

Copepod Community Changes in the Southern East China Sea between the Early and Late Northeasterly Monsoon

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Yang-Chi Lan, Ming-An Lee, Cheng-Hsin Liao, Wen-Yu Chen, Ding-An Lee, Deng-Cheng Liu, and Wei-Cheng Su (2008) Copepod community changes in the southern East China Sea between the early and late northeasterly monsoon. *Zoological Studies* 47(1): 61-74. Weather conditions in our study area during the northeasterly (NE) monsoon season are usually rough, and it is difficult to sample on board a boat in winter; therefore, knowledge of copepod assemblages is very limited. This study was carried out at the beginning and end of the NE monsoon in Dec. 2003 and Feb. 2004, respectively, in an attempt to understand variations in copepod compositions. The Kuroshio water (KW) with high temperatures and salinities flowed past our eastern stations and affected the hydrographic conditions in these 2 study periods. At the same time, the low-temperature and -salinity China coastal water (CCW) flowed southward into our western stations in the early winter, while the Kuroshio branch water (KBW) was also introduced in our study area, and affected the hydrographic conditions of station D-2 in late winter. The average chlorophyll-*a* concentration was higher (37.0 mg/m²) in the late and lower (14.8 mg/m²) in the early northeasterly monsoon. In the present study, 109 species of copepods belonging to 5 orders, 26 families, and 48 genera were identified. Copepod species diversity and evenness increased in the CCW but decreased in the KW from early to late winter, and were higher in the KW than in the CCW in our 2 study periods. Indicator species of the CCW in early winter were *Paracalanus aculeatus* (72.5%) and *Euchaeta concinna* (72.0%), which changed to *Corycaeus (Ditrichocorycaeus) affinis* (96.7%), *Calanus sinicus* (95.9%), *P. parvus* (94.6), and *Acrocalanus gracilis* (90.9%) in late winter; those of the KW in early winter were *Pleuromamma gracilis* (100%), *Calanopia minor* (94.4%), *Rhincalanus nasutus* (92.3%), *Temoropia mayumbaensis* (90.7%), *Calocalanus pavo* (80.1%), *Clausocalanus lividus* (77.7%), *Lucicutia flavicornis* (73.4%), *Acartia danae* (72.6%), which were replaced by *Aetideus acutus* (100%), *Copilia mirabilis* (100%), *Farranula concinna* (96.5%) and *Calanoides carinatus* (75.3%) in late winter.
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Key words: Diversity, Evenness, Kuroshio, China coastal water.

The East China Sea is a western marginal sea of the North Pacific Ocean between the Yellow Sea and Taiwan Strait. It is one of the largest marginal seas in the world, sustaining an enhanced primary productivity due to rich supplies of nutrients from terrestrial and marine sources (Walsh 1991, Wollast 1991 1993). The East China Sea shelf receives rich supplies of nutrients mainly from the Yangtze River but also other smaller

ivers (Gong et al. 1996) as well as from China coastal water (CCW), Kuroshio water (KW), Kuroshio branch water (KBW), and South China Sea water (SCSW) (Jan 1995, Tseng et al. 2000, Jan et al. 2002). The Kuroshio current is a strong western boundary current, which flows northward along the east coast of Taiwan and intrudes onto the East China Sea shelf forming the Kuroshio upwelling at the shelf break (Fan 1980, Wong et

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al. 1991, Liu et al. 1992, Gong et al. 1995, Chen 1996). This upwelling brings up deep-sea water with high nutrients to the upper layer. Hydrographic systems in this area are controlled by seasonal monsoons, alternating between the northeasterly (NE) monsoon in winter and the southwesterly (SW) monsoon in summer. Seasonal variations in the hydrographic conditions in the East China Sea have been the focus of 2 major oceanographic projects, the Kuroshio Edge Exchange Processes (KEEP) and the Long-term Observations and Research of the East China Sea (LORECS) (Gong et al. 1996 2000, Liu et al. 2000, Tseng et al. 2000, Wong and Zhang 2003). In summer, the prevailing SW monsoon forces the SCSW to flow northward through the Taiwan Strait to the southwestern East China Sea; in the meanwhile, the intrusion of the KW to the East China Sea occurs year-round. When the SW monsoon is waning in autumn, the CCW gradually blocks the SCSW from moving southward. When the NE monsoon prevails in winter, the southern East China Sea is dominated by the CCW in the west and the KW in the east. Spatial and temporal distributions of chlorophyll-*a* (chl-*a*) concentrations in the East China Sea have been studied by remote sensing techniques (Ning et al. 1998, Kiyomoto et al. 2001) and *in situ* observations (Gong et al. 1996 1997 2000 2003, Chang et al. 2003).

Copepods are the most abundant zooplankton in the ocean and the main food source for marine fish larvae. They play important roles in marine food webs (Last 1978 1980, Hunter 1981, Runge 1988, Sanchez 1998). Their abundances and distributions are known to be influenced by hydrographic conditions (Boucher et al. 1987, Williams et al. 1994, Shih and Chiu 1998). Some copepods have been suggested to be good biological indicator species for water masses (Zheng et al. 1992).

Several studies have focused on copepods in our study area and nearby waters. Tan (1967) reported 42 copepod species from his northern stations. Copepod compositions and diversities of different water masses in the area have been noted in spring (Shih and Chiu 1998), summer (Liao et al. 2006), and autumn (Zuo et al. 2006), but there are scant data for winter. Shih et al. (2000) reported the diurnal compositions of copepods at 6 different depths of an upwelling station in the Mienhua Canyon in spring near our study area. Lo et al. (2004) studied the diel vertical migration of planktonic copepods at an upwelling station north of Taiwan. Compositions and abundances of

copepods in the northern Taiwan Strait (Lan et al. 2004, Hsieh et al. 2004) and in waters near the Tanshui River estuary (Hsieh and Chiu 1998, Hwang et al. 2006) near our transect have also been reported. Dur et al. (2007) investigated Calanoid copepod communities influenced by the hydrography around Taiwan. Hsieh et al. (2005) reported the influences of the seasonal monsoons on the compositions and abundances of copepods and ichthyoplankton in the Taiwan Strait. Movements of *Calanus sinicus* and *Undinula vulgaris* driven by currents were discussed by Hwang and Wong (2005) and Xu (2006), respectively.

Weather conditions of the study area during the NE monsoon season are usually rough, and therefore sampling is difficult and dangerous in winter. Thus, the winter composition of copepod fauna in this study area is practically unknown. Our study intended to examine the distributional and compositional changes of copepods between the early and late NE monsoon in the southeastern East China Sea, where fishery activities are high, but information on copepods is scarce in winter.

MATERIALS AND METHODS

Plankton samples were sampled on board of the *Fishery Researcher I* using an ORI net with a mouth diameter of 160 cm and mesh size of 330 μm during the periods of 22-28 Dec. 2003 and 25-26 Feb. 2004 (Fig. 1). A flowmeter was mounted at the center of the mouth to calculate the volume of water filtered, and a depth sensor was placed at the front of the net to record the sampling depth. The net was towed obliquely from a depth near the bottom to the surface, or from 200 m to surface if the depth of the bottom exceeded 200 m. The plankton samples were preserved in seawater with 5%-10% formalin.

At each station prior to taking a plankton sample, the temperature and salinity were recorded by a CTD (conductivity, temperature, and salinity) profiler lowered from the sea surface to near the bottom. Water samples for measuring chl-*a* concentrations were collected at the 6 depths of 5, 25, 50, 75, 100, and 150 m using a Rosette Niskin attached to the CTD profiler. Wind speed and direction over the ocean surface were retrieved from measurements of the QuikScat backscattered power (Wentz et al. 2001). QuikScat is essentially a radar device that transmits radar pulses down to the Earth's surface and then measures the power that is scattered back to the instrument. NOAA

satellites provide sea surface temperature (SST) measurements from AVHRR instruments, and are practical for showing the spatial distributions of the hydrographic environment. AVHRR images with 1.1 km spatial resolution were obtained from our satellite receiving station at the Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan (Lee et al. 2005). Each plankton sample was repeatedly divided with a Folsom splitter until its subsample contained 300-500 specimens of copepods. Copepods were then sorted and identified to species, whenever possible, and the number of each copepod species was recorded. The abundance of copepods was expressed as the number of individuals per cubic meter (inds/m³).

Shannon's diversity index was used to calculate the species diversity, and Simpson's evenness was used to measure the relative abundances of species at each station. Cluster analysis with normalized Euclidean distances was used to measure the levels of similarity of the species compositions among the sampling stations, and Ward's method was used to illustrate the relations of these stations in a dendrogram. Copepod abundance was transformed by a logarithmic function [$\ln(N+1)$] for the cluster analysis. Indicator species analysis (Dufrêne and Legendre 1997) was also used to determine the indicator species in different hydrographic environments.

RESULTS

The hydrographic environment in the southern East China Sea is affected by the NE monsoon in winter. In 2003-2004, the NE monsoon was stronger in early winter than in late winter (Fig. 2), resulting in different hydrographic conditions in our 2 study periods. Spatial distributions of the SST derived from NOAA AVHRR periods showed the hydrographic conditions in these 2 study periods (Fig. 3). Offshore water, which comprised the eastern water of our study area, was occupied by a warmer water mass in contrast to onshore water which was dominated by a colder water mass in these 2 study periods. Vertical distributions of temperature and salinity (Fig. 4) derived from the CTD data showed that temperature and salinity of the stations in onshore water varied from 17.7 to 20.3°C and 32.1 to 34.41 psu, respectively, in Dec., and 15.1 to 21.0°C and 32.16 to 34.28 psu, respectively, in Feb. 2004. Temperature and salinity were higher at stations of offshore water, and the temperature decreased with increasing depth. The SST and salinity of stations of offshore water varied from 21.4 to 23.7°C and 34.55 to 34.61 psu in Dec. 2003, and 22.5 to 24.8°C and 34.31 to 34.35 psu in Feb. 2004, respectively.

The average chl-a concentrations of the layer from the surface to bottom or 100 m (if the water depth exceeded 100 m) were higher in Feb. 2004

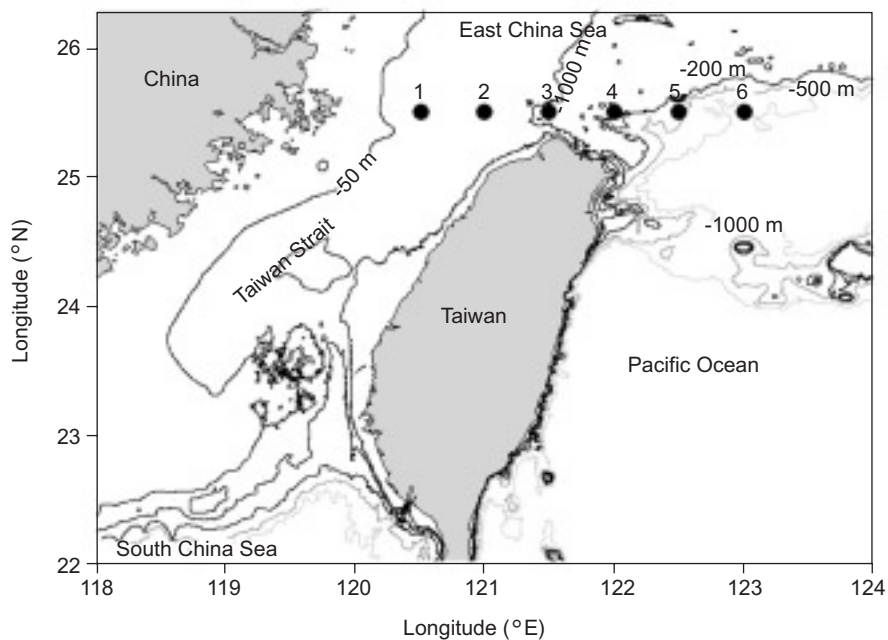


Fig. 1. Topography and locations of the sampling stations (solid circles) with isobaths of 50, 100, 200, 500 and 1000 m in this study area.

(14.8 mg/m²) than in Dec. 2003 (37.0 mg/m²), especially in the CCW (station F-1) and the submarine canyon (station F-4, Fig. 5).

In this study, 109 species of copepods belonging to 5 orders, 26 families, and 48 genera were identified (Table 1). Copepod abundances in Dec. 2003 ranged between 63.37 and 242.2 inds/m³, and were highest at station D-4 in the vicinity of the submarine canyon; in Feb. 2004, they ranged between 68.0 and 1248 inds/m³, and were higher at western stations and lower at eastern stations (Fig. 6). The dominant species in Dec. 2003 were *Paracalanus aculeatus* (mean \pm SE, 56 \pm 65.1 inds/m³), *Acrocalanus gibber* (6.9 \pm 10.7 inds/m³), and *Paracalanus parvus* (5.3 \pm 5.3 inds/m³); and in Feb. 2004, they were *P. parvus* (94.7 \pm 215.7 inds/m³), *Calanus sinicus* (34.1 \pm 56.6 inds/m³), and *Corycaeus (Ditrichocorycaeus) affinis* (16.7 \pm 24.5 inds/m³).

Species diversity and evenness of copepods at each sampling station gradually increased eastward in these 2 study periods (Fig. 7). In warm-water areas, species diversity and evenness were higher in Dec. 2003 than in Feb. 2004, but these were reversed in cold-water areas. According to the results of the cluster analysis, sampling stations were divided into 4 groups (A, B, C, and D) and 2 subgroups (A1 and A2, Fig. 8). Stations of groups A and B located in the cold-water area were influenced by the CCW, while groups C and D were found in the KW in both sampling periods (Figs. 2, 8). Group A was divided into 2 subgroups, A1 and A2, where station F-1 belongs to

subgroup A2 in the typical CCW, and stations F-2 and F-3 belong to subgroup A1 in the vicinity of warm water (KBW) coming from the southern Taiwan Strait. Species with higher indicator values (IVs) were more representative of the water mass, with a value of 100 indicating a perfect indicator. Indicator species with IV values exceeding 60% (Table 2) were chosen to represent different water masses. In the CCW, there were 2 indicator species, *Paracalanus aculeatus* (with an IV of 72.5%) and *Euchaeta concinna* (72%) in Dec. 2003, and 5 indicator species, *Corycaeus (Ditrichocorycaeus) affinis* (96.7%), *Calanus sinicus* (95.9%), *P. parvus* (94.6%), *Acrocalanus gracilis* (90.9%), *Temora turbinata* (73.9%), and *Canthocalanus pauper* (70.3%) in Feb. 2004. In the KW, there were 8 species, including *Pleuromamma gracilis* (100%), *Calanopia minor* (94.4%), *Rhincalanus nasutus* (92.3%), *Temoropia mayumbaensis* (90.7%), *Calocalanus pavo* (80.1%), *Clausocalanus lividus* (77.7%), *Lucicutia flavicornis* (73.4%), and *Acartia danae* (72.6%) in Dec. 2003, and 4 species, *Aetideus acutus* (100%), *Copilia mirabilis* (100%), *Farranula concinna* (96.5%), and *Calanoides carinatus* (75.3%), in Feb. 2004.

DISCUSSION

The marine environment of our study area is influenced by monsoon systems and the bottom topography (Chao 1991, Gong et al. 2000, Jan et

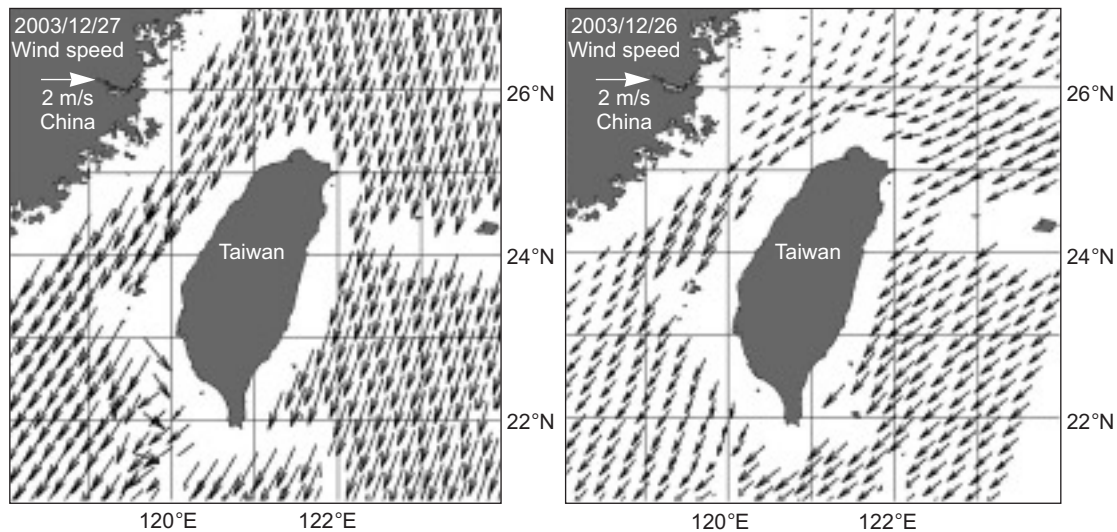


Fig. 2. Wind conditions of our 2 study periods derived from QuikScat. The direction and length of the arrows respectively indicate the direction and strength of the winds.

al. 2006). The northeasterly monsoon prevailed in our sampling period in early winter (Fig. 2), forcing the CCW (Fig. 3), characterized by lower temperatures and salinities, to flow southward from the northern East China Sea to the shelf waters of our study area (stations F-1, F-2, and F-3). Gong et al. (2000) reported that the CCW, with high nutrients (such as NO_3) in its surface water, occurred in Nov. and Mar. and resulted in chl-a blooms in late

spring; it was suggested to be correlated with solar irradiance and the turbidity of the waters. In our study periods, lower chl-a concentrations in early winter and elevated ones in late winter (especially at station F-1, Fig. 5) of the CCW may be attributed to increasing solar irradiance. Copepod abundances in the CCW increased in later winter due to elevation of chl-a concentrations (Fig. 6). Higher temperatures and salinities of offshore

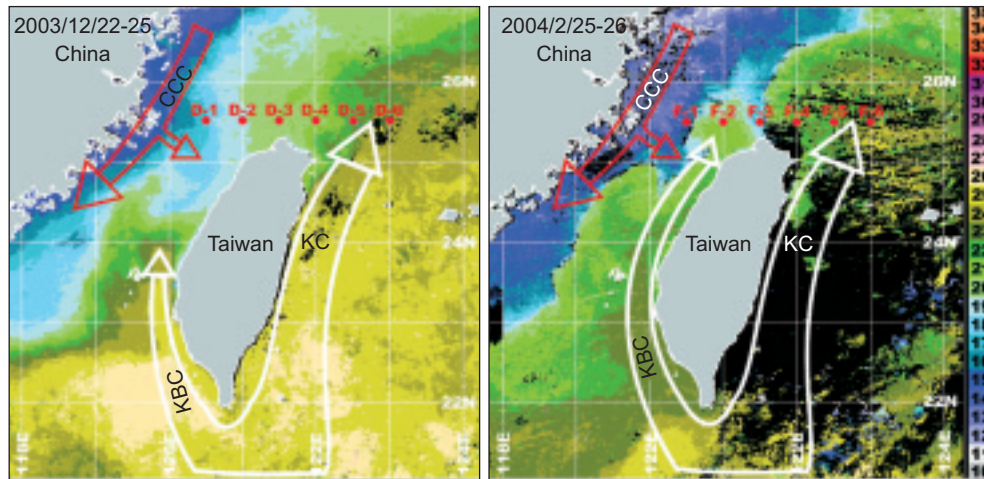


Fig. 3. Spatial distributions of the sea surface temperature ($^{\circ}\text{C}$) derived from NOAA AVHRR with sampling locations (red circles) and currents in our 2 study periods. CCC, China Coastal Current; KC, Kuroshio Current; KBC, Kuroshio Branch Current.

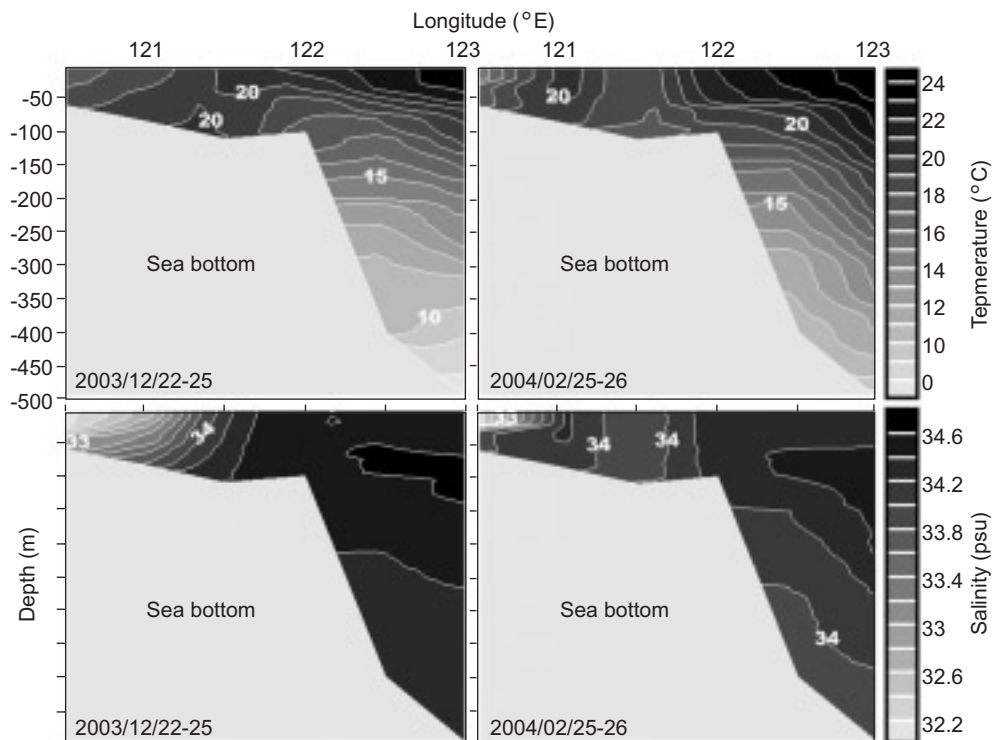


Fig. 4. Vertical distributions of temperature (A and B) and salinity (C and D) in our 2 study periods.

waters were introduced by KW (Fig. 3), and high chl-*a* concentrations were found at station F-4 in the vicinity of the Kuroshio upwelling center in our late winter cruise (Fig. 5). The location of the upwelling center shifts according to changes in the seasonal monsoons (NE and SW monsoons). It shifts shelfward when the path of the Kuroshio pushes shelfward in winter (Gong et al. 1997), providing the shelf with constant nutrient fluxes (Liu et al. 2000). Upwelling water has been recorded being pushed inshore by the intruding water of the Kuroshio surface water from mid-Oct. (Tang and Yang 1993) to mid-Apr. (Chuang and Liang 1994), and elevated chl-*a* was observed in the middle shelf (Gong et al. 2000). The relationship between chl-*a* concentrations and copepod assemblages is complex and hard to characterize in short-term research. Zuo et al. (2006) reported that salinities and temperatures were more important than chl-*a* concentrations in characterizing copepod assemblages of the continental shelf of the Yellow Sea and East China Sea. Food quantity and quality limitations are also important to copepod production (Gill and Harris 1987, Ianora and Poulet 1993, Miralto et al. 1995, Ianora et al. 1996), development (Giani 1991, Kjørbe and Sabatini 1995), and mortality (Conover 1967, Huntley et al. 1986, Gill and Harris 1987), all of which affect copepod populations. The lack of copepod abundance at station F-4 where phytoplankton bloomed in late winter was likely due to a temporal delay or a combination of limitations of hydrographic conditions and food quality.

Studies on the biodiversity of planktonic copepods are limited by sampling materials and meth-

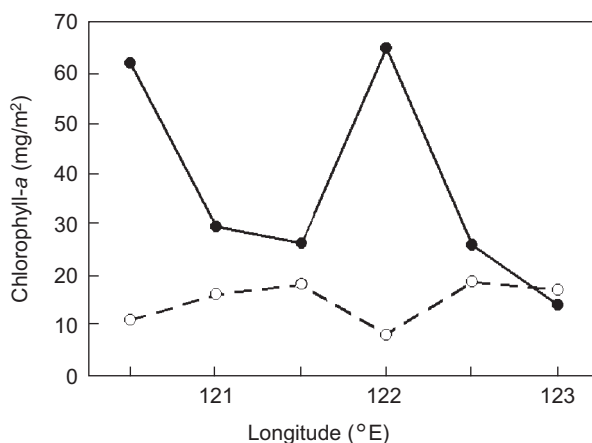


Fig. 5. Chlorophyll-*a* (chl-*a*) concentrations of each sampling station in Dec. 2003 (dotted line) and Feb. 2004 (solid line).

ods. The diel vertical migration of planktonic copepods in our study area has been reported, and it was revealed that most of the dominant copepod species are distributed in the water column shallower than 200 m (Lo et al. 2004). We collected copepod samples from 200 m deep to the sea surface when the water depth exceeded 200 m and considered that to be suitable for studying copepod assemblages in this study area; however, copepods living in water deeper than 200 m were ignored. Most data on copepod abundance and diversity were derived from net samples with a mesh size of 330 μm (Hsieh and Chiu 1998, Lan et al. 2004, Lo et al. 2004, Hwang et al. 2006, Liao et al. 2006, Dur et al. 2007) or greater (500 μm : Shih and Chiu 1998), but a few studies sampled with a mesh size of 150 (Hsieh et al. 2004 2005) and

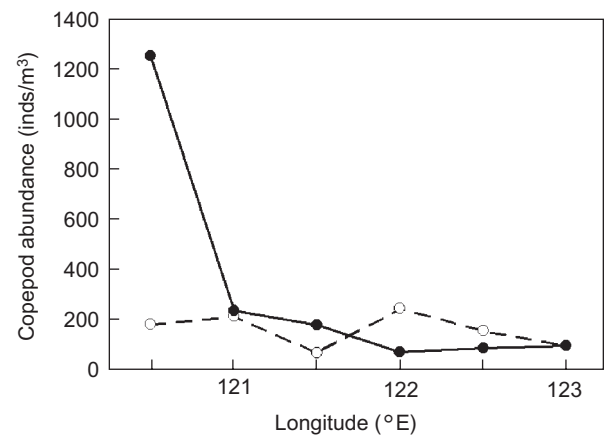


Fig. 6. Copepod abundances of each sampling station in Dec. 2003 (dotted line) and Feb. 2004 (solid line).

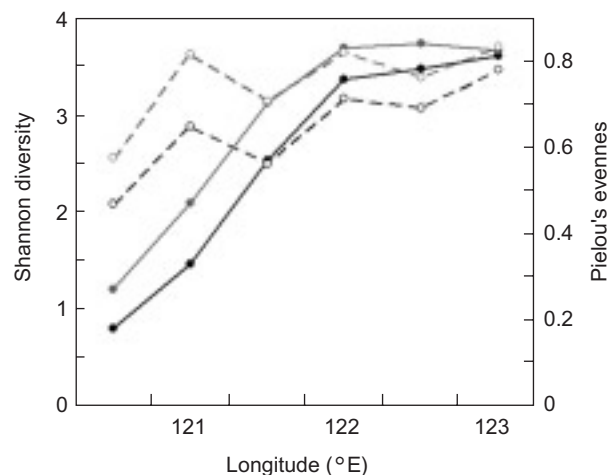


Fig. 7. Shannon's diversity (black) and Pielou's evenness (gray) of each sampling station in Dec. 2003 (solid line) and Feb. 2004 (dotted line).

Table 1. (Cont.)

| Stations: | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | F-1 | F-2 | F-3 | F-4 | F-5 | F-6 |
|--|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|
| Longitude (°E) | 120°30' | 121° | 121°30' | 122° | 122°30' | 123° | 120°30' | 121° | 121°30' | 122° | 122°30' | 123° |
| Latitude (°N) | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' |
| Copepod abundance (inds/m ³) | 178.9 | 210.5 | 63.4 | 242.2 | 152.3 | 90.8 | 1248 | 232.7 | 173.3 | 68.0 | 81.8 | 93.3 |
| Copepod percentage (%) | 90.93 | 85.01 | 81.92 | 81.22 | 74.08 | 74.12 | 72.93 | 72.62 | 62.42 | 69.04 | 62.19 | 74.08 |
| Shannon's diversity | 0.77 | 1.44 | 2.51 | 3.36 | 3.47 | 3.60 | 2.07 | 2.87 | 2.48 | 3.15 | 3.06 | 3.46 |
| Pielou's evenness | 0.27 | 0.47 | 0.70 | 0.83 | 0.84 | 0.82 | 0.57 | 0.81 | 0.70 | 0.82 | 0.76 | 0.83 |
| <i>Paracandacia bispinose</i> | 0 | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 1.04 |
| <i>Paracandacia truncata</i> | 0 | 0 | 0 | 0 | 0.17 | 0.08 | 0 | 0 | 0 | 0.25 | 0 | 0 |
| <i>Candaciidae copepodid</i> | 0 | 0 | 0 | 0.70 | 0.50 | 0.64 | 0.11 | 0.32 | 0 | 0.25 | 0.50 | 0.41 |
| CENTROPAGIDAE | | | | | | | | | | | | |
| <i>Centropages calaninus</i> | 0 | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0.33 | 0 |
| <i>Centropages elongatus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.17 | 0.21 |
| <i>Centropages furcatus</i> | 0 | 0 | 0 | 0.18 | 0 | 0.16 | 0 | 0 | 0 | 0.25 | 0 | 0 |
| <i>Centropages gracilis</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.21 |
| <i>Centropages copepodid</i> | 0 | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0.76 | 0.17 | 0.41 |
| CLAUSOCALANIDAE | | | | | | | | | | | | |
| <i>Clausocalanus arcuicornis</i> | 0 | 0 | 0 | 0.88 | 0.99 | 0.48 | 0 | 0.64 | 0 | 2.52 | 0.33 | 1.24 |
| <i>Clausocalanus farrani</i> | 0 | 0 | 0 | 1.23 | 0.33 | 0.56 | 0.22 | 0 | 0 | 0.25 | 0 | 1.24 |
| <i>Clausocalanus furcatus</i> | 0 | 0 | 3.20 | 3.50 | 5.78 | 4.75 | 0.65 | 1.92 | 2.21 | 6.05 | 8.47 | 3.52 |
| <i>Clausocalanus lividus</i> | 0 | 0 | 0 | 0.70 | 0.50 | 1.05 | 0 | 0 | 0 | 0.76 | 0.33 | 0.21 |
| <i>Clausocalanus mastigophorus</i> | 0 | 0 | 0.36 | 1.23 | 0.50 | 0 | 0 | 0 | 1.47 | 0.76 | 1.00 | 0.41 |
| <i>Clausocalanus minor</i> | 0.12 | 0 | 0.36 | 2.10 | 3.47 | 4.67 | 0.87 | 1.92 | 0.49 | 3.02 | 0.66 | 1.86 |
| <i>Clausocalanus copepodid</i> | 0.12 | 0 | 2.49 | 4.20 | 13.70 | 9.65 | 0.11 | 0.64 | 1.47 | 11.08 | 8.14 | 15.53 |
| EUCALANIDAE | | | | | | | | | | | | |
| <i>Rhincalanus nasutus</i> | 0 | 0 | 0 | 1.40 | 0.33 | 0.24 | 0 | 0 | 0 | 0.50 | 0 | 0 |
| <i>Rhincalanus rostrifrons</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0.25 | 0.50 | 0.41 |
| <i>Subeucalanus crassus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.32 | 0 | 0 | 0 | 0 |
| <i>Subeucalanus mucronatus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.32 | 0 | 0 | 0 | 0 |
| <i>Subeucalanus subtenuis</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.21 |
| <i>Subeucalanus subcrassus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0.11 | 0 | 0 | 0 | 0 | 0 |
| <i>Eucalanidae copepodid</i> | 0.24 | 0.24 | 0.36 | 5.78 | 1.65 | 1.29 | 0.87 | 3.83 | 1.23 | 9.32 | 4.65 | 4.14 |
| EUCHAETIDAE | | | | | | | | | | | | |
| <i>Euchaeta concinna</i> | 0.24 | 2.38 | 0.36 | 0 | 0 | 0 | 0.11 | 0 | 0.49 | 0 | 0 | 0 |
| <i>Euchaeta indica</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0.11 | 0 | 0 | 0 | 0 | 0 |
| <i>Euchaeta plana</i> | 0 | 0 | 0 | 0 | 0 | 0.16 | 0.32 | 0 | 0.25 | 0 | 0 | 0 |
| <i>Euchaeta rimana</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.64 | 0.25 | 0 | 0 | 0.21 |
| <i>Euchaeta spinosa</i> | 0.36 | 0 | 0 | 0 | 0 | 0.72 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Euchaetidae copepodid</i> | 4.33 | 10.01 | 10.32 | 6.13 | 5.61 | 4.42 | 6.71 | 3.51 | 3.93 | 3.53 | 3.16 | 4.97 |
| HETERORHABDIDAE | | | | | | | | | | | | |
| <i>Heterorhabdus papilliger</i> | 0 | 0 | 0 | 0.35 | 0.17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Heterorhabdus spinifrons</i> | 0 | 0 | 0 | 0.35 | 0 | 0.40 | 0 | 0 | 0 | 0 | 0 | 0.21 |
| LUCICUTIIDAE | | | | | | | | | | | | |
| <i>Lucicutia flavicornis</i> | 0 | 0 | 0.71 | 1.75 | 7.10 | 0.80 | 0.22 | 0 | 0 | 0.50 | 0.83 | 1.66 |
| <i>Lucicutia sp</i> | 0 | 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| METRIDINIDAE | | | | | | | | | | | | |
| <i>Pleuromamma abdominalis</i> | 0 | 0 | 0 | 0 | 0.33 | 3.70 | 0 | 0 | 0 | 0 | 0.17 | 0 |
| <i>Pleuromamma gracilis</i> | 0 | 0 | 0 | 0.88 | 3.96 | 6.60 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Pleuromamma robusta</i> | 0 | 0 | 0 | 0 | 0 | 0.48 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Pleuromamma xiphias</i> | 0 | 0 | 0 | 0 | 0.50 | 0.48 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Pleuromamma copepodid</i> | 0 | 0 | 0 | 1.40 | 2.81 | 2.49 | 0 | 0 | 0 | 0 | 1.99 | 0.41 |
| PARACALANIDAE | | | | | | | | | | | | |
| <i>Acrocalanus gibber</i> | 0 | 0 | 1.42 | 11.56 | 4.46 | 6.60 | 0.22 | 0.64 | 0.74 | 10.08 | 4.98 | 0.83 |
| <i>Acrocalanus gracilis</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0.22 | 2.88 | 0.49 | 1.51 | 0 | 0 |
| <i>Acrocalanus monachus</i> | 0 | 0 | 0 | 0.35 | 0 | 0 | 0 | 0 | 0 | 0.50 | 0 | 0.21 |

Table 1. (Cont.)

| Stations: | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | F-1 | F-2 | F-3 | F-4 | F-5 | F-6 |
|--|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|
| Longitude (°E) | 120°30' | 121° | 121°30' | 122° | 122°30' | 123° | 120°30' | 121° | 121°30' | 122° | 122°30' | 123° |
| Latitude (°N) | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' | 25°30' |
| Copepod abundance (inds/m ³) | 178.9 | 210.5 | 63.4 | 242.2 | 152.3 | 90.8 | 1248 | 232.7 | 173.3 | 68.0 | 81.8 | 93.3 |
| Copepod percentage (%) | 90.93 | 85.01 | 81.92 | 81.22 | 74.08 | 74.12 | 72.93 | 72.62 | 62.42 | 69.04 | 62.19 | 74.08 |
| Shannon's diversity | 0.77 | 1.44 | 2.51 | 3.36 | 3.47 | 3.60 | 2.07 | 2.87 | 2.48 | 3.15 | 3.06 | 3.46 |
| Pielou's evenness | 0.27 | 0.47 | 0.70 | 0.83 | 0.84 | 0.82 | 0.57 | 0.81 | 0.70 | 0.82 | 0.76 | 0.83 |
| <hr/> | | | | | | | | | | | | |
| <i>Paracalanus aculeatus</i> | 83.17 | 61.08 | 27.40 | 12.96 | 3.63 | 4.99 | 2.16 | 6.71 | 1.72 | 9.32 | 19.60 | 2.69 |
| <i>Paracalanus crassirostris</i> | 0.24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Paracalanus nanus</i> | 0 | 0.24 | 0 | 0 | 0.83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Paracalanus parvus</i> | 6.85 | 5.56 | 4.98 | 0.88 | 1.32 | 0.56 | 42.86 | 7.35 | 9.09 | 0.25 | 0.50 | 0 |
| <i>Paracalanus serrulus</i> | 0.24 | 0 | 1.07 | 0.35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Paracalnidiae copepodid</i> | 0 | 11.99 | 5.34 | 6.48 | 3.14 | 0 | 4.55 | 3.83 | 0 | 0 | 1.83 | 0 |
| PHAENNIDAE | | | | | | | | | | | | |
| <i>Xanthocalanus copepodid</i> | 0 | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 |
| PONTELLIDAE | | | | | | | | | | | | |
| <i>Calanopia minor</i> | 0 | 0 | 0 | 0.35 | 3.30 | 1.37 | 0 | 0 | 0.25 | 0 | 0 | 0 |
| <i>Pontellidae copepodid</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0 | 0 | 0.41 |
| SCOLECITHRICIDAE | | | | | | | | | | | | |
| <i>Scaphocalanus brevicornis</i> | 0 | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Scolecithricella dentate</i> | 0 | 0 | 0 | 0.18 | 0 | 0.48 | 0 | 0 | 0 | 0 | 0.33 | 0 |
| <i>Scolecithricella minor</i> | 1.44 | 3.65 | 9.25 | 0.53 | 0.66 | 0.16 | 0.43 | 0 | 0 | 0.50 | 0 | 0.41 |
| <i>Scolecithricella vittata</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.17 | 0 |
| <i>Scolecithricella copepodid</i> | 0 | 0 | 0 | 0 | 0 | 1.93 | 0.00 | 0 | 0 | 0 | 0 | 0 |
| <i>Scolecithrix danae</i> | 0 | 0 | 0.36 | 0.53 | 0.17 | 0.48 | 0.11 | 0.32 | 0 | 0.50 | 0.33 | 0.41 |
| <i>Scottocalanus helenae</i> | 0 | 0 | 0 | 0 | 0 | 1.29 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Scottocalanus terranova</i> | 0 | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Scottocalanus copepodid</i> | 0 | 0 | 0 | 0 | 0 | 0.56 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Scolecithricidae copepodid</i> | 0 | 0 | 0.36 | 1.05 | 1.16 | 2.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| TEMORIDAE | | | | | | | | | | | | |
| <i>Temora discaudata</i> | 0 | 0 | 0.36 | 1.23 | 0.66 | 0.56 | 0.11 | 0.64 | 0 | 0.50 | 0.66 | 0.83 |
| <i>Temora turbinata</i> | 0 | 0 | 17.79 | 0.18 | 0.17 | 0 | 1.41 | 3.83 | 4.67 | 0 | 0.33 | 0 |
| <i>Temoropia mayumbaensis</i> | 0 | 0 | 0 | 0.35 | 0.17 | 0.24 | 0 | 0 | 0 | 0 | 0.17 | 0 |
| ORDER : CYCLOPOIDA | | | | | | | | | | | | |
| OITHONIDAE | | | | | | | | | | | | |
| <i>Oithona fallax</i> | 0 | 0 | 0 | 0.70 | 0.83 | 0 | 0 | 0 | 0 | 0 | 0 | 0.62 |
| <i>Oithona plumifera</i> | 0.12 | 0.24 | 1.42 | 3.85 | 2.64 | 2.74 | 0.22 | 2.24 | 0 | 1.26 | 3.82 | 2.48 |
| <i>Oithona pseudofrigida</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.62 |
| <i>Oithona setigera</i> | 0 | 0 | 0.36 | 2.80 | 0.99 | 1.45 | 0.11 | 0 | 0 | 0 | 0.33 | 3.93 |
| <i>Oithona similis</i> | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Oithona copepodid</i> | 0 | 0.56 | 0 | 0.53 | 0.33 | 0.48 | 0 | 0 | 0.25 | 0 | 0.33 | 0.21 |
| ORDER : POECILOSTOMATOIDA | | | | | | | | | | | | |
| CORYCAEIDAE | | | | | | | | | | | | |
| <i>C.(Agetus) flaccus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0 | 0.41 |
| <i>C.(Agetus) limbatus</i> | 0 | 0 | 0 | 0 | 0 | 0.16 | 0 | 0 | 0 | 0 | 0 | 0.83 |
| <i>C.(Agetus) typicus</i> | 0 | 0 | 0 | 0.18 | 0 | 0 | 0 | 0 | 0.25 | 0.25 | 0 | 0 |
| <i>C.(Corycaeus) clausi</i> | 0 | 0 | 0 | 0.53 | 0 | 0 | 0.11 | 0 | 0 | 1.01 | 0 | 0.41 |
| <i>C.(Corycaeus) crassiusculus</i> | 0 | 0 | 0 | 0 | 0 | 0.48 | 0 | 0 | 0 | 0 | 0 | 0.62 |
| <i>C.(Corycaeus) speciosus</i> | 0 | 0 | 0 | 0.53 | 0.66 | 1.69 | 0.22 | 0 | 1.72 | 3.78 | 1.66 | 2.28 |
| <i>C.(Corycaeus) vitreus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.17 | 0 |
| <i>C.(Ditrichocorycaeus) affinis</i> | 0.60 | 0.95 | 0.36 | 0 | 0 | 0.08 | 4.33 | 1.92 | 24.08 | 0 | 0 | 0 |
| <i>C.(Ditrichocorycaeus) andrewsi</i> | 0 | 0 | 0 | 0.35 | 0 | 0 | 0 | 0.32 | 0 | 0 | 0.17 | 0 |
| <i>C.(Ditrichocorycaeus) asiaticus</i> | 0 | 0 | 0.36 | 0 | 0.17 | 0.16 | 0.76 | 0 | 0 | 0 | 0.17 | 0 |

decrease or easily be lost compared to nets with larger mesh size during phytoplankton blooms in spring. Therefore, several different mesh sizes of plankton nets should be used at the same time each season to decide the best mesh size to estimate biodiversity of copepods in the study area. In our study, copepod diversity and evenness increased eastward from the CCW to the KW, similar to that reported by Shih and Chiu (1998). The

Kuroshio is a strong western boundary current flowing northward off the eastern coast of Taiwan and carries the tropical copepod fauna with high diversity to stations in the KW of our study area (Fig. 3). However the CCW flows southward along the China coast and carries a low-diversity, temperate copepod fauna to our study area. In late winter, the KBW flows northward to the vicinity of station F-2 and enhances copepod diversity of this

Table 2. Indicator value (IV; %) of the 20 copepod species (with an IV > 60%) in Kuroshio water and China coastal water of the 2 sampling periods

| IV value | China Coastal Waters | | Kuroshio Waters | |
|---------------------------------------|----------------------|-------------|-----------------|-------------|
| | Dec. 2003 | Feb. 2004 | Dec. 2004 | Feb. 2005 |
| <i>Paracalanus aculeatus</i> | 72.5 | 11.2 | 10.2 | 6.1 |
| | | 83.7 | | 16.3 |
| <i>Euchaeta concinna</i> | 72.0 | 18.6 | 0 | 0 |
| | | 83.3 | | 0 |
| <i>Pleuromamma gracilis</i> | 0 | 0 | 100 | 0 |
| | | 0.0 | | 50.0 |
| <i>Calanopia minor</i> | 0 | 1.9 | 94.4 | 0 |
| | | 0.9 | | 47.2 |
| <i>Rhincalanus nasutus</i> | 0 | 0 | 92.3 | 2.6 |
| | | 0 | | 66.7 |
| <i>Temoropia mayumbaensis</i> | 0 | 0 | 90.7 | 3.1 |
| | | 0 | | 66.7 |
| <i>Calocalanus pavo</i> | 0.7 | 2.3 | 80.1 | 10.9 |
| | | 3.0 | | 90.9 |
| <i>Clausocalanus lividus</i> | 0 | 0 | 77.7 | 22.3 |
| | | 0 | | 100 |
| <i>Lucicutia flavicornis</i> | 0.7 | 4.2 | 73.4 | 11.9 |
| | | 4.9 | | 85.3 |
| <i>Acartia danae</i> | 0 | 6.3 | 72.6 | 2.8 |
| | | 3.1 | | 54.1 |
| <i>C. (Ditrichocorycaeus) affinis</i> | 3.2 | 96.7 | 0 | 0 |
| | | 99.9 | | 0 |
| <i>Calanus sinicus</i> | 2.5 | 95.9 | 1.6 | 0 |
| | | 98.4 | | 0.8 |
| <i>Paracalanus parvus</i> | 4.5 | 94.6 | 0.8 | 0.1 |
| | | 99.1 | | 0.7 |
| <i>Acrocalanus gracilis</i> | 0 | 90.9 | 0 | 3.0 |
| | | 45.4 | | 1.5 |
| <i>Temora turbinata</i> | 8.0 | 73.9 | 1.0 | 0.2 |
| | | 65.3 | | 1.0 |
| <i>Canthocalanus pauper</i> | 1.4 | 70.3 | 18.5 | 9.8 |
| | | 71.7 | | 28.3 |
| <i>Aetideus acutus</i> | 0 | 0 | 0 | 100 |
| | | 0 | | 50.0 |
| <i>Copilia mirabilis</i> | 0 | 0 | 0 | 100 |
| | | 0 | | 50.0 |
| <i>Farranula concinna</i> | 0 | 0 | 1.2 | 96.5 |
| | | 0 | | 66.7 |
| <i>Calanoides carinatus</i> | 0 | 16.5 | 0 | 75.3 |
| | | 8.2 | | 37.7 |

station compared to adjacent stations, F-1 and F-3 (Fig. 7). KBW originates from the KB and carried tropical copepods through the Taiwan Strait to our sampling station, F-2.

Based on the hydrographic distribution (Fig. 3) and the cluster analysis of the copepod composition (Fig. 8), stations in the same water mass had fairly similar species compositions of copepods in the 2 sampling periods, although some temporal variations were present. Distributions of copepods are significantly influenced by hydrographic dynamics in the southern East China Sea, since they are sensitive to changes in hydrographic conditions (Shih and Chiu 1998, Hsieh et al. 2004, Lan et al. 2004, Dur et al. 2007). Hydrographic conditions in the offshore waters are influenced year-round by the KW (Hsueh 200) and are more stable than those in onshore waters. The latter is influenced by CCW and KBW when the NE monsoon wanes in late winter. Therefore, as illustrated by the cluster analysis, the similarity of copepod compositions in the 2 sampling periods was higher in KW than in CCW. Stations in group B were off the center of the CCW, and their copepod compositions were also more similar with those of groups C and D in KW. Hydrographic conditions of stations in group A were affected by CCW and KBW, and its copepod compositions were dissimilar to those of the other groups. *Calanus sinicus* and *Corycaeus (Ditrichocorycaeus) affinis* dominated stations of group A, which reveals that its hydrographic conditions were similar to those of CCW since these 2 species were recorded as indicator species of the CCW (Zheng et al. 1992, Hsieh et

al. 2004, Lan et al. 2004, Dur et al. 2007).

Indicator species of CCW were *Corycaeus (Ditrichocorycaeus) affinis*, *Paracalanus parvus*, *Calanus sinicus*, *P. aculeatus*, *Euchaeta concinna*, *Canthocalanus pauper*, and *Temora turbinata*, while in KW, they were *Clausocalanus lividus*, *Calocalanus pavo*, *Lucicutia flavicornis*, *Rhincalanus nasutus*, *Temoropia mayumbaeni*, and *Farranula concinna* (Table 2). All indicator species of CCW were also recorded as being dominant species in this water (Lan et al. 2004). *Calanus sinicus* has frequently been the subject of study, and it was pointed out that its appearance usually coincides with the presence of CCW, and so it is an indicator species (Hsieh et al. 2004, Dur et al. 2007). It is carried from the East China Sea to the Taiwan Strait and the South China Sea in the winter-spring period (Zheng et al. 1992, Lan et al. 2004, Hwang and Wong 2005). Zheng et al. (1992) reported that *Calanus sinicus* and *Corycaeus (Ditrichocorycaeus) affinis* are 2 coastal/neritic species with optimal temperatures of no higher than 20°C; they are carried southward to the northern part of the South China Sea by CCW in winter. In the laboratory, *Calanus sinicus* survived between 5 and 23°C (Uye 1988), but in the field it has been sampled in waters at temperatures exceeding 24°C (Hsieh 2001, Lan et al. 2004). *Paracalanus parvus* is known to be widely distributed in most of the world's oceans (Peterson 1998), and is abundant in coastal waters off China (Chen et al. 1965, Chen and Zhang 1974). In our study, it was more dominant in CCW (especially in Feb. 2004) than in KW. Hsieh et al. (2005) recorded that it was higher in spring than in summer and early winter (Nov. 1999). *Paracalanus parvus* and *Euchaeta concinna* have also been recorded as indicator species in CCW (Dur et al. 2007). *Paracalanus aculeatus*, *Canthocalanus pauper*, and *Temora turbinata* unexpectedly confirmed the results of previous research. Hsieh et al. (2004) revealed that *Paracalanus aculeatus* as an indicator species of the KBW is a warm-water species, but it was regarded as an indicator species of CCW in this study, and also has been recorded as being dominant in the Tanshui River estuary in winter (Hsieh and Chiu 1998). *Paracalanus aculeatus* dominated in both CCW and KW, which is similar to results reported by Lan et al. (2004). Dur et al. (2007) also reported that *Paracalanus aculeatus* corresponded to a northwestern calanoid community from a cold-water mass ($14 \pm 0.02^\circ\text{C}$). Those opposite results for *Paracalanus aculeatus* support our suggestion that its spatial

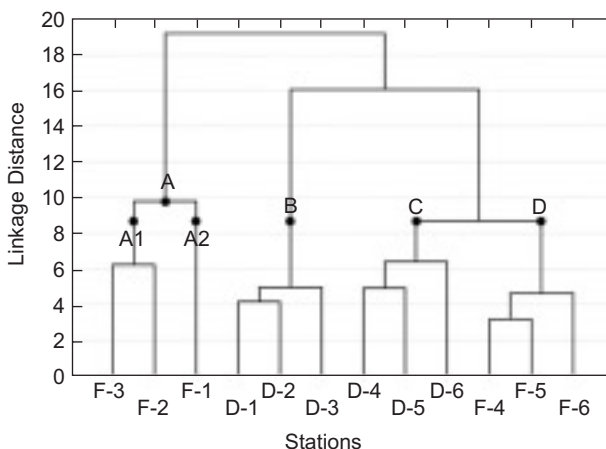


Fig. 8. Dendrogram of station associations from the cluster analysis using normalized Euclidean distances to measure the levels of similarity in species compositions among sampling stations and links using Ward's method.

distribution does not correspond to water masses. *Canthocalanus pauper* is also regarded as an indicator species of KW (Hsieh et al. 2004, Dur et al. 2007), but it represented CCW in our study. *Temora turbinata* was found to be abundant in coastal areas and in the vicinity of river estuaries in spring and autumn (Zheng 1992, Lan et al. 2004), and is an indicator species of KBW (Lan et al. 2004, Hwang et al. 2006). All indicator species in KW are warm-water species, and most of them are common in KW (Chihara and Murano 1997). Shih and Chiu (1998) reported that *Pleuromamma gracilis*, *Lucicutia flavicornis*, and *Clausocalanus lividus* were absent from or rare in CCW but relatively common and abundant in KW. Indicator species in the same water mass varied with changes in the strength of the northeasterly monsoon (Table 2). Abundances and assemblages of copepods are limited by the hydrographic conditions since they are sensitive to the marine environment (Boucher et al. 1987, Williams et al. 1994, Shih and Chiu 1998, Lan et al. 2004). Our study recorded the assemblage of copepods in winter which will be useful for understanding seasonal variations of copepod populations.

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