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Spring Distribution of Copepods in Relation to Water Masses in the Northern Taiwan Strait

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Yang-Chi Lan, Chang-Tai Shih, Ming-An Lee and Hung-Zen Shieh (2004) Spring distribution of copepods in relation to water masses in the northern Taiwan Strait. *Zoological Studies* **43**(2): 332-343. In this study, we investigated the spatial distribution of copepods and its relationship with water masses in the northern Taiwan Strait in May 2001. Based on the results of cluster analysis of species compositions of copepods collected, we could distinguish 3 copepod species composition groups, each associated with one of the 3 different water masses. The 1st group was associated with the Kuroshio Branch Current. It had high values for Shannon's species diversity and Simpson's species evenness indices. The dominant species in this group were *Temora turbinata*, *Paracalanus parvus* and *Canthocalanus pauper*. The 2nd group was associated with the China Coastal Current. It had low values for Shannon's diversity and Simpson's evenness indices, and its dominant species were *P. parvus*, *Euchaeta* sp., and *Calanus sinicus*. The 3rd group was found in the area receiving freshwater intrusion from the Tanshui River of Taiwan. It had the lowest values for Shannon's diversity and Simpson's evenness indices among the 3 groups. Its dominant species were *T. turbinata*, *C. pauper*, and *Acrocalanus gibber*. http://www.sinica.edu.tw/zool/zoolstud/43.2/332.pdf

Key words: Diversity, Evenness, *Calanus sinicus*, Kuroshio, China coastal current.

Copepods are the most abundant zooplankton in the ocean and are the main food source for marine fish larvae (Last 1978 1980, Hunter 1981, Sanchez 1998). Their abundance and distribution are known to be influenced by hydrographic conditions (Boucher et al. 1987, Shih and Chiu 1998), and it has been suggested that they might be good biological indicator species for water masses (Zheng et al. 1992).

The Taiwan Strait forms a connection between the East and South China Seas in the western North Pacific Ocean. The China Coastal Current, the Kuroshio Branch Current, and the South China Sea Surface Current dominate the hydrographic conditions of the Strait. The magnitude and strength of these currents vary with seasonal monsoons (Jan 1995, Jan et al. 2002). In winter the northeast monsoon prevails and forces the China Coastal Current in the East China Sea to flow southward along the China coast into the Taiwan Strait. A zonal oceanic front is formed over the Chang-Yuen Ridge where the China Coastal Current and the Kuroshio Branch Current meet. In spring, relaxation of the northeast monsoon allows the Kuroshio Branch Current to flow northward, blocking the southward intrusion of the China Coastal Current into the northern portion of the Strait (Fig. 1). In summer, the southwest monsoon prevails, causing the South China Sea Surface Current to flow northward, preventing the China Coastal Current from flowing southward into the Strait.

Physical and chemical oceanography in the northern Taiwan Strait has fairly comprehensively been investigated (Fan and Yu 1981, Fan 1982, Wang and Chern 1988 1991 1992a b, Jan 1995, Jan et al. 1994 2002), but reports on biological oceanography are scarce. Wu et al. (1993) and

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Wang et al. (1998) studied phytoplankton, Tzeng and Wang (1992 1993 1997) and Chang et al. (2002) examined ichthyoplankton, and Shih et al. (1991) investigated crabs.

Although copepods play an important role in fisheries and marine ecology, they have scarcely been investigated in the northern Taiwan Strait. Copepod composition in the Tanshui River estuary and adjacent waters was investigated by Tseng (1975 1976) and Hsieh and Chiu (1997), copepod diversity in the southern East China Sea (near the northern transect used in the present report) was studied by Shih and Chiu (1998), and the compositions and distributions of copepods and larval fishes in relation to hydrographic factors were investigated by Hsieh (2001).

This study attempted to examine the distribution and species composition of copepods in the northern Taiwan Strait, where fishery activities are high, but information on copepods is scarce.

MATERIALS AND METHODS

Copepods were collected at 17 stations (Fig. 2) using a Bongo plankton net in the northern Taiwan Strait in May 2001 during cruise 774 of the *Ocean Research II*. The net had a mouth diameter of 60 cm and mesh size of 335 μm. A flowmeter was mounted at the center of the mouth of the net, and a depth sensor was placed at the front of the net. The net was towed obliquely from a depth near the bottom to the surface. The zooplankton samples were preserved in sea-water with 5%~10% formalin.

At each station prior to collecting plankton samples, temperature and salinity at different depths were obtained by lowering a CTD profiler from the sea surface to a depth near the bottom. In the laboratory, each plankton sample was repeatedly divided with a Folsom splitter until its subsample contained 300~500 specimens of

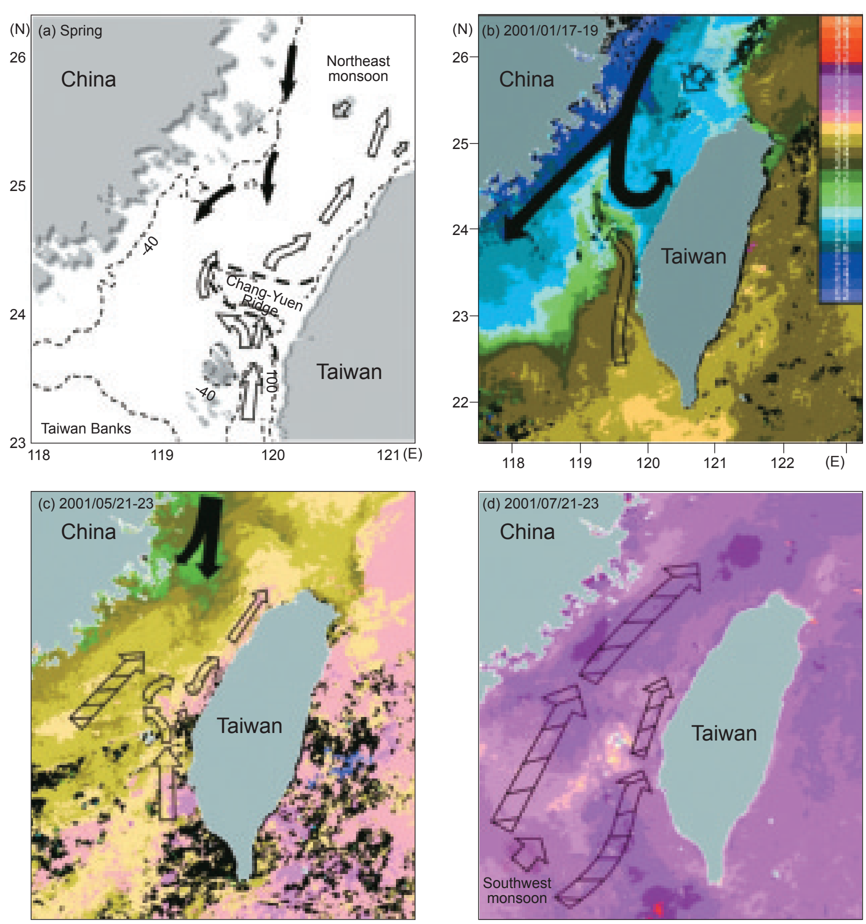

Fig. 1. A schematic showing the Kuroshio Branch Current (open arrows), China Coastal Current (solid arrows) and the South China Sea Surface Current (arrows with oblique lines) in the Taiwan Strait during the spring season modified from Jan et al. (2002) (a); the sea surface temperature (from NOAA AVHRR image) showing its seasonal variations in relation to the main currents in winter (b), spring (c), and summer (d).

copepods. The specimens were sorted and identified to species if possible using important references for the area (e.g., Chen and Zhang 1965, Chen et al. 1974, Chihara and Murano 1997).

Shannon's diversity index was used to calculate the species diversity, and Simpson's evenness was used to measure the relative abundance of species at each station. Cluster analysis with normalized Euclidean distance was used to measure the levels of similarity of species composition among the sampling stations, and Ward's method was used to illustrate those relations as a dendrogram. Data used in the cluster analysis were the percentage composition of copepods collected at each station.

RESULTS

Hydrography

Water temperatures varied from 21.5 to 27.2 °C and salinities from 31.8 to 34.3 psu. The temperature-salinity curves showed low temperature and wide ranges of salinity at stations 3 to 7, but high temperatures and narrow ranges of salinity at the other stations (Fig. 3). Stations 16 and 17, located in the vicinity of the Tanshui River estuary and receiving fresh water run-off, had high water temperatures and low salinities compared to those at nearby stations 1, 2, 12, 13, and 15. In the northern Taiwan Strait, temperatures and salinities at depths of 3~10 m were higher on the east side of the Strait, except for the areas in the vicinity of the Tanshui River estuary. Stations on the west side of the Strait had both low temperatures and salinities (Fig. 4).

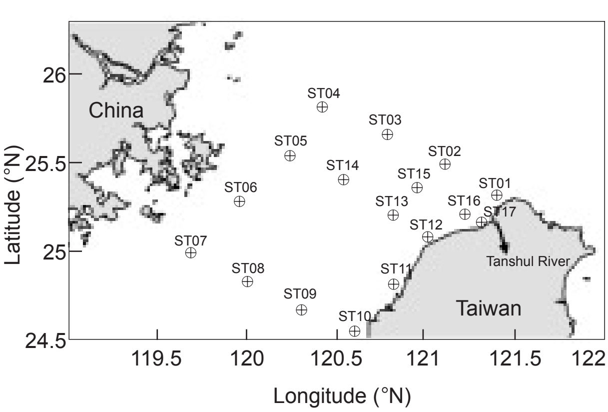

Fig. 2. The zooplankton sampling stations (ST01 to 17) in the northern Taiwan Strait in this study.

Based on the dendrogram obtained from the cluster analysis, using temperature and salinity as hydrographical data, the 17 stations were divided into 2 groups, HGI and HGII, at a linkage distance of 7 (Fig. 5). Group HGI, comprised of stations 3~7, was located on the western side of the Taiwan Strait, where surface water temperatures

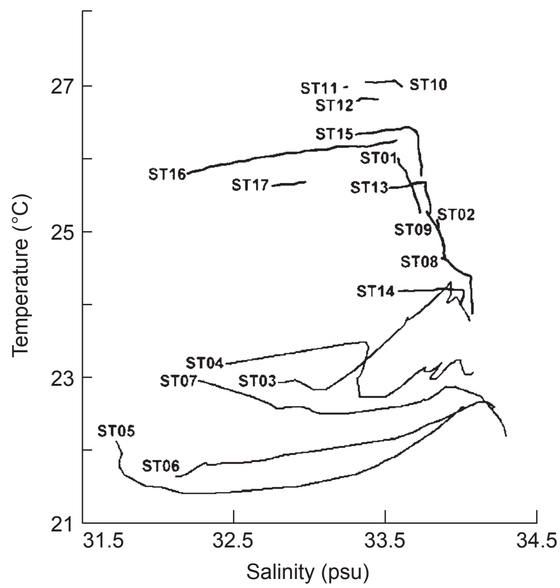

Fig. 3. The temperature-salinity (per meter column) curves at the 17 sampling stations (ST01-17) in the northern Taiwan Strait, May 2001.

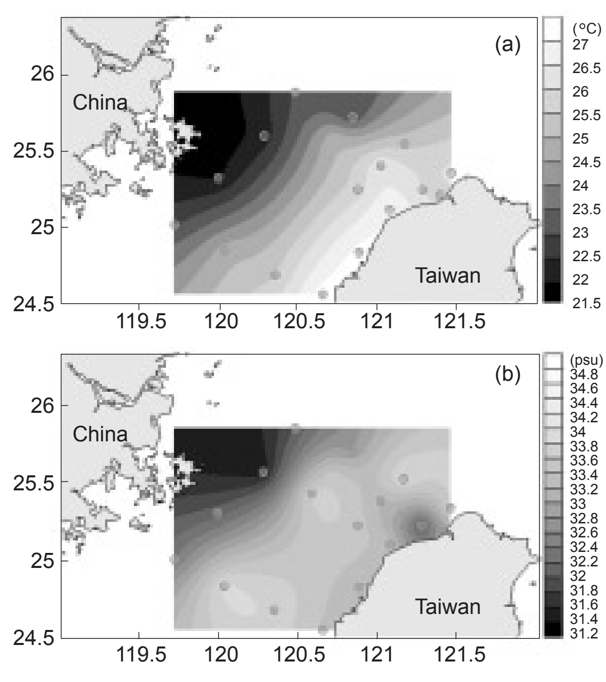

Fig. 4. Distribution of average sea surface temperatures (a) and salinities (b) at depths of 3-10 m in the northern Taiwan Strait, May 2001.

were low and salinities widely varied. Group HGII, comprised of stations 1,2, and 8~17, was located on the eastern side of the Strait, where water temperatures were high and salinities show a narrow range of variations.

Copepod Composition and Distribution

In total, 116 species of copepods belonging to 47 genera and 25 families were identified (Table. 1). The 5 species found to be the most abundant were *Temora turbinata*, *Paracalanus parvus*, *Canthocalanus pauper*, *Acrocalanus gibber*, and *Euchaeta* sp. The average copepod abundance was 41.27 individuals/m^3 (SD,= 45.75 individuals/m^3) with the highest abundance of 177.9 individuals/m^3 at station 1 and the lowest abundance of 4.0 individuals/m^3 at station 7. Abundance were high in waters adjacent to the Tanshui River estuary and along the northern transect, but were low in the southern area, particularly near the coast of mainland China (Fig. 6).

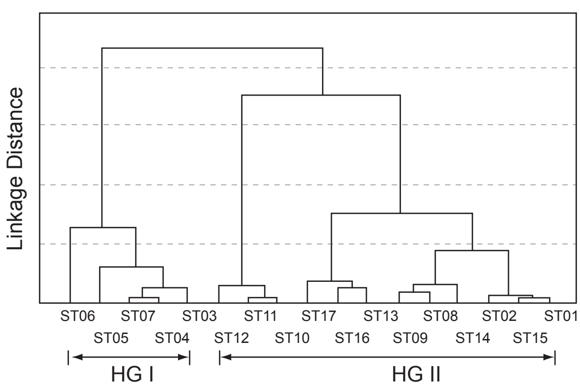

Fig. 5. The dendrogram resulted from the cluster analysis based on the hydrographic factors (surface temperature and salinity) measured at 17 stations in the northern Taiwan Strait, May 2001.

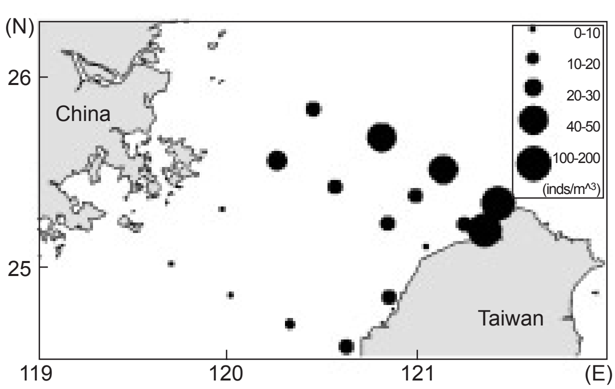

Fig. 6. Abundance of copepods at 17 stations in the northern Taiwan Strait, May 2001.

According to the dendrogram results from the cluster analysis, the species composition of copepods of the 17 stations was divided into 3 groups at a linkage distance of 80 (Fig. 7). These were BGI (stations 3~7 and 9), BGII (stations 2, 8, 10, and 12~16), and BGIII (stations 1, 11, and 17). The dominant species were *P. parvus*, *Euchaeta* sp. and *Calanus sinicus* for BGI, *Temora turbinata*, *P. aculeatus* and *Canthocalanus pauper* for BGII, and *T. turbinata*, *Acrocalanus gibber*, and *C. pauper* for BGIII (Table. 2). Means of Shannon's diversity and Simpson's evenness indices were highest for BGII and lowest for BGIII, while the indices of BGI were intermediate.

DISCUSSION

In winter, the northern front of the Kuroshio Branch Current, which flows from the Luzon Channel along the southwestern coast of Taiwan into the Taiwan Strait, is restricted to the vicinity of the Chang-Yuen Ridge by the southward flow of the China Coast Current (Fig. 1). When the northeastern monsoon beings to slacken and the southwestern monsoon gradually prevails in spring, the Kuroshio Branch Current flows through the Penghu Channel over the Chang-Yuen Ridge to converge with the China Coastal Current in the northern Strait (Jan 2002, Lee et al. 2003). Accordingly, water masses on the eastern side of the northern Strait were associated with the Kuroshio Branch Current and on the western side with the China Coastal Current in spring when this study was conducted. Waters adjacent to the Tanshui River estuary were influenced by the intrusion of freshwater run-off.

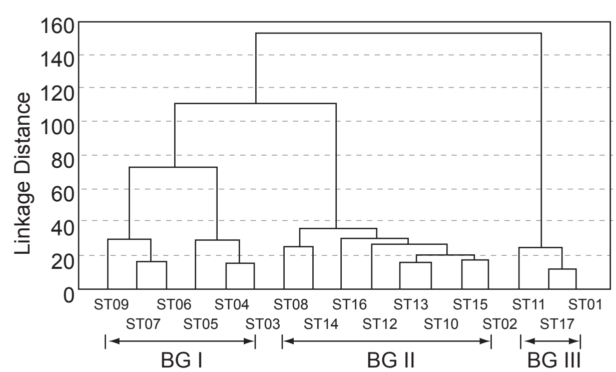

Fig. 7. The dendrogram resulted from the cluster analysis based on the copepod communities of the 17 sampling stations in the northern Taiwan Strait, May 2001.

Based on the dendrogram derived from the cluster analysis of hydrographic factors (Fig. 5), the hydrographic conditions in the study period were divided into 2 groups: group HG I associated with the China Coast Current, and group HGII with the Kuroshio Branch Current. Although group HGII included stations 1 and 17 adjacent to the Tanshui River estuary, the compositions of copepod species at these 2 stations differed from those at the other stations of group HGII.

Estuaries receive a large input of nutrients from rivers, and thus are capable of supporting large volumes of phytoplankton biomass (Adams and Bate 1999). In this study stations 1 and 17 adjacent to the Tanshui River estuary had the highest abundance of copepods, suggesting their association with rich nutrient resources from the estuary.

Tidal currents in the Taiwan Strait flow both northwardly and southwardly from the middle of the Strait during ebb tides, and converge toward the middle of the Strait during flood tides. Tidal movements in the Strait cause intrusion of fresh water of the Tanshui River into the area of stations 1 and 17 during ebb tides, and seawater intrusion into the river during flood tides. In the present study, plankton was sampled at stations 1 and 17 during the ebb tide, and at station 16 during the flood tide. Even though it is adjacent to the Tanshui River estuary, station 16 had a different species composition of copepods and comparatively lower abundance compared to stations 1 and 17, perhaps due to the different tidal phases at the sampling times.

We did not determine primary productivity data in this study, which might have been used to explain copepod abundance in relation to primary production and water masses. However, some reports have shown the presence of such relationships in the Taiwan Strait and adjacent waters. Chen (1995) recorded low primary productivity in the Kuroshio Current. Shiah et al. (1995) and Chen (2000) reported high primary productivity in an area of upwelling resulting from intrusion of the Kuroshio onto the East China Sea continental shelf in the shelf break area off the coast of northeastern Taiwan. Gong et al. (2000) reported that the middle zone of the East China Sea continental shelf has high productivity in spring and autumn. Shih and Chiu (1998) recorded copepod abundance in Apr. 1995, and showed a decreasing order from the East China Sea shelf to coastal waters of the East China Sea, and to the water of the Kuroshio. Hsieh (2001) also recorded a high abundance of copepods near our northern transect. In the current study, stations near the southern East China Sea had high abundance of copepods, particularly stations 1 to 3, while stations associated with the Kuroshio Branch Current had low copepod abundance.

Based on dendrograms of hydrographic conditions (Fig. 5) and the species composition of copepods (Fig. 7), stations located in the same water mass had fairly similar species compositions of copepods. Because we measured salinity and temperature but not nutrient and other hydrographic data in this study, our hydrographic data are inadequate to distinguish the water masses at stations influenced by the Tanshui River run-off from those at other stations in group HGII (Fig. 5). However, we were able to distinguish these water masses based on species composition of copepods, which were divided into BGII associated with the Kuroshio Branch Current and BGIII associated with the Tanshui River estuary (Fig. 7). The species composition of copepods appears to be a good indicator of water masses, and at times may be more sensitive than temperature and salinity in distinguishing water masses (Boucher 1984).

It is interesting to note that at station 11, located in the water mass influenced by the Kuroshio

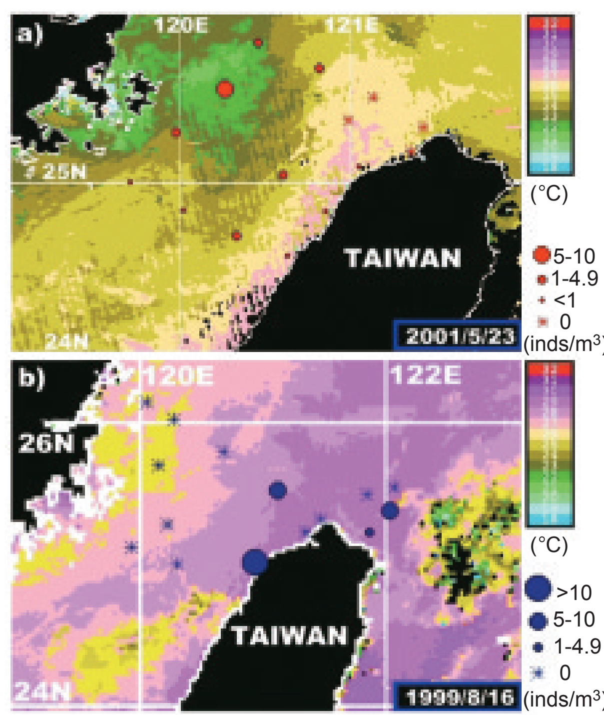

Fig. 8. The spatial distribution of sample densities of *Calanus sinicus* and sea surface temperature (NOAA AVHRR image)in the northern Taiwan Strait, 23 May 2001 (a) in this study, and the data obtained August 8, 1999 by Hsieh (2001) (b).

Branch Current, the copepod composition differed from that of BGII, but was similar to that of BGIII, which was influenced by Tanshui River run-off (Fig. 7). The dominant species of copepods at station 11 were fairly similar to those of the neighboring stations 10 and 12, except that *Temora turbinata* was exceptionally abundant at station 11. Furthermore, station 11 had a species diversity index of 3.84 and an evenness index of 0.66, which were close to those of stations of BGII (Table 1). Tou-chien Creek at a distance of 5.3 km from this station may have contributed freshwater run-off. Based on reports of the Water Resources Bureau of the Ministry of Economic Affairs, the freshwater discharge of the creek was between 13.44 and 37.76 m^3/s during our study period. Apparently, the amounts of the freshwater discharge did not significantly impact the water mass at station 11. Accordingly, based on the diversity and evenness indices of copepods, we removed station 11 from BGIII and included it with BGII.

The copepod species compositions differed among water masses in the northern Taiwan Strait. Stations in areas associated with the Kuroshio Branch Current (BGII) had higher species diversities, evenness, and numbers of dominant species than did stations in areas influenced by freshwater run-off (BGIII) (Tables 1, 2). The China Coastal Water (BGI) was influenced by the intrusion of freshwater run-off and had lower species diversity of copepods than did water masses associated with the Kuroshio Branch Current. Shih and Chiu (1998) also reported a similar phenomenon in the southern East China Sea near our northernmost transect. It is apparent that the intrusion of freshwater run-off significantly influences the areal

Table 1. A list of species of copepods and their relative abundance in the samples collected May 2001

Stations:	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17
Longitude (E)	121°25’	121°08’	120°49’	120°27’	120°16	119°58’	119°42’	120°01’	120°20’	120°38’	120°51’	121°03’	120°51’	120°34’	120°59’	121°15’	121°21’
Latitude (N)	25°19’	25°30’	25°40’	25°49’	25°33’	25°17’	25°00’	24°50’	24°40’	24°33’	24°49’	25°05’	25°12’	25°24’	25°21’	25°12’	25°10’
Date(2001)	5/21	5/21	5/21	5/21	5/22	5/22	5/22	5/22	5/22	5/22	5/22	5/22	5/22	5/22	5/22	5/23	5/23
Water depth (m)	57	70	77	61	51	55	69	48	66	51	33	33	76	72	90	55	19
Abundance (inds/m^3)	177.9	49.3	52.3	27.4	33.6	20.0	4.0	9.8	10.9	24.9	27.2	9.6	29.7	26.4	25.9	27.4	130.6
ORDER：CALANOIDA																	
ACARTIIDAE																	
Acartia bifilosa	0.498	0.973	0.664	1.296	1.089	0	0.271	5.623	0	1.974	2.467	6.349	2.685	4.384	6.489	3.509	1.572
Acartia danae	0	0.973	0	0.556	0.436	0.665	0.271	0.978	0	0	0	0	1.342	0.548	1.718	0.251	0
Acartia negligens	0	0.487	0.332	0	0	0	0	0	0	0	0	0	0	0	0	0.251	0
Acartia pacifica	0.125	0	0	0	0.218	0	0	0	0	0.219	0	0.227	0.336	0	0	0	0.121
CALANIDAE																	
Calanoides carinatus	0	0	0	0.37	0	0	0	0	0	0	0	0	0	0	0.191	0	0
Calanus sinicus	0	0	3.322	4.074	21.13	19.73	23.31	4.401	16.4	0.219	0.759	0.227	1.678	0.548	0	0.251	0
Canthocalanus pauper	6.289	8.029	4.319	2.407	2.179	2.661	9.485	4.156	1.386	7.456	1.518	2.041	9.396	1.918	3.053	23.06	4.837
Cosmocalanus darwini	0.062	1.946	0.664	0.37	0.218	0.222	0	4.156	2.079	0.219	2.087	2.494	0	0.548	4.771	0	0
Nannocalanus minor	0	0.73	0.664	1.111	0	0	0	0.244	0.231	0.219	0.19	0.68	0.336	4.384	1.908	0.251	0
Neocalanus gracilis	0	0.243	1.329	0.741	0	0	0	0	0	0	0	0	0	0	0.382	0	0
Neocalanus sp.	0	1.217	0.997	0.185	0	0	0	0	0	0	0	0	0	0	0.763	0	0
Undinula vulgaris	1.806	3.406	1.993	2.222	0.436	0.443	1.626	8.557	17.09	3.07	0.949	1.361	2.013	1.918	1.145	4.01	1.572
Calanidae copepodid	0.249	0	1.661	2.037	0	0.887	0	2.934	0	0.439	0	0.907	0	0.822	1.718	1.003	0
CALOCALANIDAE																	
Calocalanus pavo	0.125	1.217	0	0.185	0	0	0	0.244	0	0.439	0.19	1.814	2.685	0.274	1.145	0	0
Calocalanus pavoninus	0	0	0	0	0	0	0	0	0	0.439	0	0	0.336	0	0	0	0
Calocalanus plumulosus	0	0.243	0	0	0	0	0	0	0	0	0	0	0.336	0	0	0.752	0.242
Calocalanus styliremis	0	0	0	0	0	0	0	0	0	0	0	0.227	0	0	0	0	0
CANDACIIDAE																	
Candacia bradyi	0	0.243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Candacia catula	0	0	0.332	0	0	0	0.271	0	0.924	0.439	0.19	0.68	1.007	0.548	0.191	0.251	0.242
Candacia columbiae	0	0.243	0	0	0	0	0	0	0	0	0	0	0	0	0	0.501	0
Candacia curta	0	0	0	0	0	0	0	0	0.231	0	0	0	0	0	0	0	0
Candacia discaudata	0	0	0.332	0	0	0	0	0	0.462	0.219	0	0.227	0	0	0	0	0
Candacia tuberculata	0	0	0	0	0	0.443	0	0	0	0	0	0	0	0	0	0	0

Table 1. (Cont.)

Stations:	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17
Candacia sp.	0.062	0.487	0	0	0	0	0	0.978	0	0.439	0	0	0	0	0	0.251	0
Paracandacia truncata	0	0	0.332	0.37	0	0	0	0	0	0.439	0.19	0.227	0.336	0	0.191	0	0.121
Candaciidae copepodid	0.374	0	0	0	2.832	0.222	0	0	0	1.096	0	0	1.342	0	0.382	0	0.242
CENTROPAGIDAE																	
Centropages calaninus	0	0	0	0	0	0	0	0	0	0.219	0.19	0	0	0	0.191	0	0
Centropages elongatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.382	0	0
Centropages furcatus	0	0	0	0	0	0	0.271	0.489	0	0.219	0.38	0	0.671	0.274	0	0.251	0.363
Centropages gracilis	0	0	0	0.185	0	0	0	0	0	0	0	0.227	0	0	0	0	0
Centropages tenuiremis	0.187	0	0	0	0	0.222	0.271	0	0	0.219	0.19	3.175	0	0	0.191	0.251	0.121
Centropages sp.	0.125	0	0	0.185	0	0	0	0	0	0.219	0.19	2.041	0	0	1.336	0	0
CLAUSOCALANIDAE																	
Clausocalanus arcuicornis	0	0	0	0.741	0	0	0	0.244	0	0	0.38	2.721	0	0	1.336	0	0.121
Clausocalanus farrani	0	0.243	0.997	0.741	0	0	0	0.244	0	0	0.759	0.227	0	0	0.382	0.251	0
Clausocalanus furcatus	0.062	1.46	1.993	1.111	0.436	0	0.271	1.467	0.231	0.219	1.139	0.68	0	1.37	1.145	0.251	0.484
Clausocalanus lividus	0	0	0	0	0	0	0	0	0	0.219	0.38	0	0	0	0.763	0	0
Clausocalanus mastigophorus	0	0	0	0	0	0	0	0.244	0	0	0.569	1.587	0.336	0	0.573	0	0
Clausocalanus minor	0	4.136	2.326	3.889	0.218	0.222	2.168	0.489	0	0	1.518	2.948	0.336	2.466	6.87	0.752	0.121
Clausocalanus sp.	0	0.243	0	0	0	0	0	0	0	0	0	0	0.336	0.274	0	0	0
Ctenocalanus vanus	0	0.243	0	0.37	0	0	0	0	0	0	0	0	0	0	0	0	0.121
EUCALANIDAE																	
Paraeucalanus attenuatus	0.062	0	0.332	0.37	0	0	0	0.244	1.386	0	0.19	0	0.671	0	0.573	0	0
Paraeucalanus langae	0	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	0
Rhincalanus rostrifrons	0	0.487	0	0	0	0	0	0.244	0	0	0	0	0	0.822	0.191	0	0
Subeucalanus crassus	0.062	0	0.332	0.185	0.436	0	0	0	0.462	0	0	0	0	0.274	0	0	0
Subeucalanus mucronatus	0	8.273	3.987	0.185	0	0	0	0.733	0.924	0	0	0	0.336	0.274	1.145	0	0.242
Subeucalanus subtenuis	0	0.487	0	0	0	0	0	0	0	0	0	0	0.336	0	0.191	0	0
Subeucalanus subcrassus	0.374	0.487	0	0	0	0	0	1.467	1.848	0.219	0.19	0	0.336	0.548	0.382	0.501	0
Subeucalanus sp.	1.059	0.973	0	0	0	0	0.542	0	0	0	0	0	0	8.219	0	0.251	0
Eucalanidea copepodid	0.249	0	4.651	2.963	1.307	0.665	0	5.134	12.01	3.509	1.898	1.134	12.42	1.37	2.672	0.752	2.297
EUCHAETIDAE																	
Euchaeta concinna	0	0	0	3.519	0.871	7.317	1.084	0.978	4.85	0	0	0	0	2.192	0.191	0	0
Euchaeta indica	0	0	0.997	0	0	0	0	0.489	0	0.439	0.38	0	0	0.274	0.763	0.251	0
Euchaeta plana	0	0	0	0	2.614	1.552	0.271	0.489	2.079	0	0	0	0	0.822	0	0	0
Euchaeta rimana	0.062	0.243	0	0.37	0	0	0	1.467	0.693	0.877	0	0	0.336	0	0.191	0.501	0
Euchaeta sp.	0.062	0.487	2.99	14.26	21.13	43.24	34.42	8.802	26.1	3.728	0.949	0.907	1.342	10.14	4.58	0.251	0.605
Paraeuchaeta biloba	0	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	0
LUCICUTIIDAE																	
Lucicutia curta	0	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	0
Lucicutia flavicornis	0	0	0.997	0.37	0	0	0	0	0	0.877	0	0	0.336	0	0	0	0
Lucicutia sp.	0	0	0	0	0.218	0	0	0	0	0	0	0	0.336	0	0	0	0
Lucicutiidae copepodid	0	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	0
MECYNOCERIDAE																	
Mecynocera clausi	0	0	0	0	0	0	0	0	0	0	0	0	0	0.274	0	0	0
METRIDICIDAE																	
Pleuromamma gracilis	0	0.243	0	0.185	0	0	0	0	0	0	0	0	0	0	0	0	0
Metridinidae copepodid	0	0	0	0.185	0	0	0	0	0	0	0	0	0	0	0	0	0
PARACALANIDAE																	
Acrocalanus gibber	3.549	5.839	3.987	2.407	0.218	0.222	0	3.667	0	6.798	7.78	10.2	6.711	1.918	4.962	1.253	9.069
Acrocalanus gracilis	0.809	0.973	1.661	2.778	0	0	0	0	0	0	0	0	0	1.37	2.29	2.256	0
Acrocalanus monachus	0.125	0.73	0	0	0	0	0	0	0	2.193	1.708	0.454	2.685	0.548	0.954	0	0.242

Table 1. (Cont.)

Stations:	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17
Acrocalanus sp.	0.436	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paracalanus aculeatus	0.685	10.95	13.29	6.111	2.179	0.887	2.71	11.98	0.462	5.263	1.898	3.175	6.711	21.37	4.198	5.263	2.177
Paracalanus gracilis	0.062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paracalanus parvus	2.615	8.759	26.58	29.26	33.33	11.53	5.149	3.178	0.231	3.07	1.328	13.38	1.678	4.932	4.008	13.78	5.079
Paracalanus serrulus	0.685	0.243	0.332	0	0	0	0	0.244	0	0	0	0	0	0	0	0	0
Paracalanus spp.	0.311	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PONTELLIDAE																	
Calanopia elliptica	0.062	0	2.326	0.741	0.218	2.882	1.626	0.489	0.693	0.219	0	0.454	0	0.274	0	0.501	1.209
Calanopia minor	0	0	0	0	0	0	0	0	1.617	0	0	0	0	0	0.573	0.251	0
Labidocera acuta	0.062	0	0	0	0	0	0	0	0.231	0	0	0	0.336	0	0	0.251	0
Labidocera bipinnata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.121
Labidocera detruncata	0.125	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	0
Labidocera euchaeta	0	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	1.572
Labidocera japonica	0.062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labidocera minuta	0.062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labidocera pavo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.003	0
Labidocera sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.752	0.121
Pontellina plumata	0	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	0
Pontellidae copepodid	0.747	0.973	0.332	0.556	0	0	1.355	0.489	0.231	1.754	0.38	0.454	1.342	0	0.191	0.752	0.121
SCOLECITRICHIDAE																	
Scolecithricella longispinosa	0	0	0	0.185	0.871	0	0	0	0	0	0	0	0	0	0	0	0
Scolecithricella minor	0	0	0	0	0	0.665	0.542	0	0	0	0	0	0	0	0	0	0
Scolecithrix danae	0	0.487	0.332	0.185	0	0	0	0.244	1.617	0	0.38	0	0.336	0	0.191	0	0
TEMORIDAE																	
Temora discaudata	0.56	0.487	1.661	0.556	0.436	0	0.271	0.978	3.464	3.07	2.277	5.442	2.013	0.822	2.29	2.005	0.484
Temora stylifera	0.872	0.73	1.329	0.185	0	0	0	0	0	0	0	0	0	0	0.191	0.251	0
Temora turbinata	63.82	16.3	4.319	2.407	0.654	3.104	4.878	0	0.462	23.46	41.56	5.215	16.78	13.42	13.93	25.06	56.47
ORDER:CYCLOPOIDA																	
OITHONIDAE																	
Oithona fallax	0	0.243	0	1.296	1.089	0	0.813	0.978	0	0.219	0	0.227	0	0	0.191	0	0
Oithona plumifera	0	2.676	0	1.111	1.743	0	0	1.711	0	1.754	1.139	3.175	2.013	0.822	3.435	0.501	0.484
Oithona rigida	0.062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oithona setigera	0	0.487	0	0.185	0.218	0	0	0	0.231	1.316	0.19	1.134	4.027	0.548	1.908	0.251	0
Oithona tenuis	0	0	0	0.185	0	0	0	0	0	0	0	0	0.671	0	0.573	0	0
Oithona sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.846
ORDER：HARPACTICOIDA																	
CLYTEMNESTRIDAE																	
Clytemnestra scutellata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.191	0	0
ECTINOSOMATIDAE																	
Microsetella norvegica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.191	0	0
MIRACIIDAE																	
Macrosetella gracilis	0	0	0	0	0	0.222	0.271	0.244	0	0	0	0.227	0	0	0.382	0	0
EUTERPINIDAE																	
Euterpina acutifrons	0	0	0	0	0	0.222	0	0	0	0	0	0	0	0	0	0	0.121
ORDER：POECILOSTOMATOIDA																	
CORYCAEIDAE																	
C.(*Agetus*) *flaccus*	0	0	0	0	0	0	0	0	0	0	0	0.227	0	0	0	0	0
C.(*Agetus*) *limbatus*	0	0	0	0.185	0	0	0	0	0	0	0	0.227	0	0	0	0	0
C.(*Corycaeus*) *clausi*	0	0	0	0.185	0	0	0	0.244	0.231	0	0	0.227	0	0	0.382	0	0
C.(*Corycaeus*) *crassiusculus*	0.062	0.243	0.332	0	0	0	0	0	0	0.219	0.38	0.454	0.336	0.274	0	0.251	0
C.(*Corycaeus*) *speciosus*	0.311	0.243	0.332	0.185	0	0	0	0.489	0.231	1.316	4.554	0.907	1.678	0.822	0.763	0.251	0
C.(*Corycaeus*) sp.	0.062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1. (Cont.)

Stations:	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17
C.(*Ditrichocorycaeus*) *affinis*	0	0	0.332	0	0	0	0.271	0.244	0	0	0	0.454	0	0.822	0	0	0.242
C.(*Ditrichocorycaeus*) *andrewsi*	1.308	0.487	0	0.185	0.218	0.222	0.271	0.489	0	2.412	0.569	2.268	0.336	0.274	0.382	0	1.693
C.(*Ditrichocorycaeus*) *asiaticus*	1.121	0.487	0	0	0	0	0.271	0	0	0	0.759	0	0.671	1.096	0	0	2.418
C.(*Ditrichocorycaeus*) *dahli*	0	0	0	0.926	0.436	0	0.271	0	0	0.658	0	0	0	0.548	0	0	0.484
C.(*Ditrichocorycaeus*) *erythraeus*	0.062	0	0	0	0.218	0	0	0	0	0	0	0	0	0	0	0	0
C.(*Ditrichocorycaeus*) sp.	0.062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C.(*Monocorycaeus*) *robustus*	0	0	0.664	0	0	0	0	0.244	0.231	0	0.19	0	0	0	0	0	0
C.(*Onychocorycaeus*) *agilis*	0.187	0.243	0	0	0.218	0	0	0.733	0	1.535	0.19	0.68	0.336	0.274	0	0	0.121
C.(*Onychocorycaeus*) *asiaticus*	0	0	0	0	0	0	0	0.978	0	0.877	0	0	0	0	0	0	0
C.(*Onychocorycaeus*) *catus*	0.374	0.487	0	1.296	0.654	0.222	0	0.489	0	0.877	2.277	2.721	1.342	0.548	0.763	0	2.056
C.(*Onychocorycaeus*) *giesbrechti*	0	0	0	0.185	0	0	0	0	0	0.219	0	0	0	0	0	0	0
C.(*Onychocorycaeus*) *pacificus*	0.311	0.73	0.664	0.185	0	0	0.271	0.244	0	1.096	1.898	0.907	1.007	0	0	0.501	0
C.(*Urocorycaeus*) *lautus*	0	0	0	0	0	0	0	0	0	0.439	0	0	0	0	0	0	0
C.(*Urocorycaeus*) *longistylis*	0	0.243	0	0	0	0	0	0	0	0.219	0	0.454	0	0	0	0	0
Farranula carinata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.501	0
Farranula concinna	0.062	0	0	0	0	0	0	0	0	0	0	0.227	0	0	0	0	0
Farranula gibbula	0.685	0.487	0.332	0	0.218	0	0	0.244	0	3.289	3.416	7.029	1.007	0.548	0.573	0.752	0.242
Farranula sp.	1.432	0.243	0	0.556	0	0.665	0.271	1.467	0	1.096	0.949	0.907	2.013	1.096	1.145	0	0
ONCAEIDAE																	
Oncaea conifera	0	0	0.332	0	0	0	0	0	0	0	0	0	0	0	2.099	0	0
Oncaea venusta	6.102	5.839	3.987	1.852	1.307	0.222	0.542	13.2	0.462	6.798	5.123	4.082	2.349	2.192	4.198	4.762	0.967
Oncaea media	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.251	0
Oncaea mediterranea	0	0.243	0	0	0	0	0	0.244	0	0.439	0.38	0	0	0	0.191	0	0
Oncaea minuta	0	0	0	0.185	0	0	0	0	0	0	0	0	0	0	0	0	0
SAPPHIRINIDAE																	
Copilia mirabilis	0.249	0.973	0.332	0	0	0	0	0.489	0	0.877	1.328	1.134	0	0	0.573	0	0
Copilia quadrata	0	0	0	0	0	0	0	0	0	0	0	0	0.336	0	0	0	0
Sapphirina auronitens	0	0	0	0	0	0	0	0	0	0	0	0.227	0	0	0	0	0
Sapphirina metallina	0	0	0	0	0	0	0	0	0.231	0	0	0	0.671	0	0	0	0
Sapphirina nigromaculata		0	0	0	0	0	0	0	0	0	0.219	0	0	0.336	0	0	0 0
Sapphirina setellata	0	0	0	0	0	0	0	0	0	0	0.569	0.227	0.336	0	0	0	0
Sapphirina sp.	0	0.243	0	0	0	0	0	0	0	0	0	0	0	0	0.191	0	0
ORDER:SIPHONOSTOMATOIDA																	
PONTOECIELLIDAE																	
Pontoeciella abyssicola	0	0	0	0.185	0	0	0	0	0	0	0	0	0	0	0	0	0
RATANIIDAE																	
Ratania flava	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.121
Ratania sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.121
COPEPODID	0	0.487	0	0	0	0.443	5.691	0.489	0	0	0	0	0	0	0	0	0
Total number of species	40	47	38	36	21	20	26	45	30	47	49	47	45	40	55	38	34
Shannon's diversity index	2.51	4.50	4.22	4.19	3.04	2.77	3.14	4.59	3.44	4.54	3.84	4.80	4.60	4.27	5.02	3.64	2.80
Simpson's evenness index	0.44	0.77	0.78	0.72	0.60	0.58	0.63	0.81	0.68	0.79	0.66	0.84	0.81	0.77	0.84	0.66	0.52

species composition as well as diversity and evenness indices of copepods.

In this study, *Paracalanus parvus* was widely distributed and dominant in the northern Taiwan Strait. A similar result was also reported by Shih and Chiu (1998) and Hsieh (2001). *P. parvus* is also known to be widely distributed in most of the world's oceans (Peterson 1998). Apparently it is a species with high tolerance and adaptability to a wide range of hydrographic conditions and therefore is often a dominant species in different water masses of the world's oceans.

In contrast to *P. parvus*, *Calanus sinicus* is restricted to water masses with temperature of between 5 and 23°C (Uye 1988), and is intolerant of temperatures higher than 24°C (Uye et al. 1990). Salinity is not an important limiting factor of the distribution of this species (Uye 2000). *C. sinicus* is widely distributed in the South China Sea, Taiwan Strait, East China Sea, Yellow Sea, Bohai Sea, and waters around Japan. It is particularly abundant in the shelf ecosystem of the northwestern Pacific Ocean (Uye 2000). Zheng et al. (1992) reported that *C. sinicus* is carried into the Taiwan Strait and the northern South China Sea from the East China Sea by the China Coastal Current in winter and spring. In this study, *C. sinicus* was the dominant species in BGI associated with the China Coastal Current and adjacent waters (Fig. 8a). Sometimes it occurred at stations where water temperatures were comparatively higher (maximum, 27.2°C) than the limit of its reported tolerance at 23°C (Uye et al. 1990). Hsieh (2001) also reported that this species occurred in warmer areas where temperatures were about 28°C (Fig. 8b). This suggests that the upper thermal limit of

Table 2. The dominant species and percentage compositions of copepods in Groups BG Ⅰ, BGⅡ, and BG Ⅲ; and their Shannon's diversity and Simpson's evenness indices

BG Ⅰ (influenced by China coast water)			BG Ⅱ (influence by Kuroshio branch current water)			BG Ⅲ (influence by Tanshui River freshwater)		
Stations: 3、4、5、6, and 7			Stations: 2、8、10, and 12-16			Stations: 1、17		
species	inds/m^3	%	species	inds/m^3	%	species	inds/m^3	%
Paracalanus parvus	7.123	26.0	*Temora turbinata*	4.172	19.7	*Temora turbinata*	93.660	60.7
Euchaeta sp.	4.518	16.5	*Paracalanus aculeatus*	2.293	10.8	*Acrocalanus gibber*	9.081	5.9
Calanus sinicus	2.965	10.8	*Canthocalanus pauper*	2.102	9.9	*Canthocalanus pauper*	8.754	5.7
Paracalanus aculeatus	1.927	7.0	*Paracalanus parvus*	1.662	7.8	*Oncaea venusta*	6.060	3.9
Canthocalanus pauper	0.911	3.3	*Acrocalanus gibber*	1.255	5.9	*Paracalanus parvus*	5.644	3.7
Temora turbinata	0.790	2.9	*Oncaea venusta*	1.241	5.9	*Undinula vulgaris*	2.633	1.7
Eucalanidae copepodid	0.763	2.8	*Acartia bifilosa*	0.841	4.0	*C.*(*Ditrichocorycaeus*) *asiaticus*	2.577	1.7
Oncaea venusta	0.619	2.3	*Euchaeta* sp.	0.805	3.8	*C.*(*Ditrichocorycaeus*) *andrewsi*	2.269	1.5
Acrocalanus gibber	0.572	2.1	Eucalanidae copepodid	0.804	3.8	*Paracalanus aculeatus*	2.031	1.3
Euchaeta concinna	0.553	2.0	*Undinula vulgaris*	0.739	3.5	*C.*(*Onychocorycaeus*) *catus*	1.675	1.1
Clausocalanus minor	0.497	1.8	*Clausocalanus minor*	0.638	3.0	Eucalanidae copepodid	1.722	1.1
Subeucalanus mucronatus	0.427	1.6	*Subeucalanus mucronatus*	0.577	2.7			
Calanopia elliptica	0.427	1.6	*Oithona plumifera*	0.509	2.4			
Undinula vulgaris	0.390	1.4	*Temora discaudata*	0.448	2.1			
Acrocalanus gracilis	0.326	1.2	*Cosmocalanus darwini*	0.380	1.8			
Calanidae copepodid	0.321	1.2	*Subeucalanus* sp.	0.339	1.6			
Clausocalanus furcatus	0.301	1.1	*Oithona setigera*	0.323	1.5			
			Farranula gibbula	0.320	1.5			
			Nannocalanus minor	0.290	1.4			
			Acrocalanus monachus	0.267	1.3			
			Calocalanus pavo	0.259	1.2			
			Acrocalanus gracilis	0.256	1.2			
			Farranula sp.	0.226	1.1			
			Clausocalanus furcatus	0.214	1.0			
sum	23.43	85.6	Sum	20.960	98.9	Sum	136.106	88.3
Mean Shannon's diversity	3.47		Mean Shannon's diversity	4.49		Mean Shannon's diversity	2.66	
Mean Simpson's evenness	0.66		Mean Simpson's evenness	0.79		Mean Simpson's evenness	0.4	

C. sinicus is higher than what has previously been reported.

Temora turbinata, highly abundant in BGII, was associated with the Kuroshio Branch Current, and particularly in BGIII, it was associated with the Tanshui River estuary. It contributed 96.3% to the total abundance in BGIII. Zheng (1992) also reported that this species was abundant in coastal areas and in the vicinity of the river estuaries.

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