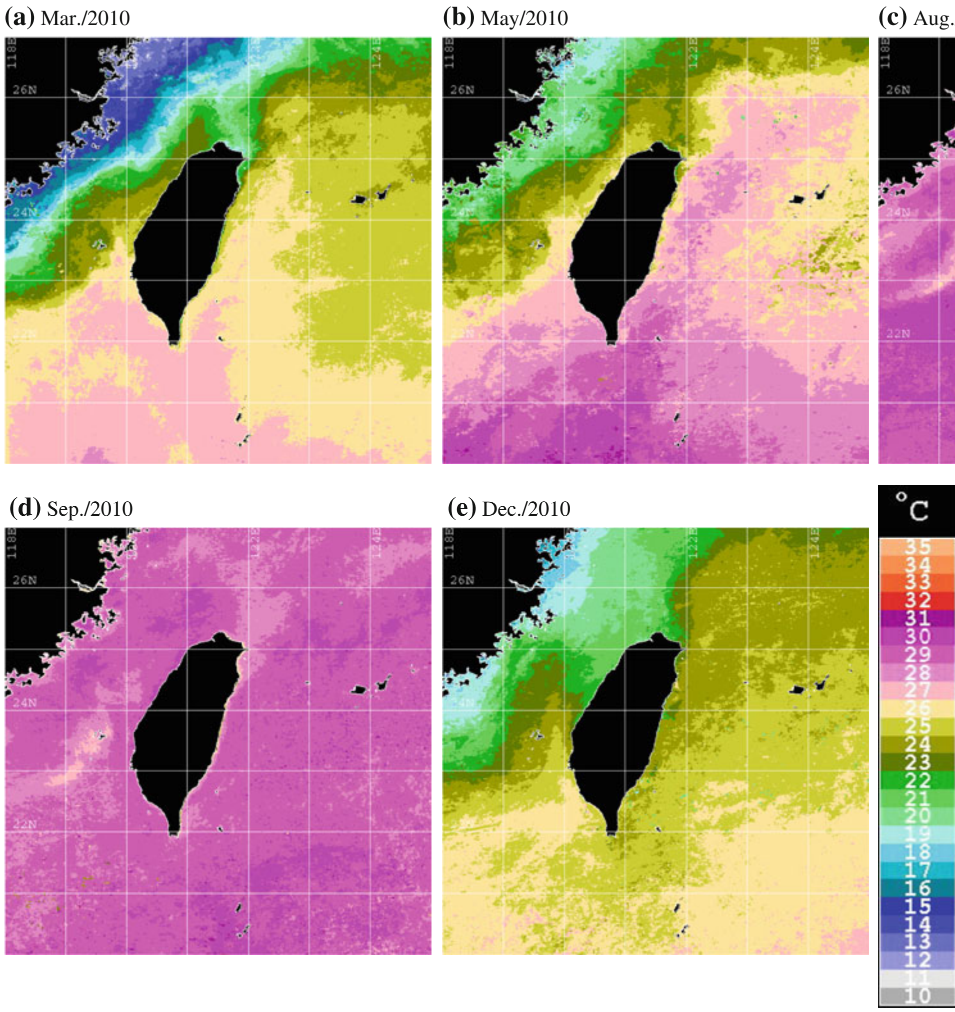

Fig. 2 Satellite images of monthly average sea surface temperatures (SSTs). The images were selected from March (**a**), May (**b**), August (**c**), September (**d**), to December (**e**) in 2010

ranged from 10 (Station 1 in March) to 42 (Station 1 in May) (Fig. 4a). The richness index of sampling stations ranged from 1.32 at Station 3 in August 2010 to 7.64 at Station 1 in May 2010. The Shannon–Wiener diversity index of sampling stations ranged from 0.52 at Station 5 in August 2010 to 3.0 at Station 1 in December 2010. Similarly, Pielou's evenness index of sampling stations ranged from 0.16 at Station 5 in August 2010 to 0.86 at Station 1 in December 2010 (Fig. 4b).

The average abundance of five sampling cruises for copepods ranged from 102.58 ± 53.38 inds./m^3 (December 2010) to 1669.89 ± 1866.17 inds./m^3 (March 2010) (Table 2). Among all samples, the five most abundant species were dominated by *Temora turbinata* (relative abundance, RA: 26.89 %), *Paracalanus parvus* (RA: 22.34 %), *Corycaeus* (*Ditrichocorycaeus*) *affinis* (RA: 12.77 %), *Paracalanus nanus* (RA: 9.54 %), and *C. sinicus* (RA: 7.83 %). The total number of the five most abundant species accounted for 79.37 % of the total abundance of all samples (Table 2). Calanoida copepod *A. gracilis* was recorded in all samples with a 100 % occurrence rate (OR). The four species *T. turbinata*, *U. vulgaris*, *C. pauper*, and *Temora discaudata* accounted for 84 % OR. Among taxon results, 19 copepod species with the lowest value of OR (4.0 %) were identified from a single sample (Table 2). The present study records the highest abundance of total copepod at Station 1 in March 2010 (Fig. 4a) that might be caused by KW (Fig. 3). The top three dominant species at Station 1 were *C.*(*D.*) *affinis* (2154.36 inds./m^3), *P. parvus* (2027.63 inds./m^3), and *C. sinicus* (136.48 inds./m^3), with RA 43.08, 48.97, and 2.73 %, respectively.

Figure 5 shows the variation of proportion in the five most dominant copepod species at each sampling cruise. The dynamic proportion of each sampling cruise indicated a clear succession. The species *C. sinicus*, *P. parvus*, and *Corycaeus* (*D.*) *affinis* were dominant in March and May, when cold-water masses of CCC reached the area off northeastern Taiwan. *T. turbinata*, *U. vulgaris,* and

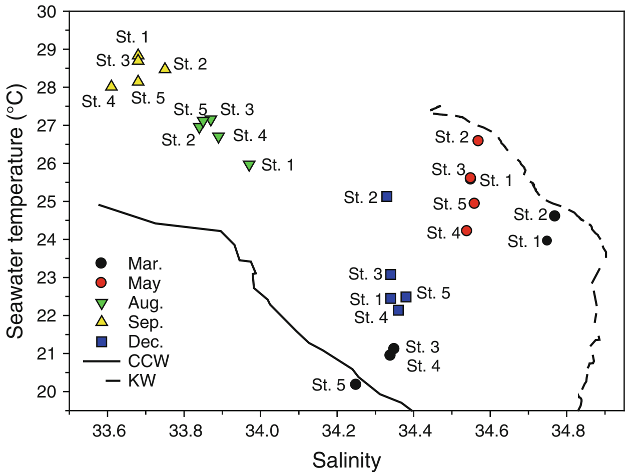

Fig. 3 Temperature and salinity of all stations during each sampling cruise. The T–S diagram shows the distribution of T and S in each station in five sampling cruises. The *solid* and *dotted lines* of T–S curves represent the CCW (plume of Yangtze River; 30° 30′ N; 122° 52′ E) and KW (Kuroshio water; 25° 10′ N; 123° 10′ E) recorded from a cruise on July 15 to July 29, 2001

C. pauper were dominant in August and September with high temperature (Fig. 3). The species *T. turbinata* exhibited relatively high RA values in May (2.89 %), August (76.79 %), and September (23.75 %). *Paracalanus nanus* was dominant in May, September, and December. *Paracalanus aculeatus* (RA 15.78 %) and *Clausocalanus arcuicornis* (RA 18.23) were dominant only in September and December, respectively (Fig. 5).

Statistical analysis

Among five sampling cruises, multiple comparisons of mean values (Table 2) were conducted through one-way ANOVA, followed by the Tukey's test (Fig. 6). Results of one-way ANOVA demonstrated no significant difference among all sampling cruises ($p > 0.05$, Fig. 6a). The number of copepod species was significantly larger in May samples than in the August ($p = 0.004$) and September ($p = 0.012$) samples (Fig. 6b). The richness index was significantly larger in May than in March ($p = 0.04$), August ($p = 0.003$), and September ($p = 0.01$). The richness index was also significantly greater in December than in August ($p = 0.008$) and September ($p = 0.027$) (Fig. 6c). By contrast, the evenness index was significantly lower in March than in September ($p = 0.012$) and December ($p = 0.001$) (Fig. 6d). The Shannon–Wiener diversity index was significantly greater in December than in March ($p = 0.002$) and August ($p = 0.027$) (Fig. 6e).

Only a few copepod species demonstrated a change in density that significantly correlated with seawater temperature. For example, the abundance of *G. minor* ($r = -0.403$, $p = 0.046$), *C. sinicus* ($r = -0.46$, $p = 0.021$), *E. elongates* ($r = -0.589$, $p = 0.002$), *R. nasutus* ($r = -0.403$, $p = 0.046$), and *R. rostrifrons* ($r = -0.709$, $p < 0.001$) exhibited a significantly negative correlation with water temperature. By contrast, the densities of two copepod species, *C. pauper* ($r = 0.461$, $p = 0.02$) and *U. vulgaris* ($r = 0.414$, $P = 0.039$), exhibited a significantly positive correlation with seawater temperature.

Copepod association analysis

Figure 7 shows the NMDS results derived from all copepod data of 25 samples collected from five different sampling months. The compositions of copepod assemblages in samples of different months were separated (Fig. 7), which further revealed a differential grouping pattern of copepod communities in comparison with samples collected from various water masses. The species association of the 16 most abundant species was evaluated by normalized Bray–Curtis distances. Species with similar distribution patterns formed clusters that revealed the extent of co-occurrence of copepod species (Fig. 8). Table 3 lists samples and their mean temperature for associated copepod species of cluster grouping results.

The first assemblage (Group I B) displayed its principal association in samples of March and May, which was characterized by low water temperature (24.30 ± 2.58 °C, Table 3). These three species were not identified in September, when seawater temperature was high (Table 3). The second group (Group II A) contained only two copepod species, *Paracalanus nanus* and *Paracalanus aculeatus*. These two species did not appear in March. In particular, calanoida copepod *Paracalanus aculeatus* was only identified in September. The average temperature of these two species was in the range of 25.9 ± 2.39 °C. The third group (Group II B) included 11 copepod species. These copepods were identified in all five sampling cruises, and they belong to common native species in waters around Turtle Island. The average temperature of these two species was in the range of 25.16 ± 2.58 °C (Table 3). Results of cluster grouping of communities indicated that the copepod assemblage was affected by the interplay of water masses during various periods. This phenomenon implies a substantial succession in copepod communities in the area off northeastern Taiwan (Fig. 8).

Discussion

Dominant copepod species and seasonality

Previous studies reported that copepod communities in coastal seas off northern Taiwan exhibited a clear seasonal

Table 2 Density (mean ± standard deviation, individuals m^{-3}) of total copepod, number of copepod species, indices of Shannon–Wiener diversity, richness, evenness, total filtered water volume, relative abundance (RA, %), and occurrence rate (OR, %) recorded from each sampling cruise

	Sampling month of 2010					All samples		
	March	May	August	September	December	Total	RA	OR
Number of species identified in total	51	54	36	35	56	87		
Total felted water volume (m^3)	144.38	239.04	49.96	55.49	190.57	679.44		
Scientific classification								
Order Calanoida								
Acartiidae								
Acartia(*Plantacartia*) *negligens* Dana 1849	0.11 ± 0.24	0.71 ± 0.55	0.59 ± 0.86	4.24 ± 4.96	0.97 ± 1.0	1.32 ± 2.6	0.159	60.0
Aetideidae								
Aetideus giesbrechti Cleve 1904	0.1 ± 0.23	–	–	–	–	0.02 ± 0.1	0.002	4.0
Gaetanus minor Farran, 1905	0.12 ± 0.27	–	–	–	–	0.02 ± 0.12	0.003	4.0
Calanidae								
Calanoides carinatus (Kroeyer) 1849	0.47 ± 0.78	–	–	–	–	0.09 ± 0.37	0.011	8.0
Calanoides philippinensis Kitou & Tanaka, 1969	–	0.1 ± 0.22	–	–	–	0.02 ± 0.1	0.002	4.0
***Calanus sinicus* Brodsky 1965**	**172.09 ± 141.3**	**153.03 ± 225.72**	–	–	–	**65.02 ± 135.88**	**7.831**	**40.0**
***Canthocalanus pauper* (Giesbrecht) 1888**	**10.96 ± 16.07**	**1.5 ± 1.61**	**40.8 ± 47.31**	**40.06 ± 35.97**	**3.08 ± 4.79**	**19.28 ± 30.94**	**2.322**	**84.0**
***Cosmocalanus darwini* (Lubbock) 1860**	**0.93 ± 1.36**	**0.51 ± 0.47**	**39.82 ± 76.98**	**1.12 ± 2.02**	**1.98 ± 2.93**	**8.87 ± 35.21**	**1.068**	**60.0**
Nannocalanus minor (Claus) 1863	2.05 ± 4.31	0.3 ± 0.34	0.59 ± 1.32	–	0.19 ± 0.43	0.63 ± 2	0.075	28.0
***Undinula vulgaris* (Dana) 1849**	**11.12 ± 21.11**	**2.16 ± 2.22**	**55.31 ± 45.19**	**40.1 ± 51.37**	**3.58 ± 4.37**	**22.45 ± 36.54**	**2.704**	**84.0**
Calocalanidae								
Calocalanus contractus Farran 1926	–	0.25 ± 0.36	–	–	–	0.05 ± 0.18	0.006	8.0
Calocalanus pavo (Dana) 1849	1.95 ± 4.36	0.47 ± 0.58	2.42 ± 3.86	3.11 ± 4.29	0.46 ± 0.27	1.68 ± 3.16	0.203	52.0
Calocalanus plumulosus (Claus) 1863	–	1.01 ± 0.81	–	1.13 ± 2.02	0.38 ± 0.86	0.5 ± 1.08	0.061	32.0
Candacia bipinnata (Giesbrecht, 1889)	0.1 ± 0.23	–	–	–	–	0.02 ± 0.1	0.002	4.0
Candaciidae								
Candacia bradyi A. Scott 1902	–	–	0.38 ± 0.84	0.2 ± 0.44	–	0.11 ± 0.42	0.014	8.0
Candacia catula (Giesbrecht) 1889	0.12 ± 0.27	0.05 ± 0.11	–	–	0.13 ± 0.29	0.06 ± 0.18	0.007	12.0
Candacia curta (Dana) 1849	–	0.18 ± 0.4	–	–	–	0.04 ± 0.18	0.004	4.0
Candacia discaudata A. Scott 1909	–	–	–	–	0.11 ± 0.24	0.02 ± 0.11	0.003	4.0
Candacia ethiopica (Dana) 1849	–	–	–	–	0.16 ± 0.37	0.03 ± 0.16	0.004	4.0
Candacia pachydactyla (Dana) 1849	0.11 ± 0.24	–	–	–	–	0.02 ± 0.11	0.003	4.0
Paracandacia truncata (Dana) 1849	2.18 ± 4.24	–	0.59 ± 1.32	0.74 ± 1.21	–	0.7 ± 2.05	0.085	24.0
Centropagidae								
Centropages calaninus (Dana) 1849	0.32 ± 0.47	0.28 ± 0.41	–	2.0 ± 4.46	–	0.52 ± 1.99	0.063	20.0
Centropages furcatus (Dana) 1849	–	0.09 ± 0.2	–	2.75 ± 4.2	–	0.57 ± 2.05	0.068	16.0
Centropages orsini Giesbrecht 1889	–	–	8.57 ± 14.73	0.19 ± 0.41	–	1.75 ± 6.95	0.211	16.0

Table 2 continued

	Sampling month of 2010					All samples		
	March	May	August	September	December	Total	RA	OR
Clausocalanidae								
***Clausocalanus arcuicornis* (Dana) 1849**	–	**5.25 ± 7.74**	–	**17.3 ± 28.32**	**18.7 ± 16.0**	**8.25 ± 16.01**	**0.994**	**40.0**
Clausocalanus farrani Sewell, 1929	–	–	–	–	6.43 ± 9.06	1.29 ± 4.54	0.155	16.0
***Clausocalanus furcatus* (Brady) 1883**	**8.14 ± 17.25**	**8.94 ± 8.9**	**0.59 ± 1.32**	**2.62 ± 2.4**	**9.25 ± 8.82**	**5.91 ± 9.51**	**0.712**	**64.0**
Clausocalanus mastigophorus (Claus) 1863	0.23 ± 0.32	–	–	–	0.13 ± 0.29	0.07 ± 0.2	0.009	12.0
Eucalanidae								
Eucalanus elongatus (Dana, 1848)	0.46 ± 0.5	–	–	–	–	0.09 ± 0.28	0.011	12.0
Pareucalanus attenuatus (Dana) 1849	0.22 ± 0.31	0.36 ± 0.4	–	–	0.77 ± 1.15	0.27 ± 0.59	0.033	28.0
Rhincalanus nasutus Giesbrecht 1888	0.12 ± 0.27	–	–	–	–	0.02 ± 0.12	0.003	4.0
Rhincalanus rostrifrons (Dana) 1852	1.15 ± 1.1	0.16 ± 0.24	–	–	0.26 ± 0.57	0.31 ± 0.68	0.038	24.0
Subeucalanus crassus (Giesbrecht) 1888	0.34 ± 0.53	1.22 ± 1.68	–	–	1.03 ± 1.41	0.52 ± 1.06	0.062	28.0
***Subeucalanus subcrassus* (Giesbrecht) 1888**	**1.05 ± 1.78**	**1.27 ± 1.67**	**6.83 ± 10.03**	**11.03 ± 11.53**	**4.34 ± 3.23**	**4.9 ± 7.5**	**0.591**	**72.0**
Subeucalanus subtenuis (Giesbrecht) 1888	3.86 ± 3.93	–	0.59 ± 1.32	–	0.39 ± 0.86	0.97 ± 2.29	0.117	24.0
Euchaetidae								
Euchaeta concinna (Dana) 1849	0.12 ± 0.27	0.08 ± 0.18	–	–	–	0.04 ± 0.14	0.005	8.0
Euchaeta indica Wolfenden 1905	–	–	1.61 ± 3.61	–	–	0.32 ± 1.61	0.039	4.0
Euchaeta rimana Bradford 1973	15.88 ± 29.35	0.61 ± 0.57	0.38 ± 0.84	0.93 ± 2.08	0.26 ± 0.57	3.61 ± 13.56	0.435	44.0
Lucicutiidae								
Lucicutia flavicornis (Claus) 1863	3.9 ± 8.72	0.05 ± 0.11	–	–	0.19 ± 0.43	0.83 ± 3.89	0.100	12.0
Metridinidae								
Pleuromamma abdominalis (Lubbock) 1856	–	–	–	–	0.41 ± 0.68	0.08 ± 0.33	0.010	8.0
Pleuromamma gracilis (Claus) 1863	3.9 ± 8.72	–	–	–	2.49 ± 4.57	1.28 ± 4.35	0.154	12.0
Pleuromamma robusta (Dahl) 1893	–	–	–	0.93 ± 2.08	0.79 ± 1.26	0.34 ± 1.08	0.041	12.0
Paracalanidae								
Acrocalanus gibber Giesbrecht 1888	–	–	–	0.39 ± 0.88	–	0.08 ± 0.39	0.009	4.0
***Acrocalanus gracilis* Giesbrecht 1888**	**17.46 ± 33.93**	**2.84 ± 1.61**	**10.93 ± 12.18**	**39.82 ± 41.09**	**9.18 ± 7.74**	**16.04 ± 26.04**	**1.932**	**100.0**
Acrocalanus longicornis Giesbrecht 1888	–	–	–	–	4.32 ± 6.94	0.86 ± 3.34	0.104	16.0
Acrocalanus monachus Giesbrecht 1888	2.07 ± 4.3	1.41 ± 1.58	–	–	0.11 ± 0.24	0.72 ± 2.07	0.086	28.0
***Paracalanus aculeatus* Giesbrecht 1888**	–	–	–	**127.27 ± 162.89**	–	**25.45 ± 84.39**	**3.066**	**20.0**
***Paracalanus nanus* Sars 1907**	–	**87.09 ± 87.29**	**16.71 ± 27.5**	**282.18 ± 390.11**	**10.09 ± 7.08**	**79.21 ± 196.16**	**9.540**	**64.0**
***Paracalanus parvus* (Claus) 1863**	**817.8 ± 683.75**	**63.52 ± 44.92**	**43.71 ± 27.68**	–	**2.35 ± 2**	**185.48 ± 427.93**	**22.338**	**76.0**
Parvocalanus crassirostris (Dahl) 1893	–	–	0.38 ± 0.84	–	–	0.08 ± 0.38	0.009	4.0
Pontellidae								
Calanopia elliptica (Dana) 1849	0.34 ± 0.53	0.37 ± 0.59	0.76 ± 1.69	4.36 ± 8.76	0.22 ± 0.31	1.21 ± 4	0.146	36.0

Table 2 continued

	Sampling month of 2010					All samples		
	March	May	August	September	December	Total	RA	OR
Calanopia minor A. Scott 1902	–	0.09 ± 0.2	–	1.67 ± 2.31	0.21 ± 0.47	0.39 ± 1.17	0.048	16.0
Labidocera acuta (Dana) 1849	–	–	3.08 ± 4.96	1.12 ± 1.21	–	0.84 ± 2.42	0.101	24.0
Labidocera minuta Giesbrecht 1889	0.1 ± 0.23	–	–	–	–	0.02 ± 0.1	0.002	4.0
Pontella fera Dana 1849	–	–	–	0.74 ± 1.66	–	0.15 ± 0.74	0.018	4.0
Pontellina plumata (Dana) 1849	2.07 ± 4.3	0.15 ± 0.35	0.38 ± 0.84	–	–	0.52 ± 1.97	0.063	16.0
Pontellopsis regalis (Dana) 1849	0.11 ± 0.24	0.15 ± 0.35	–	–	–	0.05 ± 0.19	0.006	8.0
Scolecithricidae								
Scolecithricella longispinosa (Giesbrecht) 1888	0.2 ± 0.45	–	–	–	–	0.04 ± 0.2	0.005	4.0
Scolecithrix danae (Lubbock) 1856	2.05 ± 4.31	0.18 ± 0.24	4.33 ± 7.19	–	0.08 ± 0.18	1.33 ± 3.83	0.160	32.0
Temoridae								
***Temora discaudata* (Giesbrecht) 1889**	**8.13 ± 11.91**	**2.16 ± 2.06**	**6.82 ± 7.99**	**5.36 ± 2.92**	**1.23 ± 1.24**	**4.74 ± 6.63**	**0.571**	**84.0**
***Temora turbinata* (Dana) 1849**	**5.28 ± 8.07**	**11.29 ± 14.1**	**908.11 ± 950.82**	**191.49 ± 371.54**	**0.34 ± 0.49**	**223.3 ± 548.87**	**26.894**	**84.0**
Order Cyclopoida								
Oithonidae								
Oithona attenuata Farran 1913	–	0.3 ± 0.44	3.44 ± 7.1	0.75 ± 1.22	–	0.9 ± 3.23	0.108	24.0
Oithona fallax Farran 1913	–	–	–	–	0.68 ± 0.8	0.14 ± 0.43	0.016	12.0
Oithona setigera (Dana) 1849	10.33 ± 21.49	0.87 ± 0.9	–	0.2 ± 0.44	1.16 ± 1.05	2.51 ± 9.66	0.302	44.0
Oithona tenuis Rosendorn 1917	–	0.49 ± 0.71	–	–	–	0.1 ± 0.35	0.012	8.0
Order Harpacticoida								
Clytemnestridae								
Clytemnestra scutellata Dana 1847	–	0.26 ± 0.4	–	–	0.1 ± 0.22	0.07 ± 0.21	0.009	12.0
Miraciidae								
Macrosetella gracilis (Dana) 1847	2.28 ± 4.18	2.14 ± 1.47	0.38 ± 0.84	–	0.13 ± 0.29	0.99 ± 2.11	0.119	44.0
Order Poecilostomatoida								
Corycaeidae								
Corycaeus(*Agetus*) *flaccus* Giesbrecht 1891	–	–	–	–	0.81 ± 0.9	0.16 ± 0.49	0.019	12.0
Corycaeus(*Corycaeus*) *crassiusculus* Dana 1849	–	–	–	–	0.38 ± 0.86	0.08 ± 0.38	0.009	4.0
Corycaeus(*Corycaeus*) *speciosus* Dana 1849	4.71 ± 8.29	0.7 ± 0.79	0.97 ± 1.38	2 ± 4.46	0.13 ± 0.29	1.7 ± 4.24	0.205	44.0
***Corycaeus*(*Ditrichocorycaeus*) *affinis* McMurrich 1916**	**516.23 ± 924.79**	**11.72 ± 10.03**	**1.03 ± 2.31**	–	**1.11 ± 1.59**	**106.02 ± 431.74**	**12.769**	**56.0**
Corycaeus(*Ditrichocorycaeus*) *andrewsi* Farran 1911	–	2.07 ± 2.66	–	–	0.92 ± 1.28	0.6 ± 1.47	0.072	24.0
Corycaeus(*Ditrichocorycaeus*) *dahli* Tanaka 1957	4.13 ± 8.6	1.27 ± 0.63	0.34 ± 0.77	0.19 ± 0.41	0.23 ± 0.32	1.23 ± 3.86	0.148	48.0
Corycaeus(*Ditrichocorycaeus*) *erythraeus* Cleve 1901	4.12 ± 8.61	0.3 ± 0.48	0.22 ± 0.48	–	0.64 ± 0.91	1.06 ± 3.88	0.127	28.0
Corycaeus(*Farranula*) *concinna* (Dana) 1847	–	3.44 ± 3.14	5.24 ± 3.83	–	0.57 ± 0.46	1.85 ± 2.97	0.223	56.0
Corycaeus(*Farranula*) *gibbula* Giesbrecht 1891	2.17 ± 4.26	4.5 ± 5.79	6.24 ± 5.79	3.11 ± 4.29	2.67 ± 1.31	3.74 ± 4.45	0.450	76.0

Table 2 continued

	Sampling month of 2010					All samples		
	March	May	August	September	December	Total	RA	OR
Corycaeus(*Onychocorycaeus*) *agilis* Dana 1849	–	1.42 ± 1.84	1.38 ± 3.09	5.67 ± 8.19	0.61 ± 0.65	1.81 ± 4.19	0.219	48.0
Corycaeus(*Onychocorycaeus*) *catus* F. Dahl 1894	0.1 ± 0.23	1.51 ± 0.93	–	–	0.13 ± 0.29	0.35 ± 0.72	0.042	24.0
Corycaeus(*Onychocorycaeus*) *pacificus* M. Dahl 1912	–	–	–	–	0.13 ± 0.29	0.03 ± 0.13	0.003	4.0
Corycaeus(*Urocorycaeus*) *lautus* Dana 1849	–	–	–	–	0.13 ± 0.29	0.03 ± 0.13	0.003	4.0
Oncaeidae								
Oncaea clevei Fruhtl 1863	–	0.1 ± 0.22	–	–	–	0.02 ± 0.1	0.002	4.0
***Oncaea conifera* Giesbrecht 1891**	**14.11 ± 30.26**	**1.24 ± 0.85**	**1.18 ± 2.64**	**7.02 ± 7.44**	**2.62 ± 4.33**	**5.23 ± 13.84**	**0.630**	**68.0**
Oncaea media Giesbrecht 1891	–	–	–	–	0.7 ± 0.72	0.14 ± 0.41	0.017	12.0
Oncaea minuta Giesbrecht 1892	0.12 ± 0.27	4.73 ± 2.31	4.35 ± 4	0.75 ± 1.22	3.8 ± 5.03	2.75 ± 3.45	0.331	64.0
Oncaea venusta Philippi 1843	11.59 ± 20.8	4.99 ± 3	3.49 ± 3.3	3.86 ± 4.91	0.13 ± 0.29	4.81 ± 9.71	0.579	72.0
Sapphirinidae								
Copilia mirabilis Dana 1849	2.27 ± 4.2	0.1 ± 0.22	–	–	0.2 ± 0.28	0.51 ± 1.94	0.062	24.0
Sapphirina gemma Dana 1849	–	0.14 ± 0.2	–	–	–	0.03 ± 0.1	0.003	8.0

Species in boldface indicate that the abundance of copepod with RA value over 0.5 % was applied to the Bray–Curtis cluster analysis

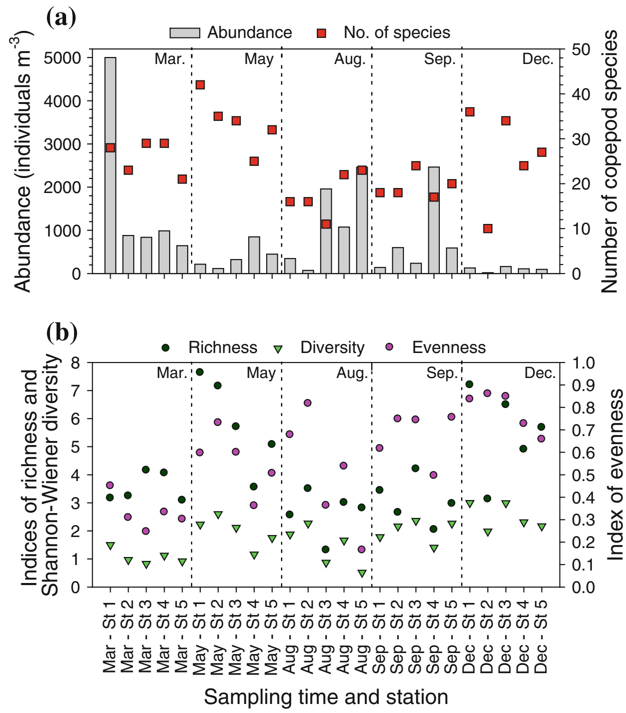

Fig. 4 Distributions of copepod density and species number (**a**), indices of richness, evenness, and Shannon–Wiener diversity (**b**) during five sampling cruises

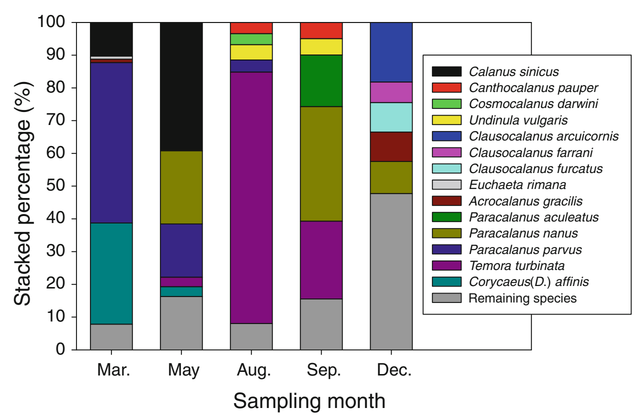

Fig. 5 Relative abundance (proportion) of the five most dominant species in each sampling cruise

succession (Hwang et al. 2004, 2006; Dur et al. 2007; Tseng et al. 2008b). In this study, the community analysis demonstrated a rapid dynamic in a monthly scale in samples between August and September, indicating that the interaction and mixing of water masses was noticeable (Fig. 7). The present results show that three copepod species belong to the cold-water species: *P. parvus*, *C.*(*D.*) *affinis,* and *C. sinicus* (Group I B, Fig. 8; Table 3). Hwang et al. (2006) reported the 5-year investigation of copepod communities in estuarine water at northwestern Taiwan. *C. sinicus* and *C.*(*D.*) *affinis* were identified as the dominant

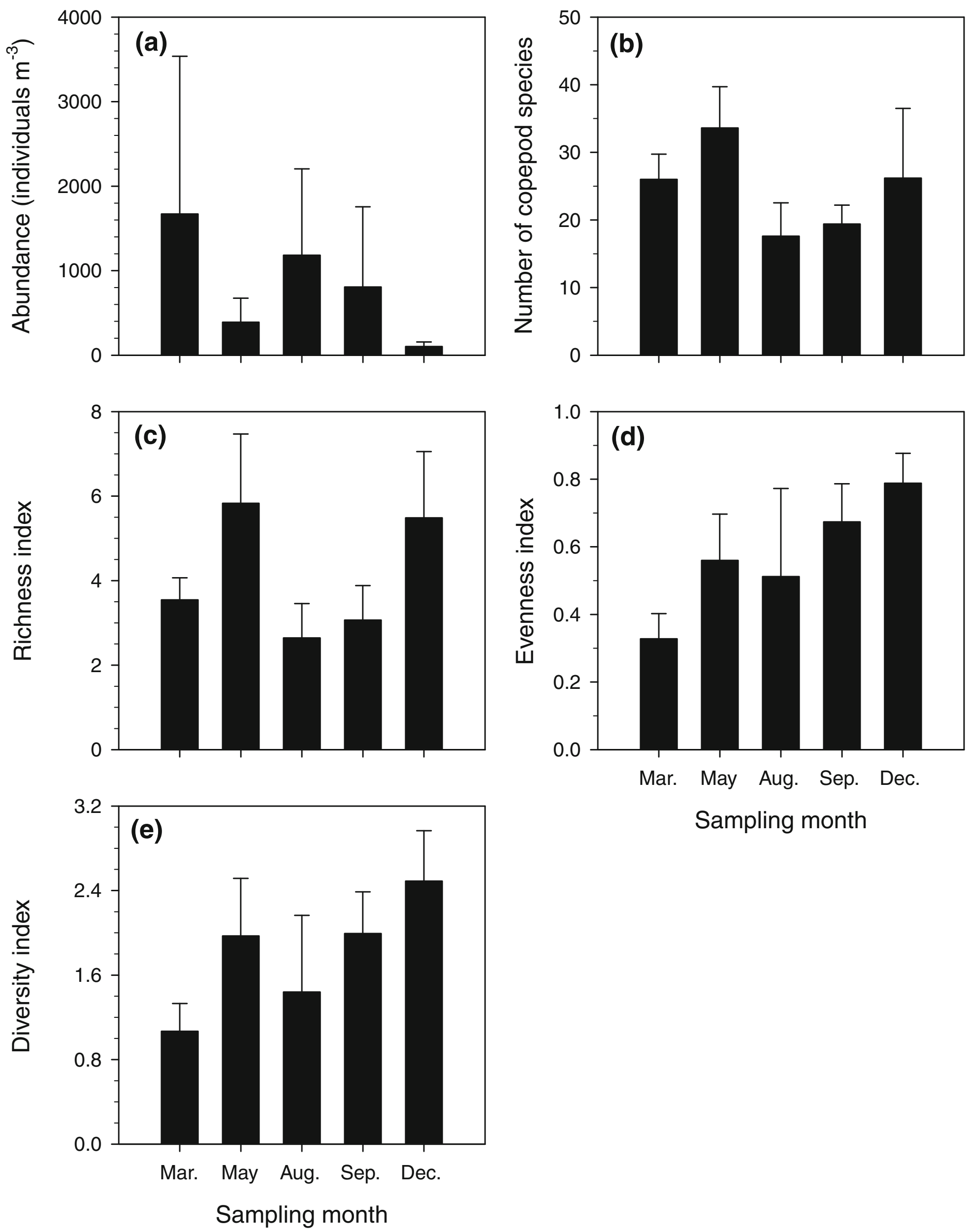

Fig. 6 Comparisons of abundance (**a**), number of species (**b**), indices of richness (**c**), evenness (**d**), and diversity (**e**) from five sampling cruises using one-way ANOVA followed by the Tukey's test

species in cold waters (14.42 ± 0.16 °C), with higher densities during winter and spring when northeast monsoon prevailed. The geographical locations of stations in this study and those of Hwang et al. (2006) were generally influenced by cold water of CCC. Thus, our results are consistent with those of Hwang et al. (2006) in that *C. sinicus* and *C.*(*D.*) *affinis* belong to cold CCC water species. Their results provide evidence that CCW can transport zooplankton of cold water to the boundary area of Kuroshio Current off northeast Taiwan. In the cluster results of this study, Group II A contained two dominant species, *P. nanus* and *P. aculeatus*. Kâ and Hwang (2011) also reported that these two species were abundant in coastal waters of northeastern Taiwan in September 2009. Their results are consistent with the findings of this study, which identified these two species in samples of August and September. These two species were also recorded in samples of KC (Hsiao et al. 2004, 2011a; Hwang et al. 2007; Kâ and Hwang 2011). Group II B, including 11 copepod species, were widely distributed and commonly found in waters around Taiwan (Shih and Young 1995; Hwang et al. 2006; Dur et al. 2007; Tseng et al. 2008b, c, d; Hsiao et al. 2011b). The results of statistical correlation indicated that copepod species of Group II B live in

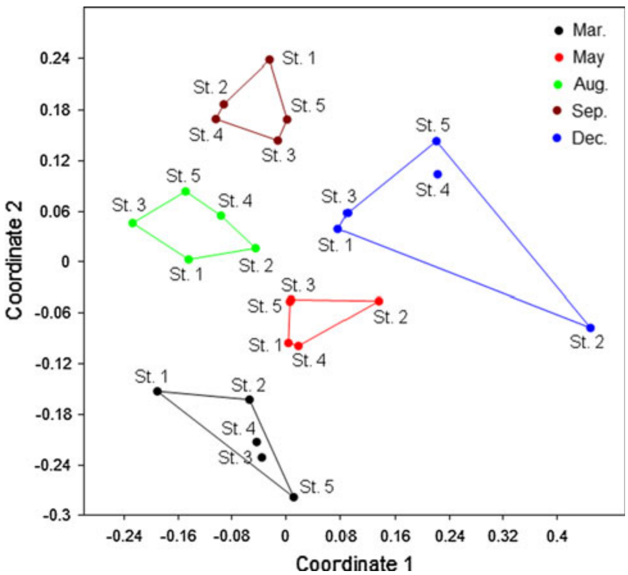

Fig. 7 Non-metric multidimensional scaling (NMDS) of all copepod data from 25 samples collected from five sampling cruises

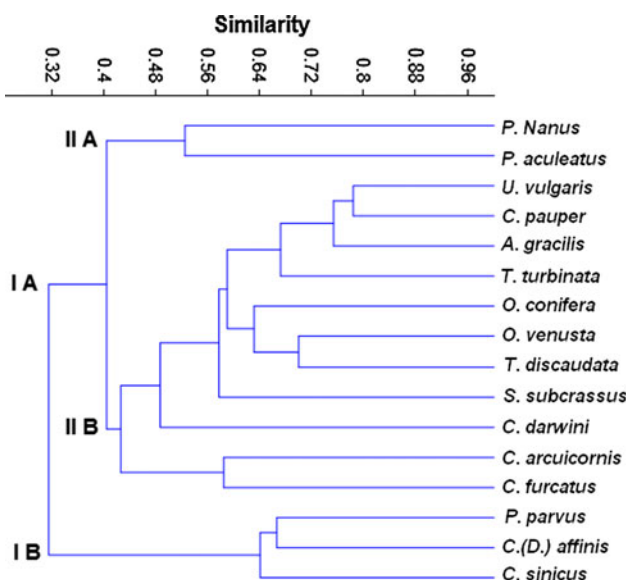

Fig. 8 Dendrogram of the 16 most abundant copepod species (comprising 94.54 % of the total copepod) measured by Bray–Curtis distances. The dendrogram shows the degree of relative similarity of distribution between species in the surface water around Turtle Island

(or favor) warm-water masses. Among these species, the abundance of *C. pauper* and *U. vulgaris* was significantly and positively correlated with seawater temperature. The species *T. turbinata* plays a vital role as an indicator of warm-water masses and was abundant in coastal areas of Taiwan (Hwang et al. 2006, 2009; Dur et al. 2007; Tseng et al. 2008c, 2011d). In the present studies, the *T. turbinata* exhibited the highest RA (26.89 %) with an average density of 223.3 ± 548.87 inds./m^3 (Table 2), implying that *T. turbinata* was the most abundant in northern Taiwan.

The highest total abundance record was at Station 1 in March 2010 (Fig. 4a). The T–S curve hints that copepod composition in sample may be influenced by KW (Fig. 3). The top three dominant species in this sample were *C.*(*D.*) *affinis*, *P. parvus,* and *C. sinicus*. These three species belong to a group of cold-water species (Hwang et al. 2004; Hwang and Wong 2005; Dur et al. 2007; Tseng et al. 2008b; Chou et al. 2012). The present results support the evidence of SST satellite images (Fig. 2a) that China coastal water intruded into region off northeastern Taiwan. In addition, the low-temperature water in the present study area might produce negative effect on species in KW (Chen 1992; Chou et al. 2012). Further, the cold-water copepod species become dominant in sample.

Remarks on *Calanoides philippinensis*

The *Calanoides philippinensis* (Calanoida: Calanidae), recorded in a single sample of May, was noticeable species among all copepods. First, the copepod taxonomic records reviewed by Shih and Young (1995) revealed that this species was not found in the seas around Taiwan. Similarly, Yamaji (1996) did not record this species in waters around Japan. By contrast, our findings are supported by the comprehensive results of Chihara and Murano (1997) and Liu (2008). This species has been reported in the ECS and in the southern area of Kagoshima Island by Chihara and Murano (1997). Furthermore, this species was distributed in SCS and Pacific Ocean adjacent to Mainland China (Liu 2008). However, several studies did not report *C. philippinensis* in the ECS (Hwang et al. 1998; Liao et al. 2006; Tseng et al. 2008d, 2011c, 2012). Therefore, previous evidence indicates that *C. philippinensis* is not the native copepod in the ECS.

Table 3 Included samples and their mean temperature for associated copepod species of cluster grouping results in Fig. 8

Cluster group	Included samples	Mean temperature (°C)
I B	All samples of March, May, August, and Station 1, 3, 4, and 5 in December	24.30 ± 2.58
II A	Station 2, 3, 4, and 5 in May, Station 2, 4, and 5 in August, all samples of September and Station 1, 3, 4, and 5 in December	25.39 ± 2.39
II B	All samples	25.16 ± 2.58

The KC is proposed as the possible pathway for the transport of *C. philippinensis* to the present study area. A number of previous studies recorded this species living in the KC-influenced area in the northeastern coast of Taiwan (Kâ and Hwang 2011), in the KC system (Hsiao et al. 2004, 2011a), and in the intruded water of KC (Hwang et al. 2007). This species was recorded in the waters around Turtle Island (Lee et al. 2006, 2009) and in the western North Pacific (Kitou and Tanaka 1969).

Tseng et al. (2008a) and Chang et al. (2010) did not identify *C. philippinensis* in their studies of the northern SCS. We traced the origin of location for *C. Philippinensis* based on the records of Chihara and Murano (1997). The previous records indicated that *C. philippinensis* originally appeared in waters of SCS near the equator. Arinardi et al. (1990) and Baars et al. (1990) reported the grazing study for this species in the Banda Sea (Indonesia) and the abundance of *C. philippinensis* in the eastern Banda Sea and northern Arafura Sea, respectively. Previous two reports suggested that *C. philippinensis* belongs to tropical species living in the SCS close to the equator.

Remarks on *Calanus sinicus*

The species *C. sinicus* was recorded in samples of March and May in this study. The recorded period exhibits a time lag when compared with previous studies in northwestern Taiwan (Hwang et al. 2006; Dur et al. 2007; Tseng et al. 2008b). The previous studies recorded *C. sinicus* in samples collected before April. The time lag may have been caused by CCC moving from China coast to northeastern Taiwan. As indicated in numerous literature, *C. sinicus* as an indicator species of ECS cold-water masses (Shih et al. 2000; Hwang and Wong 2005; Tseng et al. 2008b, 2012) originated from Bohai Sea (Chen 1992). In the waters of western Taiwan, the CCW transported *C. sinicus* to the areas close to Hong Kong (Hwang and Wong 2005), Hainan Island, and Vietnam (Chen and Zhang 1965). On the opposite site in eastern Taiwan, Turtle Island has the lowest recorded latitude that enables CCW to transport *C. sinicus* to the area (Lee et al. 2009). Our results confirmed that *C. sinicus* can be identified in the KC. Tseng et al. (2008d) reported *C. sinicus* during the cruise in July, indicating that this species appeared at stations in southwest East China Sea, except for KC-dominated stations. Considering that the KC flows northward along the eastern coast of Taiwan to Japan, Tseng et al. (2008d) suggested that water masses mix and exchange with the ECS water in the northeast of Taiwan in the upwelling region. This study provided additional information to that of Tseng et al. (2008d). Sampling time is a critical factor for the study in the Kuroshio region. Tseng et al. (2008d) conducted samplings in July, during the prevailing southwest monsoon. The CCW retreated to the northern coast of Mainland China. *C. sinicus* appeared at all stations in the southern and western East China Sea, except for the stations in the Kuroshio Current region. This may be the reason that Tseng et al. (2008d) did not find *C. sinicus* distributed in the KC area. Our results confirmed that *C. sinicus* was a seasonal succession species in the Pan-south East China Sea area.

Conclusions

This study was conducted in the area off northeast Taiwan. The SST images provided evidence that CCC affects the study areas between March and May. The occurrence of indicator species *C. sinicus* in samples confirms that the water masses of East China Sea reached the study area during that period. This study also recorded *C. philippinensis* in the sample of May, suggesting that *C. philippinensis* may originate from southern SCS. The KC may act as a transporter to bring *C. philippinensis* from the southern SCS to the study area. Eventually, the species *C. philippinensis* can reach Kagoshima Island of southern Japan. The previous and current evidence supports our hypothesis that the SCSW can ride on the Kuroshio Current and reach the southeastern ECS. Furthermore, the species *C. philippinensis* can be regarded as a bioindicator species of SCSW, similar to the species *C. sinicus*, as the bioindicator of cold water in CCC. The present study revealed that (1) KC plays an important role in transporting tropical species to the study area and (2) the composition and assemblages of copepod community exhibit a seasonal succession because of the interplay of different water masses: the CCW and the KW Current in region off northeastern Taiwan.

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