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Copepods Assemblages in an Embayment of Taiwan during Monsoonal Transitions

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Wen-Been Chang, Hans-Uwe Dahms, and Li-Chun Tseng (2010) Copepods assemblages in an embayment of Taiwan during monsoonal transitions. *Zoological Studies* **49**(6): 735-748. In coastal waters around the island of Taiwan, oceanic currents are mainly influenced by the prevailing East Asian monsoonal winds: the northeasterly (NE) monsoon during winter and the southwesterly (SW) monsoon during summer. We identified 101 copepod species (including 27 species solely identified to generic level) belonging to 44 genera and 31 families in Nan-Wan Bay, southern Taiwan. *Corycaeus* (*Onychocorycaeus*) *catus* (15.00%), *Oncaea venusta* (11.97%), and *Clausocalanus furcatus* (5.93%) were predominant in Apr., and together they comprised 32.9% of the total number of copepods. *Paracalanus parvus* (10.08%), *Par. aculeatus* (9.12%), and *Cor.* (*O.*) *catus* (8.01%) were predominant in Sept. and together contributed to 27.3% of the total copepod abundance. The average copepod abundance was significantly higher in Sept. samples than in Apr. samples. Copepod community parameters showed apparent variations and succession between the 2 sampling months, implying that different species may dominate in different regions with different seasonal distribution patterns. Our results indicate that the copepod assemblages changed with water conditions at the northeastern margin of the South China Sea where water masses of the Kuroshio Current and those of the South China Sea mix. http://zoolstud.sinica.edu.tw/Journals/49.6/735.pdf

Key words: Copepod composition, Monsoon, Taiwan, Kuroshio Branch Current, South China Sea.

Coastal waters are commonly characterized by abrupt temporal and spatial changes in environmental parameters due to the influences of tides, coastal currents, freshwater runoff, periodic atmospheric processes such as monsoons, and erratic oceanographic disturbances such as storms, typhoons, and tsunamis. Nan-Wan Bay is a semi-enclosed embayment in tropical southern Taiwan at the northern margin of the South China Sea (SCS) with coral reefs distributed along the coastline at depths of < 30-50 m. The water masses of the South China Sea and the Kuroshio Branch Current bring warm water to the southern coastal area of Taiwan through the Luzon Strait year around (Jan et al. 1998 2002, Lo et al. 2004a, Tseng et al. 2008b c). The circulation in the bay is dominated by a strong zonal tidal current. Recent studies in coastal waters around Taiwan indicated the substantial role of monsoonal winds in the seasonal succession of the copepod community structure (Hwang et al. 2006, Hsu et al. 2008, Tseng et al. 2008c e). Nan-Wan Bay is an interesting study site since it is located at the northern margin of the SCS west of the northerly flowing Kuroshio Current at the western boundary of the Pacific Ocean.

Nan-Wan Bay is geographically located in southern Taiwan, and the physical properties of the water within the bay are primarily affected by

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the water masses from the Western Philippine Sea (WPS) and SCS (Lee 1999). The marine environment in the study area is directly affected by the warm water masses of the SCS, and the Kuroshio Branch Current transports water of high temperature and high salinity from the WPS (Jan et al. 1998 2002) year round. Various physical forces, e.g., alternating monsoons, typhoons, El Niño cycles (Mann and Lazier 1996), and upwelling, may enhance the vertical mixing, also resulting in a mixing of nutrients that causes a cascade of biological and chemical events in surface waters (Liao et al. 2006). Copepod assemblages may be affected by the Kuroshio Current intrusion through the Luzon Strait (Hwang et al. 2007a). Previous studies indicated that zooplankton assemblages, particularly copepods, show high temporal and spatial variations. Several recent studies of the seasonal succession of copepods around Taiwan suggested that variations in community structure were related to the monsoons and seasonal water mass translocations (Lo and Hwang 2000, Chang and Fang 2004, Hwang et al. 2006, Dur et al. 2007, Lo et al. 2008, Tseng et al. 2008b c).

Wind patterns around Taiwan are typical for East Asia, with the northeasterly (NE) monsoon prevailing in Oct.-Mar. and the southwesterly (SW) monsoon prevailing in May-Aug. Monsoonal winds commonly alternate in Apr. and Sept. Many studies around Taiwan reported monsoon-related variations in copepod assemblages. However, we have no information on possible changes in copepod assemblages during monsoon transitional periods.

Several studies focused on copepod communities in coastal areas of Taiwan, in the northeast area (Hwang et al. 1998, Wong et al. 1998), the coastal area of a nuclear power plant (Hwang et al. 2004), the estuary of the Danshuei River (Tseng 1975 1976, Hsieh and Chiu 1997, Hwang et al. 2006), the northeastern Taiwan Strait (Tseng et al. 2008c), an outfall area in southwestern Taiwan (Tseng et al. 2008a c), Kaohsiung Harbor (Chang and Fang 2004), and southwestern Taiwan (Lo et al. 2001 2004a b, Hwang et al. 2003). A recent study by Hwang et al. (2007a) reported on the copepod assemblages in the northern SCS closer to our sampling area and discussed the effect of intrusions of the Kuroshio Current. Tseng et al. (2008b) reported on copepod assemblages in the northern SCS during winter and discussed their distributions along a vertical profile. However, the community structure and seasonal variations of copepods in this semi-enclosed bay have not been studied as yet.

In the present study, we examined the copepod community structure in Apr. (during the transition to the SW monsoon) and Sept. (during the transition to the NE monsoon), to compare changes in copepod distributions and species compositions in surface waters of Nan-Wan Bay along the northern margin of the SCS. Our objective was to compare the composition and abundance of copepods during the change between 2 monsoonal seasons, spring and autumn, and the influence of the monsoon itself.

MATERIALS AND METHODS

Study area and zooplankton sampling

Seventeen stations extending from the coast to near-shore waters in the embayment were sampled on 2 research cruises on 12 Apr. (before the onset of the SW monsoon) and 5 Sept. 2007 (before the NE monsoon prevails), respectively, at the northern margin of the SCS during monsoon transitional periods. These stations are located in the coastal area of southern Taiwan. No large river provides fresh water to the sampling area. A station map is provided in figure 1. The sample area is shallow water with reef distribution. Copepod samples were collected from the upper 3 m at each station by horizontal tows using a standard Norpac net with a 45-cm mouth opening and a 333 μm mesh, and a flow meter (HydroBios, Germany) mounted in the center of the mouth opening to calculate the water volume filtered. A 333 μm mesh net was previously widely used for copepod studies around Taiwan (Hwang et al. 1998 2003, Wong et al. 1998, Dur et al. 2007, Tseng et al. 2008b c). We selected the 333 μm mesh size for the sake of comparability of results with previous studies in different sampling areas. Hauls were towed for 10 min at a speed of approximately 1 knot (0.5 m/s). After retrieval, zooplankton samples were immediately preserved in 5%-10% buffered formalin in seawater on board for further identification. Seawater conductivity, temperature, and depth (CTD) values were recorded with an automatic instrument prior to sampling.

Copepod enumeration and identification

In the laboratory, each zooplankton sample was repeatedly divided using a Folsom plankton splitter until the subsample contained about

300-500 specimens. Some copepods were then identified to genus level. Only adult individuals were counted. The total number of individuals (ind.) of each copepod taxon was recorded (as ind./m^3). References utilized for identification were Chen and Zhang (1965) and Chen et al. (1974).

Statistical analyses

The computer software Plymouth Routines In Multivariate Ecology Research (PRIMER) program (Version 4) was applied to work out Bray-Curtis similarities between sampling stations in order to find similar station groups. In order to reduce higher heteroscedasticity observed in the original species abundance data, we applied the Box and Cox (1964) test before transformation of the data for the similarity analysis. The log(x+1) transformation was applied to treat individual densities of all samples depending on the value of the power transformation (λ = 0.94). Furthermore, non-metric multidimensional scaling (NMDS) and a cluster analysis were employed to estimate similarities of copepod community compositions among 34 samples of 2 sampling cruises. The Shannon-Wiener diversity index, richness index, and Pielou's evenness index were applied to estimate the biodiversity of the Copepoda and to characterize the copepod community composition. Student's *t*-test was applied to compare the mean values of copepod abundance, species richness, and indices between the Apr. and Sept. samples. Prior to applying the Student's *t*-test, an *F*-test was used to check the variability between comparable groups.

RESULTS

Monsoon and hydrological structure

Figure 2 shows average daily variations (monitored and recorded each hour) of air temperature, wind direction, and wind speed during the investigation periods in 2007. The data were adopted from an automatic monitoring instrument at Hengchun Township of the Central Weather Bureau, Ministry of Transportation and Communications, Taiwan. The Hengchun Township is located adjacent to our sampling area. The daily average temperature varied from 17.6 to 30.4°C (Fig. 2A). Temperatures of > 25°C were recorded from the end of Apr. to Oct. In Jan. to Mar. and Nov. to Dec., the air temperatures varied in the range of 20-25°C during most days. Monsoonal changes in different months are shown in figure 2B. However, the NE monsoon

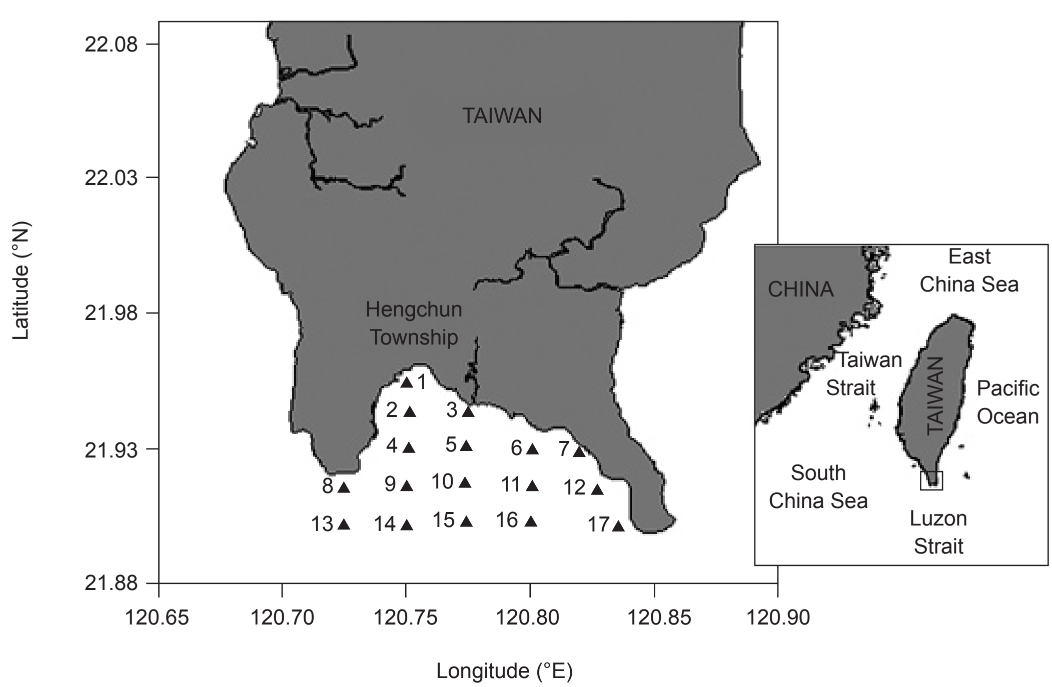

Fig. 1. Map of sampling stations at the northern margin of the South China Sea.

prevailed in Jan. to mid-May and mid-Sept. to the end of Dec., at which time the air temperature was < 25°C (Fig. 2B). In Taiwan, the SW monsoon prevails from mid-May to mid-Sept., whereas the NE monsoon prevails from mid-Sept. to the end of Dec. The automatic monitoring instrument at Hengchun Township recorded a northwesterly wind direction in the period of mid-May to Sept. which was caused by mountain effects that change the direction of the monsoons. The daily average wind speed varied 0.6-10.7 m/s, with a higher wind speed recorded at the end of Oct. when the northeasterly monsoon prevailed. Recorded wind speeds were relatively weak from May to Sept. (Fig. 2C), with an average of < 4.0 m/s.

Figure 3 shows temperature vs. salinity (T-S) of surface waters at each station during the 2 sampling cruises with reference to a T-S plot of water masses of the SCS and Kuroshio Current. The reference sources for the SCS and Kuroshio Current water properties were obtained from the Department of the Ocean Data Bank, Taiwan. The T-S curves show the characteristics of water masses in the northern SCS (21.5°-22.0°N, 119.0°-119.5°E) and in the Kuroshio Current area (21.5°-22.0°N, 121.5°-122.0°E) above 100 m in depth in summer. During Apr., the T-S curve indicated that water properties of the present study area belonged to mixed water masses of the SCS and the Kuroshio Current. In Sept., the waters of Nan-Wan Bay were similar to those of the SCS. The average surface water temperature at the sampling stations ranged 25.7-27.4°C in Apr., and 24.7-28.2°C in Sept. The average temperature in Sept. (26.32 ± 0.70°C) was significantly higher (p = 0.001, t-test) than that in Apr. (25.82 ± 0.41°C). The surface water salinity at each sampling station ranged 34.3‰-34.5‰ in Apr., and 33.4‰-33.8‰ in Sept. Salinity showed contrasting results from those of temperature, being significantly higher (p < 0.001, t-test) in Apr. (34.40‰ ± 0.05‰) than in Sept. (33.59‰ ± 0.11‰) (Fig. 3). The temperature and salinity of the water masses during the 2 sampling cruises significantly differed.

Copepod community structure

From a total of 34 samples, we identified 101 copepod species (including 27 species which were solely identified to generic level). These belonged to 44 genera, 31 families, and 5 orders. Tables 1 and 2 show average values of copepod abundance, species number, richness, Shannon-Wiener diversity, and evenness indices

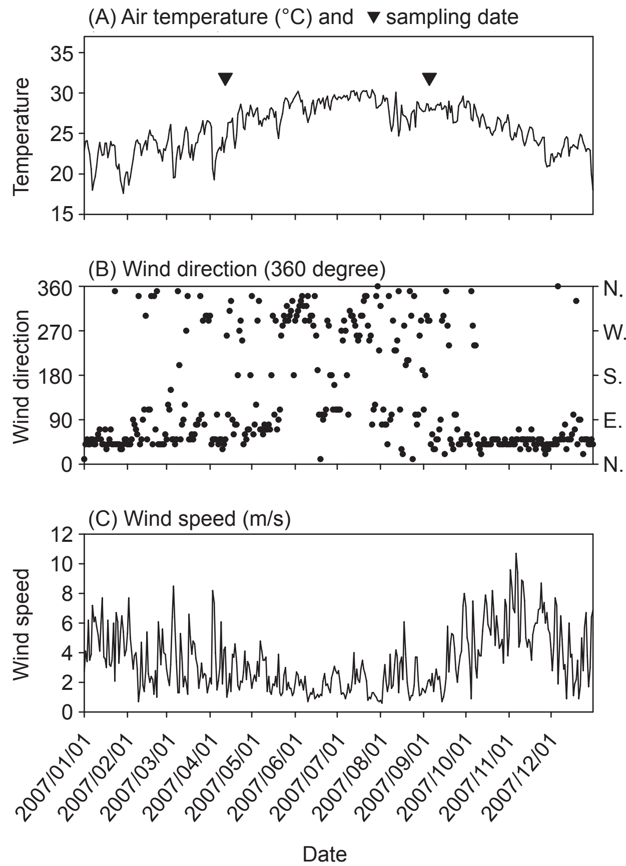

Fig. 2. Average daily air temperature, wind direction, and wind speed in 2007 retrieved from an automatic monitoring station of Hengchun Township adjacent to the sampling area. (A) Air temperatures, (B) wind directions of 0°, 90°, 180°, and 270° refer to northerly, easterly, southerly, and westerly winds, respectively, and (C) wind speed.

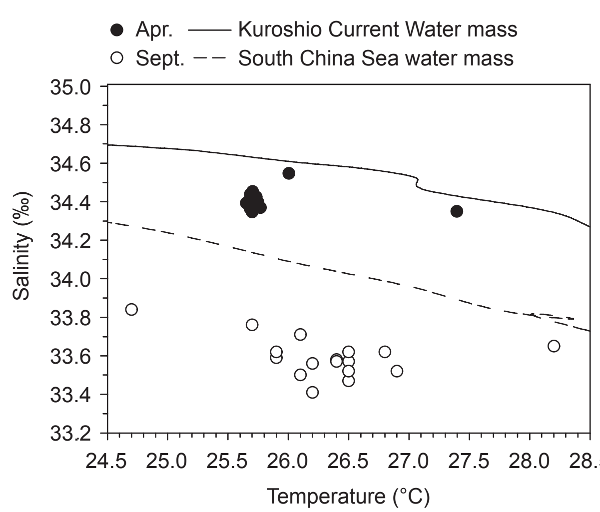

Fig. 3. Temperature vs. salinity (T-S) of surface waters at each station during 2 sampling cruises. Typical Kuroshio and South China Sea water T-S curves above 100 m depth are shown.

of each sampling cruise. Copepods belonging to 82 species (including 20 species only identified to generic level) were found in Apr., whereas 87 copepod species (including 25 unidentified species) were recorded in Sept. Among the Apr. samples, *Oncaea venusta* and *Corycaeus* (*Onychocorycaeus*) *catus* were recorded in all 17 samples with a 100% occurrence rate, followed by *Acrocalanus gracilis* and *Corycaeus* sp. with occurrence rates of 88.24%. *Paracalanus aculeatus* and *Par. Parvus* were found in all samples of Sept., which was *Oithona plumifera* had occurrence rates of 94.12% in the Sept. samples.

Copepod abundances in samples collected in Apr. ranged from 11.1 (station 7) to 174.5 ind./m^3 (station 17), whereas it ranged from 12.9 (station 4) to 367.8 ind./m^3 (station 17) in Sept. Sampling station 17, located in the southeastern sampling area near the area of the Kuroshio Branch Current (Fig. 1), recorded the highest values of copepod abundance on both cruises. The mean copepod abundance was significantly higher ($p = 0.015$, *t*-test, Table 1) in Sept. (100.1 ± 102.6 ind./m^3) than in Apr. (47.9 ± 42.7 ind./m^3). Figure 4 shows details of copepod abundance, species number, species richness, Shannon-Wiener diversity index, and Pielou's evenness index in Apr. (A) and Sept. 2007 (B). The number of species at each station ranged from 14 (station 1) to 36 (station 6) species/station in Apr., and from 12 (station 15) to 36 (station 14) species/station in Sept. The richness index of sampling stations ranged 4.77-9.53 in Apr., whereas it ranged 3.22-9.38 in Sept. The species number and richness index were higher in Sept. but did not significantly differ from those in Apr. The Shannon-Wiener diversity index of sampling stations ranged 2.26-3.22 in Apr. and 2.44-3.36 in Sept. According to the abundance of copepods, mean values of the Shannon-Wiener diversity index were significantly higher ($p = 0.008$, *t*-test, Table 1) in Sept. (3.10 ± 0.24) than in Apr. (2.84 ± 0.28). Pielou's evenness index of sampling stations ranged 0.83-0.96 in Apr. and 0.89-0.99 in Sept. Similarly, Pielou's evenness index was significantly higher ($p = 0.002$, *t*-test, see Table 1) in Sept. (0.95 ± 0.02) than in Apr. (0.90 ± 0.04).

A seasonal succession of the copepod composition was recognized for both copepod abundance and dominant copepod species. Figure 5 shows the percentages (%) of the top 10 species with a ranking of the relative abundances on the 2 sampling cruises. The top 10 abundant species in Apr. were *Cor.* (*O.*) *catus* (15.00%), *Onc. venusta* (11.97%), *Clausocalanus furcatus* (5.93%), *Acrocalanus gracilis* (4.95%), *Undinula darwinii* (4.41%), *Corycaeus* sp. (3.41%), *Par. aculeatus* (2.93%), *Acr. gibber* (2.72%), *Onc. media* (2.67%), and *Oithona* sp. (2.42%). The relative abundance ranking changed in the Sept. samples, with the top 10 abundant species being *Par. parvus* (10.08%), *Par. aculeatus* (9.12%), *Cor.* (*O.*) *catus* (8.01%), *Temora turbinata* (6.38%), *Oithona* sp. (5.86%), *Acr. gracilis* (4.28%), *Cla. furcatus* (3.64%), *Oit. plumifera* (3.12%), *Onc. venusta* (2.81%), and *Calocalanus pavo* (2.30%). The ranking positions of the species differed in the 2 different sampling months.

Furthermore, we identified 68 species (including 20 taxa identified to generic level) in both sampling cruises, with 33 species (including 7 taxa identified to generic level) only appearing in a single cruise (Table 2). These results indicate different autecological optima of the respective species.

Table 1. Average values (mean ± S.D.) of copepod abundance, species number, richness, diversity, and evenness indices of each sampling cruise, and *p* values of Student's *t*-test comparing differences between the 2 cruises

Sampling date	12 Apr. 2007	5 Sept. 2007	*p* value of *t*-test
Copepod abundance (individuals m^{-3})	47.9 ± 42.7	100.1 ± 102.6	0.015*
Copepod species number (number/ station)	24.0 ± 5.3	27.2 ± 5.6	0.110
Richness index	6.57 ± 1.30	6.60 ± 1.63	0.946
Shannon-Wiener diversity index	2.84 ± 0.28	3.10 ± 0.24	0.008**
Pielou's evenness index	0.90 ± 0.04	0.95 ± 0.02	0.002**

*Significant at the $p < 0.05$ level (2-tailed); **significant at the $p < 0.01$ level (2-tailed)

Hierarchical classification and identification of copepod assemblages

Figure 6 illustrates the copepod community analysis based on Bray-Curtis similarities. The NMDS analytical results (stress 0.12) of all copepod data from 34 samples showed that the 2 groups were separated on the basis of sampling period (Fig. 6A). The dendrogram revealed different clustering patterns of the copepod species composition in the 2 different monsoon transitional periods, in Apr. (Fig. 6B) and Sept. (Fig. 6C).

Tables 3 and 4 provide information for understanding the copepod composition and distribution of 17 stations during the 2 different sampling periods. In the Apr. samples, stations were separated into 2 clusters (Figs. 4A, 6B). Higher abundances of copepods were recorded at 6 stations (group IA, stations 2, 6, 11, 14, 15 and 17), and these were separated from the other stations (group IB). The 3 main copepod species of group IA were *Cor.* (*O.*) *catus* (with a relative abundance of 11.7%), *Onc. venusta* (11.4%), and *Cla. furcatus* (7.4%) (Table 3). Group IB included 11 stations, and the 3 dominant copepod species were *Cor.* (*O.*) *catus* (with a relative abundance of 21.9%), *Onc. venusta* (13.2%), and *Corycaeus* sp. (4.5%) (Table 3). In Sept., station 4 (group IA) had the lowest copepod abundance (12.92 ind./m^3) and highest richness index value (9.38) and was

Table 2. Average density (individuals/m^3) (mean ± S.D.), occurrence rate (OR, %), and relative abundance (RA, %) of various copepod species recorded during 2 different cruises

Sampling date	12 Apr. 2007			5 Sept. 2007		
Scientific classification (species name)	Abundance (mean ± S.D.)	OR (%)	RA (%)	Abundance (mean ± S.D.)	OR (%)	RA (%)
Order Calanoida						
Acartiidae						
Acartia (*Odontacartia*) *erythraea* Giesbrecht 1889	0.1 ± 0.2	11.76	0.17	0.7 ± 2.3	11.76	0.71
Acartia (*O.*) *spinicauda* Giesbrecht 1889	0	0	0	0.2 ± 0.5	11.76	0.16
Acartia (*Plantacartia*) *negligens* Dana 1849	0.5 ± 0.8	47.06	1.15	1.4 ± 1.7	58.82	1.37
Acartia sp.	0.8 ± 1.4	47.06	1.63	1.0 ± 1.4	47.06	1.02
Aetideidae						
Aetideus acutus Farran 1929	0	0	0	0.1 ± 0.2	11.76	0.08
Augaptilidae						
Haloptilus longicornis (Claus) 1863	0	0	0	0.5 ± 1.1	29.41	0.52
Calanidae						
Calanus pacificus Brodsky 1948	< 0.1 ± 0.2	5.88	0.08	0.1 ± 0.3	5.88	0.06
Calanus sp.	0.1 ± 0.4	11.76	0.29	0.4 ± 0.9	29.41	0.42
Canthocalanus pauper (Giesbrecht) 1888	0.2 ± 0.7	11.76	0.50	0.7 ± 1.5	35.29	0.68
Neocalanus sp.	0.1 ± 0.4	5.88	0.19	0.4 ± 1.5	5.88	0.36
Undinula darwinii (Lubbock) 1860	2.1 ± 4.2	58.82	4.41	1.5 ± 2.3	47.06	1.47
Undinula vulgaris (Dana) 1849	0.7 ± 1.6	29.41	1.46	0.6 ± 1.0	41.18	0.59
Calocalanidae						
Calocalanus pavo (Dana) 1849	0.9 ± 0.7	82.35	1.88	2.3 ± 2.9	70.59	2.30
Calocalanus pavoninus Farran 1936	0.2 ± 0.5	23.53	0.46	1.3 ± 1.4	64.71	1.33
Calocalanus plumulosus (Claus) 1863	0.4 ± 0.8	29.41	0.82	0.9 ± 2.3	35.29	0.92
Calocalanus sp.	0.2 ± 0.5	23.53	0.48	0.4 ± 1.5	11.76	0.42
Calocalanus styliremis Giesbrecht 1888	0.7 ± 1.4	41.18	1.40	1.0 ± 1.9	52.94	1.03
Candaciidae						
Candacia bradyi A. Scott 1902	0.2 ± 0.7	5.88	0.33	0	0	0
Candacia catula (Giesbrecht) 1889	0.1 ± 0.3	11.76	0.17	0.3 ± 0.9	23.53	0.33
Candacia curta (Dana) 1849	0.2 ± 0.7	5.88	0.33	0	0	0
Candacia discaudata A. Scott 1909	< 0.1 ± 0.1	5.88	0.04	0.3 ± 0.9	17.65	0.31
Candacia ethiopica (Dana) 1849	< 0.1 ± 0.1	5.88	0.06	0	0	0
Candacia sp.	0.4 ± 0.7	29.41	0.77	1.2 ± 1.8	47.06	1.19
Paracandacia truncata (Dana) 1849	0.1 ± 0.5	5.88	0.27	0.7 ± 1.7	29.41	0.72

Table 2. (continued)

Sampling date	12 Apr. 2007			5 Sept. 2007		
Scientific classification (species name)	Abundance (mean ± S.D.)	OR (%)	RA (%)	Abundance (mean ± S.D.)	OR (%)	RA (%)
Centropagidae						
Centropages calaninus (Dana) 1849	0.4 ± 0.6	41.18	0.88	0.2 ± 0.9	11.76	0.24
Centropages furcatus (Dana) 1849	0	0	0	0.1 ± 0.2	5.88	0.05
Centropages gracilis (Dana) 1849	0.7 ± 1.3	47.06	1.42	0.7 ± 1.8	17.65	0.74
Centropages sp.	0.2 ± 0.4	17.65	0.38	< 0.1 ± 0.2	5.88	0.04
Clausocalanidae						
Clausocalanus furcatus (Brady) 1883	2.8 ± 5.3	64.71	5.93	3.6 ± 6.9	70.59	3.64
Eucalanidae						
Eucalanus pseudattenuatus Sewell 1947	0.1 ± 0.4	17.65	0.29	0.6 ± 1.1	41.18	0.65
Pareucalanus attenuatus (Dana) 1849	0	0	0	0.2 ± 0.9	5.88	0.21
Rhincalanus sp.	0	0	0	0.1 ± 0.2	11.76	0.08
Subeucalanus crassus (Giesbrecht) 1888	0	0	0	0.2 ± 0.8	5.88	0.21
Subeucalanus pileatus (Giesbrecht) 1888	< 0.1 ± 0.1	5.88	0.06	0	0	0
Subeucalanus sp.	0.3 ± 0.6	35.29	0.73	1.4 ± 2.4	64.71	1.39
Subeucalanus subcrassus (Giesbrecht) 1888	0.4 ± 0.8	29.41	0.82	0.1 ± 0.4	11.76	0.12
Subeucalanus subtenuis (Giesbrecht) 1888	0.1 ± 0.3	5.88	0.17	0.5 ± 1.1	23.53	0.50
Euchaetidae						
Euchaeta concinna (Dana) 1849	0.2 ± 0.7	11.76	0.42	0.8 ± 1.8	23.53	0.80
Euchaeta marinella Bradford 1974	< 0.1 ± 0.1	5.88	0.06	0	0	0
Euchaeta plana Mori 1937	< 0.1 ± 0.2	5.88	0.08	< 0.1 ± 0.2	5.88	0.04
Euchaeta sp.	0.4 ± 0.5	47.06	0.82	0.6 ± 1.1	29.41	0.55
Euchaeta wolfendeni Scott A. 1909	0.2 ± 0.5	17.65	0.48	0.7 ± 2.3	11.76	0.72
Heterorhabdidae						
Heterorhabdus papilliger (Claus) 1863	0	0	0	0.1 ± 0.2	5.88	0.05
Lucicutiidae						
Lucicutia flavicornis (Claus) 1863	0.3 ± 0.7	29.41	0.71	0.7 ± 1.5	41.18	0.69
Mecynoceridae						
Mecynocera clausi Thompson 1888	0.2 ± 0.4	29.41	0.44	1.4 ± 2.4	47.06	1.35
Metridinidae						
Pleuromamma robusta (Dahl) 1893	0	0	0	0.1 ± 0.4	5.88	0.10
Pleuromamma sp.	0.1 ± 0.3	11.76	0.21	0.1 ± 0.3	11.76	0.11
Paracalanidae						
Acrocalanus gibber Giesbrecht 1888	1.3 ± 2.6	52.94	2.72	0.7 ± 1.6	29.41	0.75
Acrocalanus gracilis Giesbrecht 1888	2.4 ± 3.9	88.24	4.95	4.3 ± 6.9	82.35	4.28
Acrocalanus monachus Giesbrecht 1888	0.5 ± 0.7	47.06	1.02	1.2 ± 2.4	35.29	1.18
Acrocalanus sp.	1.0 ± 1.4	70.59	2.17	2.1 ± 2.9	58.82	2.13
Paracalanus aculeatus Giesbrecht 1888	1.4 ± 3.3	41.18	2.93	9.1 ± 16.0	100	9.12
Paracalanus parvus (Claus) 1863	0.9 ± 2.1	23.53	1.78	10.1 ± 12.0	100	10.08
Pontellidae						
Calanopia elliptica (Dana) 1849	0	0	0	0.7 ± 1.2	35.29	0.65
Calanopia minor A. Scott 1902	0.1 ± 0.3	5.88	0.17	1.1 ± 2.5	29.41	1.11
Calanopia sp.	0	0	0	< 0.1 ± 0.1	5.88	0.03
Labidocera acuta (Dana) 1849	0.1 ± 0.3	5.88	0.17	0	0	0
Labidocera detruncata (Dana) 1849	0.1 ± 0.3	11.76	0.21	0	0	0
Labidocera euchaeta Giesbrecht 1889	0.1 ± 0.4	17.65	0.29	0	0	0
Labidocera sp.	0.2 ± 0.5	17.65	0.44	0.2 ± 0.9	5.88	0.21
Pontella sp.	0.1 ± 0.3	17.65	0.29	0	0	0
Pontellina plumata (Dana) 1849	< 0.1 ± 0.1	5.88	0.06	0	0	0
Pontellopsis krameri (Giesbrecht) 1896	< 0.1 ± 0.2	5.88	0.08	0	0	0
Pontellopsis sp.	0.3 ± 0.7	23.53	0.65	0.2 ± 0.9	11.76	0.24
Pseudodiaptomidae						
Pseudodiaptomus marinus Sato 1913	0	0	0	1.0 ± 2.6	17.65	0.96

Table 2. (continued)

Sampling date	12 Apr. 2007			5 Sept. 2007		
Scientific classification (species name)	Abundance (mean ± S.D.)	OR (%)	RA (%)	Abundance (mean ± S.D.)	OR (%)	RA (%)
Rhincalanidae						
Rhincalanus cornutus (Dana) 1849	0.1 ± 0.4	17.65	0.27	0.8 ± 1.3	29.41	0.76
Scolecithricidae						
Scolecithricella sp.	0.2 ± 0.7	11.76	0.50	0.1 ± 0.3	11.76	0.09
Scolecithrix danae (Lubbock) 1856	0.3 ± 0.8	17.65	0.69	0.8 ± 1.9	29.41	0.83
Scolecithrix sp.	0	0	0	0.2 ± 0.5	11.76	0.15
Temoridae						
Temora discaudata (Giesbrecht) 1889	0.5 ± 0.8	29.41	0.94	1.0 ± 1.5	41.18	1.00
Temora stylifera (Dana) 1849	0.4 ± 0.6	41.18	0.82	2.0 ± 2.3	70.59	1.97
Temora turbinata (Dana) 1849	0.1 ± 0.4	11.76	0.25	6.4 ± 9.3	82.35	6.38
Order Cyclopoida						
Oithonidae						
Oithona plumifera Baird 1843	0.8 ± 0.8	70.59	1.78	3.1 ± 4.4	94.12	3.12
Oithona similis Claus 1866	< 0.1 ± 0.1	5.88	0.04	0.4 ± 1.5	5.88	0.36
Oithona sp.	1.2 ± 1.4	64.71	2.42	5.9 ± 6.2	88.24	5.86
Order Harpacticoida						
Clytemnestridae						
Clytemnestra sp.	0	0	0	< 0.1 ± 0.1	5.88	0.03
Ectinosomatidae						
Microsetella spp.	0.1 ± 0.2	17.65	0.19	0.2 ± 0.5	11.76	0.18
Euterpinidae						
Euterpina acutifrons (Dana) 1847	0	0	0	0.6 ± 1.7	17.65	0.60
Miraciidae						
Macrosetella gracilis (Dana) 1847	0.2 ± 0.5	11.76	0.33	1.2 ± 2.4	41.18	1.22
Monstrilloida						
Monstrillidae						
Monstrilla helgolandica Claus 1863	0	0	0	0.1 ± 0.3	5.88	0.06
Monstrilla sp.	0	0	0	0.1 ± 0.4	5.88	0.10
Order Poecilostomatoida						
Corycaeidae						
Corycaeus sp.	1.6 ± 1.4	88.24	3.41	1.6 ± 2.2	70.59	1.63
Corycaeus (*Agetus*) *flaccus* Giesbrecht 1891	0.1 ± 0.3	5.88	0.13	0.6 ± 1.7	17.65	0.60
Corycaeus (*Corycaeus*) *speciosus* Dana 1849	1.1 ± 0.9	76.47	2.21	0.7 ± 1.6	29.41	0.68
Corycaeus (*Onychocorycaeus*) *catus* F. Dahl 1894	7.2 ± 4.8	100	15.00	8.0 ± 10.3	88.24	8.01
Corycaeus (*Urocorycaeus*) *lautus* Dana 1849	0.4 ± 0.5	47.06	0.88	< 0.1 ± 0.2	5.88	0.05
Oncaeidae						
Lubbockia sp.	0.1 ± 0.3	5.88	0.17	< 0.1 ± 0.1	5.88	0.03
Oncaea media Giesbrecht 1891	1.3 ± 2.0	52.94	2.67	1.7 ± 1.9	64.71	1.74
Oncaea sp.	0.2 ± 0.7	5.88	0.33	< 0.1 ± 0.2	5.88	0.04
Oncaea venusta Philippi 1843	5.7 ± 5.2	100	11.97	2.8 ± 3.1	82.35	2.81
Pachysoma punctatum Claus 1863	0	0	0	0.1 ± 0.3	5.88	0.08
Pachysoma sp.	0	0	0	0.2 ± 0.7	5.88	0.16
Sapphirinidae						
Copilia mirabilis Dana 1849	0.2 ± 0.4	23.53	0.40	0.2 ± 0.7	5.88	0.16
Copilia quadrata Dana 1852	0.9 ± 0.9	70.59	1.94	0.4 ± 0.9	29.41	0.41
Copilia sp.	0.6 ± 0.8	52.94	1.32	0.6 ± 1.2	35.29	0.62
Sapphirina darwini Haeckel 1864	0.2 ± 0.5	11.76	0.36	0	0	0
Sapphirina gemma Dana 1849	0.2 ± 0.7	17.65	0.46	0	0	0
Sapphirina nigromaculata Claus 1863	0.2 ± 0.7	17.65	0.48	0	0	0
Sapphirina ovatolanceolata Dana 1849	< 0.1 ± 0.1	5.88	0.04	0.1 ± 0.2	5.88	0.05
Sapphirina scarlata Giesbrecht 1891	0.2 ± 0.4	23.53	0.40	0.3 ± 0.9	17.65	0.33
Sapphirina sp.	0.4 ± 0.6	35.29	0.90	0.9 ± 2.0	35.29	0.93

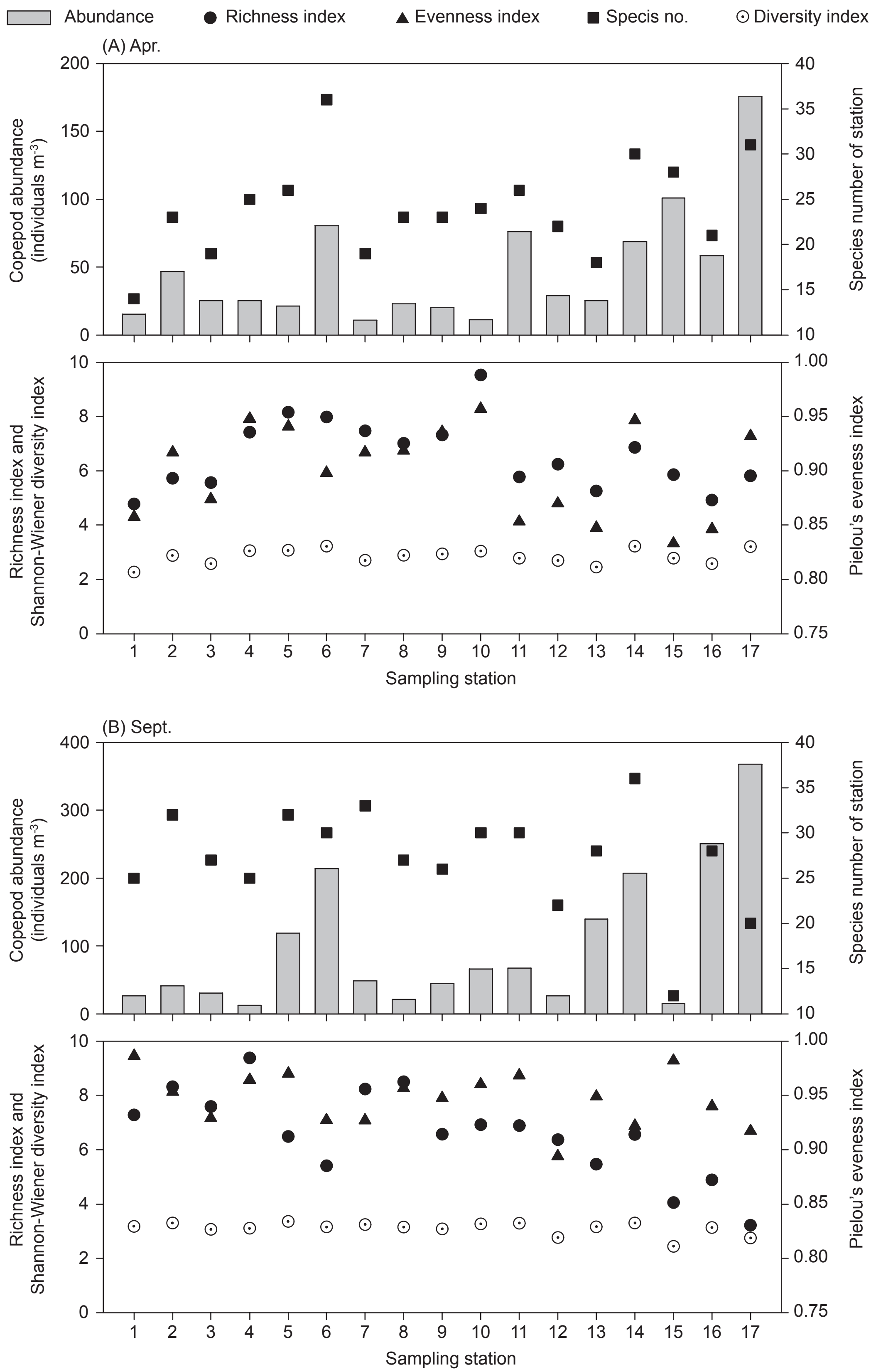

Fig. 4. Copepod abundance, species number, species richness, Shannon-Wiener diversity index, and Pielou's evenness index recorded in Apr. (A) and Sept. (B) 2007.

separated at the 1st hierarchical level. Next was station 15 (group IIA) which recorded the 2nd-lowest abundance (15.14 ind./m^3) and lowest species number (12 species), and was separated from the other stations at the 2nd hierarchical level (Fig. 4B). The other 15 stations were separated into 2 groups depending on their copepod compositions. Six stations (group IIIA, stations 5, 6, 13, 14, 16 and 17) had higher copepod abundances. The 3 dominant copepod species of group III A were *Par. parvus* (with a relative abundance of 9.9%), *Par. aculeatus* (9.9%), and *Cor.* (*O.*) *catus* (8.5%). All remaining stations were accommodated in group IIIB, with a different composition of copepod species (Table 4) and were dominated by *Par. parvus* (with a relative

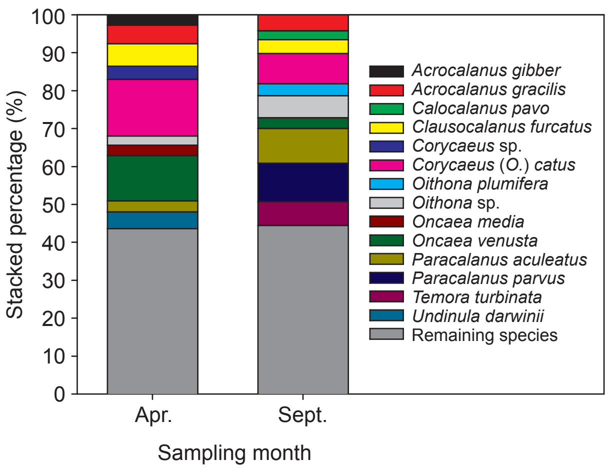

Fig. 5. Percent (%) relative abundances of the top ranking 10 species during the 2 sampling cruises.

Table 3. Dominant species contributing > 50% to the relative abundance of each cluster of the Apr. sampling cruise which resulted from a Bray-Curtis cluster analysis (see Fig. 6B).

Dominant species	Cluster level	
	Group I A	Group I B
Acrocalanus gibber	3.5	
Acrocalanus gracilis	5.7	3.5
Clausocalanus furcatus	7.4	
Corycaeus sp.	2.9	4.5
Corycaeus (*C.*) *speciosus*		3.9
Corycaeus (*O.*) *catus*	11.7	21.9
Oithona sp.		4.0
Oncaea venusta	11.4	13.2
Paracalanus aculeatus	4.0	
Undinula darwinii	5.4	
Cumulative contribution (%)	51.8	50.9

Table 4. Dominant species contributing > 50% to the relative abundance of each cluster of the Sept. sampling cruise which resulted from a Bray-Curtis cluster analysis (see Fig. 6C)

Dominant Species	Cluster level			
	Group I A	Group II A	Group III A	Group III B
Acrocalanus gibber	5.9			
Acrocalanus gracilis			4.3	4.4
Aetideus acutus	2.9			
Calocalanus pavo		7.1		
Clausocalanus furcatus			3.7	3.6
Corycaeus (*O.*) *catus*	8.8		8.5	6.6
Haloptilus longicornis	2.9			
Oithona plumifera		7.1	2.8	4.2
Oithona sp.	11.8		6.0	5.4
Oncaea media				3.4
Oncaea venusta		7.1		2.8
Paracalanus aculeatus	5.9	14.3	9.9	6.4
Paracalanus parvus	5.9	14.3	9.9	10.7
Temora stylifera	5.9			
Temora turbinata			7.4	3.5
Cumulative contribution (%)	50.0	50.1	52.4	50.7

abundance of 10.7%), *Cor.* (*O.*) *catus* (6.6%), and *Par. aculeatus* (6.4%) (Table 4).

DISCUSSION

The monsoon pattern in the present study area differs from that recorded in northwestern Taiwan (Tseng et al. 2008c). The different patterns are caused by different coastal topographies, resulting in different wind speeds and directions, and seasonal climatic changes. The hydrography in our sampling region is primarily affected by water masses from the Kuroshio Branch Current and SCS (Jan et al. 1998 2002, Hwang et al. 2003). Temperature records of surface waters were > 20°C during both sampling cruises. The surface water temperature was higher in Sept.

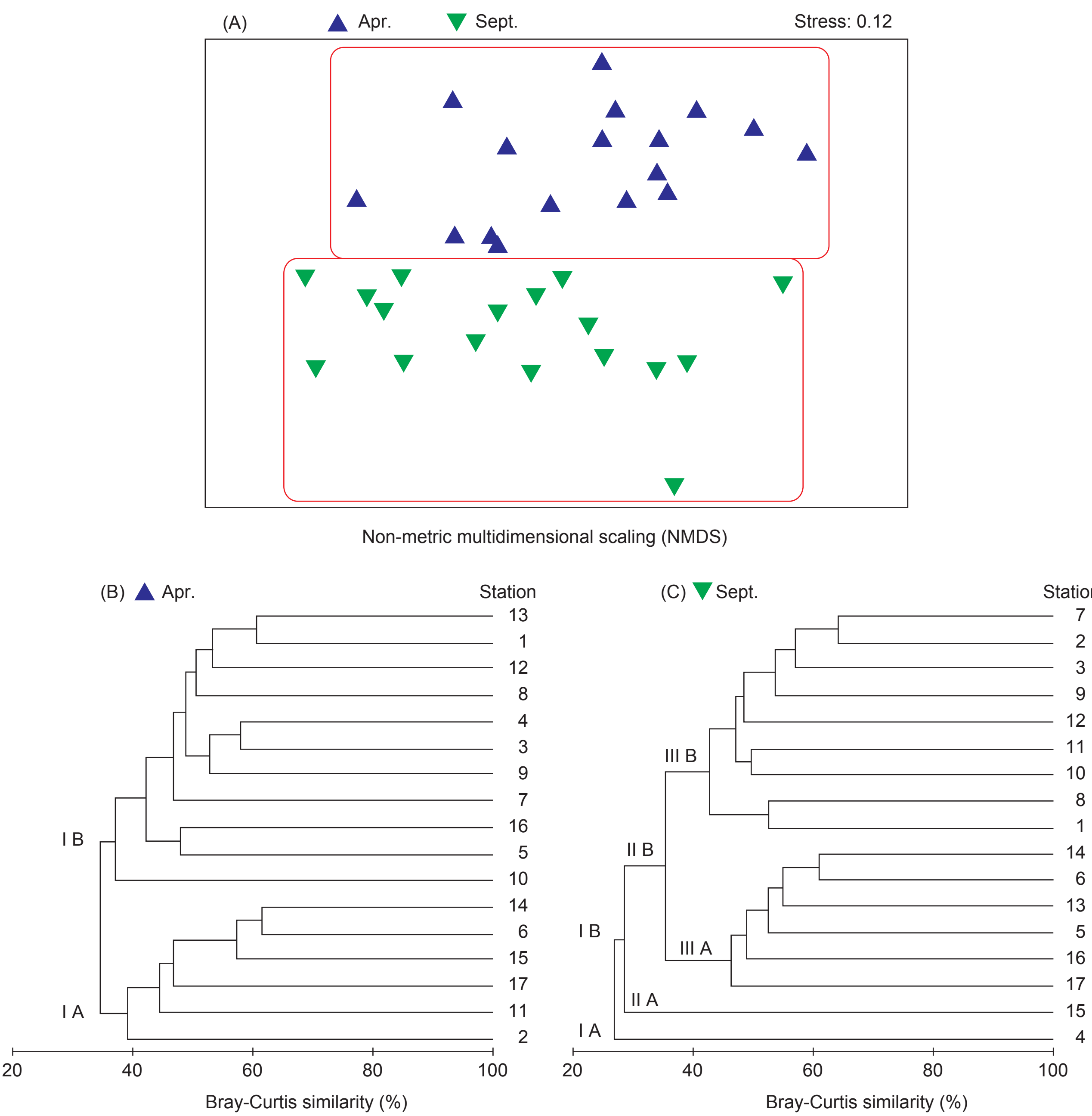

Fig. 6. Non-metric multidimensional scaling (NMDS) of all copepod data from 34 samples for 2 different cruises (A) and clustering dendrograms for copepod samples collected in Apr. (B) and Sept. (C).

before the NE monsoon, being affected by the SW monsoon which transferred warm water masses from the SCS to our study area (Jian et al. 2001). The water movement from the SCS transferred warm water species from the SCS to our study sites. In Sept., we found the following dominant species: *Par. parvus*, *Par. aculeatus*, and *Cor.* (*O.*) *catus*, which became indicating copepod species for the monsoon transitional periods caused by the prevailing SW monsoon in the SCS (Chen 1992, Shih and Young 1995). Hwang et al. (2007a) reported on Kuroshio Current water mass intrusions to the Luzon Strait that changed the plankton community composition during a cruise in Oct. 2004. The hydrological structure shows that intrusion waters of the Kuroshio Current appeared during Apr., but mostly SCS water was brought to Nan-Wan Bay in Oct. When the northeasterly monsoon prevails, the wind drives the China Coastal Current from the East China Sea into the Taiwan Strait. At the same time, the water mass of the Kuroshio Branch Current is driven back to southwestern Taiwan from the west coast of Taiwan. This in turn brings water masses of the northern SCS to Nan-Wan Bay. The different water masses strongly affect copepod communities during the monsoon transitional period (Chang and Fang 2004, Tseng et al. 2008c). According to our results, the copepod *Cla. furcatus* was dominant in a ranking of top 10 species during both sampling cruises. This species is dominant in the SCS as reported by Tseng et al. (2008a). The present study confirmed that successions of copepod communities were correlated with changes in the water masses in coastal areas of southern Taiwan.

Chang and Fang (2004) studied the copepod composition in Kaohsiung Harbor, southwestern Taiwan. Their findings of monthly copepod successions suggested that the abundance and diversity of copepod species were correlated with salinity. Hwang et al. (2006) analyzed inter-annual changes during a 5-yr period in the estuary of Danshuei River, northern Taiwan, and found monsoon-related variations in copepod assemblages. Tseng et al. (2008c) revealed that changes in copepod community structures in Dec. and Mar. were affected by the NE monsoon which drives the China Coastal Current that brings cold water species to northeastern Taiwan. The Kuroshio Branch Current in turn carries warm-water species along the coastal area of southern Taiwan to northeastern Taiwan during the SW monsoon, which causes changes in copepod communities in May and Aug.

The Changyun Ridge west of central Taiwan in the eastern Taiwan Strait blocks the cold China Coastal Current on its way to the southern Taiwan Strait during the NE monsoon period and causes an intrusion of warm-water masses from the SCS and Kuroshio Branch Current into the southern Taiwan Strait. Furthermore, water masses with different oceanographic features support copepod faunas with different species compositions during different seasons, causing a seasonal succession. Tseng et al. (2008e) described the copepod communities in southwestern Taiwan and found substantial seasonal changes during 3 sampling seasons. In their study, the warm-water calanoid, *Temora turbinata*, was dominant during all sampling cruises and was able to tolerate the otherwise polluted environment. Seasonal succession became apparent in variations in abundances between months and stations, and in the distribution patterns of copepods. Hsu et al. (2008) studied the copepod assemblages in the lagoon of Tapong Bay in southwestern Taiwan and suggested that seasonal succession was apparent as a variation during some months at some stations that changed the distribution patterns of copepods. The present results confirmed the seasonal succession of copepod assemblages as a common phenomenon in coastal areas of subtropical southwestern Taiwan.

Our values of the richness index (4.77-9.53 in Apr. and 3.22-9.38 in Sept.) and diversity index (2.26-3.22 in Apr. and 2.44-3.36 in Sept.) were higher than previous studies of the northwestern Taiwan coastal area (Tseng et al. 2008c). In the present sampling area located at the northern margin of the SCS, water masses and the plankton of 2 current regimes (the SCS and the Kuroshio Branch Current) are translocated to the sampling area which increases the probability of obtaining more copepod species. Furthermore, our study area was located at an ecotone where the water masses of the Kuroshio Branch Current and SCS mix. Such edge effects increase the diversity and species number (Nybakken 1993) and also raise the richness index values when the abundances remain constant. A similar inference can be attributed to the present study area and station 17 where the front area of intrusion water masses from the Kuroshio Current showed the highest copepod abundance during both sampling cruises.

The dominant species composition in the 2 transitional periods showed seasonal succession during the 2 sampling cruises. Relative abundances were low, but seasonal succession was apparent (Fig. 5). The copepod *Cor.* (*O.*) *catus* was the most abundant species in Apr. but it ranked 3rd in Sept. Similar trends were recorded for *Onc. venusta* and *Cla. furcatus* which were respectively ranked 2nd and 3rd in Apr. but descended to 9th and 7th in Sept. In contrast, *Par. parvus* was not dominant in Apr., whereas it was the most abundant species in Sept. A similarly elevated ranking was seen for *Par. aculeatus*, which was 7th in Apr. and 2nd in Sept. Several previous studies found dominant species around Taiwan to be variable and to change with the season (Hsieh and Chiu 1997, Hwang et al. 2006, Hsu et al. 2008, Tseng et al. 2008c e, Lan et al. 2009), sampling time (Hwang et al. 2003), and sampling location (Tseng 1975, Hwang et al. 1998 2007a, Shih and Chiu 1998, Wong et al. 1998, Lo et al. 2001 2004a, Hsiao et al. 2004, Tseng et al. 2008a d). The calanoid copepod *Tem. turbinata* was reported in many studies of the coastal waters around Taiwan as a common species (Tseng 1975, Hsieh and Chiu 1997, Hwang et al. 1998 2003 2004 2006, Wong et al. 1998, Lo et al. 2001, Hsu et al. 2008, Tseng et al. 2008c e), in Kaohsiung Harbor (Chang and Fang 2004), the SCS (Tseng et al. 2008a), the Kuroshio Current (Hsiao et al. 2004), and the East China Sea (Shih and Chiu 1998, Shih et al. 2000, Lo et al. 2004b, Tseng et al. 2008d). We found this species in Sept. when the water temperature was higher and this species ranked 4th in abundance. *Tem. turbinata* was shown to be an indicator species of warm-water masses (Hwang et al. 2006, Dur et al. 2007) and can become dominant in polluted waters (Fang et al. 2006, Tseng et al. 2008e). Copepods that were predominant in coastal waters of southern Taiwan, therefore, showed a seasonal succession and remarkable spatial variations with water-mass changes.

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