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Intrusions of the Kuroshio Current in the northern South China Sea affect copepod assemblages of the Luzon Strait

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Abstract

We analyse the influence of the Kuroshio Current on copepod assemblages in the northern South China Sea. The assumption was tested whether predominant current regimes bring marine zooplankton and Copepoda from subtropical and tropical waters to the south of Taiwan. A total of 101 copepod species were identified from 26 families and 48 genera that include Calanoida, Cyclopoida, Harpacticoida and Poecilostomatoida. High copepod abundances in the study area are shown to be caused by both, a year-round Kuroshio Current intrusion and the SW monsoon, prevailing in the South China Sea during summer. *Calanus sinicus* did not appear in the samples, indicating that there was no cold water mass intrusion in the area during sampling. Both, the intrusion of the Kuroshio Branch Current to the Luzon Strait and the South China Sea circulation may play a more important role in shaping copepod assemblages in the region than hitherto expected. The abundance of copepods was higher above the 50 m isoline than at deeper strata. Species number and the Shannon–Wiener diversity index were higher with increasing depth. Copepod assemblage structure changed with different sampling depth and different sampling areas. Copepod abundance and species richness were higher in the northern South China Sea than in the Kuroshio Current area, and higher at lower latitudes than at higher latitudes. Some indicator species are characteristic for the Kuroshio Current and indicate with others that the study area accomodated water masses from the northern South China Sea as well as from the Kuroshio Current.

Keywords: Community ecology; Copepoda; Current regimes; Kuroshio Branch Current; Marine plankton

1. Introduction

Marine life around the island of Taiwan is highly diverse. There are estimates that the marine fauna comprises about 10% of the world's total marine fauna, including a large number of endemic species (Hwang et al., 2000a; Shao, 1998). As for zooplankton and its predominant taxon the Copepoda, Shih and Young (1995) have reviewed the published records of 431 copepod species from the marginal seas of China, including those surrounding Taiwan. The diversity of Taiwan's marine life is enriched by the transport of temperate and subtropical species from the north and tropical species from the south (Chiu and Chen, 1998; Chiu and Hsyu, 1994; Hwang et al., 2000b, 2004a, 2006; Hwang and Wong, 2005; Shih and Chiu, 1998).

Hwang and coworkers (Hwang et al., 2004a,b,c) suggest that oceanic waters of different origin that

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converge at Taiwan are the primary driving forces of enriched marine biodiversity in Taiwan (see also Liu et al., 2003; Wong et al., 2000). The NE monsoon is suggested to bring plankter during winter to the north and west of Taiwan; from the Bohai Sea, the Yellow Sea and the East China Sea (ECS) into the Taiwan Strait (TS) (Chen, 1992; Hwang and Wong, 2005; Hwang et al., 2006). The SW monsoon brings species from the South China Sea (SCS) to the south of Taiwan during summer (Chen, 1992; Hwang et al., 2000b, 2003, 2004a; Liu et al., 2003). To the east of Taiwan, the northward flow of the Kuroshio Current (KC) provides a continuous year-round addition to the marine biodiversity of eastern Taiwan that influences the oceanic regime all year round. To the west, along the TS and the southern edge of the ECS, the water circulation is strongly influenced by monsoon winds.

During the NE monsoon period in winter (September to April), the China Coastal Current (CCC) brings cold water from the Yellow Sea and the ECS into the TS (Lee and Chao, 2003; Liang et al., 2003; Liu et al., 2003; Tseng and Shen, 2003). Water circulation in the TS varies seasonally with changes in wind direction (Jan et al., 1995, 2002; Lee and Chao, 2003; Liang et al., 2003; Tseng and Shen, 2003).

A long-term multidisciplinary project of Kuroshio Edge Exchange Processes (KEEP) was launched in the 1990s to study influences of the KC on the physical, chemical and biological processes of the ECS and its surroundings (Liu et al., 2003; Wong et al., 2000). Data from physical oceanography indicate that the KC intrudes into both, the northern SCS and coastal waters of southern Taiwan via the Luzon Strait, particularly during winter (Jan et al., 1995, 2002). From late autumn to early spring (November to March) the NE monsoon drives water masses from the ECS along the China coast line towards the TS, resulting in the obstruction of the north-flowing KC at the Changyun Ridge. The KC flows over the Changyun Ridge and may impact the northern part of the TS only when the NE monsoon begins to subside in spring. The Luzon Strait, between Taiwan and the Philippines is the most important water passage connecting between the west Pacific KC and the northern SCS. We suppose that the Luzon Strait is an important waterway transporting marine fauna from the KC towards the northern SCS and coastal waters of southern Taiwan.

Zooplankton community composition can provide suitable indication for water mass movements that are otherwise characterized by parameters such as different temperature and salinities (Paffenhoefer and Flagg, 2002; Peterson and Keister, 2003). In Taiwan waters, such attempts are as yet restricted to short term studies on copepods (Hsieh et al., 2004; Hwang and Wong, 2005) and ichthyoplankton (Chiu and Chen, 1997; Chiu and Hsyu, 1994).

Several studies indicated that copepod assemblages in waters of Taiwan have been highly influenced by water masses from ocean currents (Hwang and Wong, 2005; Hwang et al., 2004a, 2006). Hwang and Wong (2005) used *Calanus sinicus* as a biological indicator to trace water movements. They suggested that during the NE monsoon that prevails in winter, *C. sinicus* gets transported from the Bohai Sea, Yellow Sea, and ECS into northern Taiwan waters and along the China coast southwards to the waters of Hong Kong.

Our study area located in the KBC, and the South China Sea Surface Current (SCSSC) is supposed to have a major impact on the abundance and diversity of biotic communities in this region (Hsieh et al., 2004; Hwang et al., 2000b, 2004b; Hwang and Wong, 2005; Lan et al., 2004; Lo et al., 2004b; Shih and Chiu, 1998).

Based on the results of previous studies, we propose and test the following two hypotheses here: (i) the effect of the Kuroshio Branch Current intrusion is substantial for copepod assemblages in the northern South China Sea, and (ii) the copepod composition in coastal areas of southern Taiwan is affected by South China Sea waters. We use data from 3 stations along 2 latitudinal transects in the northern South China Sea to test these hypotheses.

2. Materials and methods

2.1. Zooplankton sampling

Zooplankton samples were collected on board the Ocean Research Vessel I at 6 stations along the KC edge, the Luzon Strait, and the NSCS around the southern tip of Taiwan (Fig. 1). Sea water temperature and salinity were measured on board using SeaBird CTD probes. The study is based on plankton collections by the Taiwan Ocean Research Vessel I during the CR 734 cruise from the 12th to 23rd of October in 2004. Stations along two latitudinal transects were sampled from the northern SCS towards the KC (Fig. 1). These transects are along two latitudinal lines, 21.419 (°N) and 22.164 (°N) respectively. A western group of stations was situated in the NSCS and included stations A, S1, M1 (S1 and M1 are directly influenced by KC intrusion waters) and the KC that included stations S3, S4, S5. Latitude, longitude, sampling depths, and sample numbers of each station during the ORI CR-734 cruise are listed in Table 1. Zooplankton samples were collected down to 4500 m depth by oblique net tows with a modified Norpac zooplankton net (0.45 m mouth diameter, 200 μm mesh).

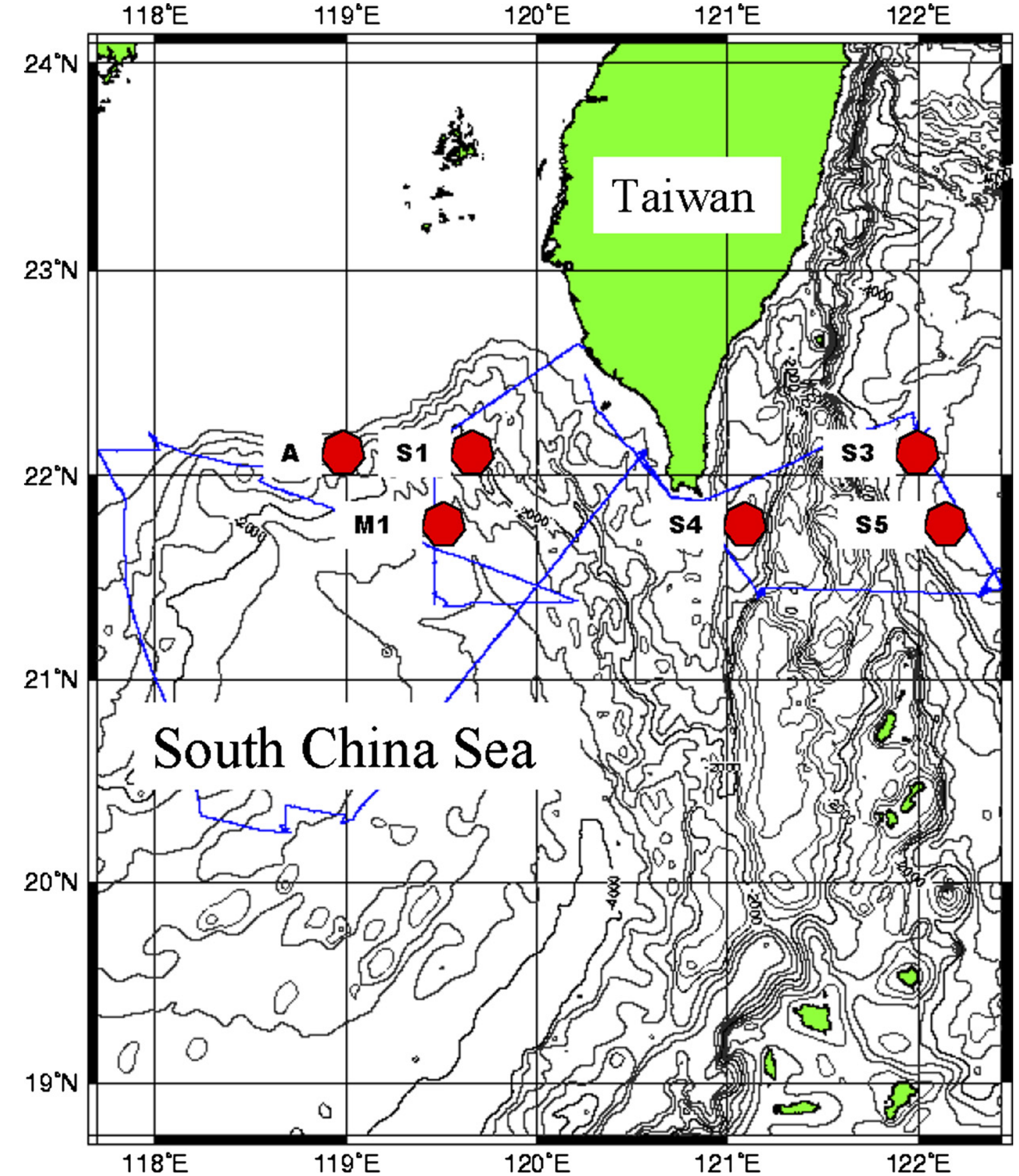

Fig. 1. Map of sampling stations along two transects following latitude 21.419 (°N) and latitude 22.164 (°N) in the northern South China Sea.

Zooplankton samples were preserved in 5% buffered formalin in seawater, immediately after collection on board. At station A, horizontal net tows were taken at 2 m depth and oblique net tow samples were obtained from 50 m depth since the area provided an average depth of 55 m. In the laboratory, subsamples were taken using a zooplankton Folsom Splitter. Mature copepods were counted, sorted and identified to species level. The

Table 1
Latitude, longitude, sampling depths and sample numbers at each station during the ORI CR-734 cruise

Station	Latitude (°N)	Longitude (°E)	Sampling depth (m)	Sample number
S1	22.164	119.469	50, 600	3
S3	22.164	122.000	50, 600, 2500	6
S4	21.419	121.167	50, 600, 1400	5
S5	21.419	122.333	50, 600, 2500, 4500	6
A	22.164	118.000	2, 50	5
M1	21.419	119.500	50, 600, 2500	5

following keys and taxonomic references were used for copepod identification if not mentioned otherwise (Chen, 1992; Chen and Zhang, 1965; Chen et al., 1974; Chihara and Murano, 1997; Huys and Boxshall, 1991).

2.2. Data analysis

2.2.1. Spatial similarity analysis

It is hypothesized that the hydrographic situation of the study area is influenced by the surrounding ocean currents and that water sources will affect the structure of copepod communities at spatial and temporal scales. In order to elucidate the relative importance of spatial and temporal scales in this analysis, we compared similarities of species composition among stations for each sampling date. We first computed a centroid vector representing the average composition of species. Then

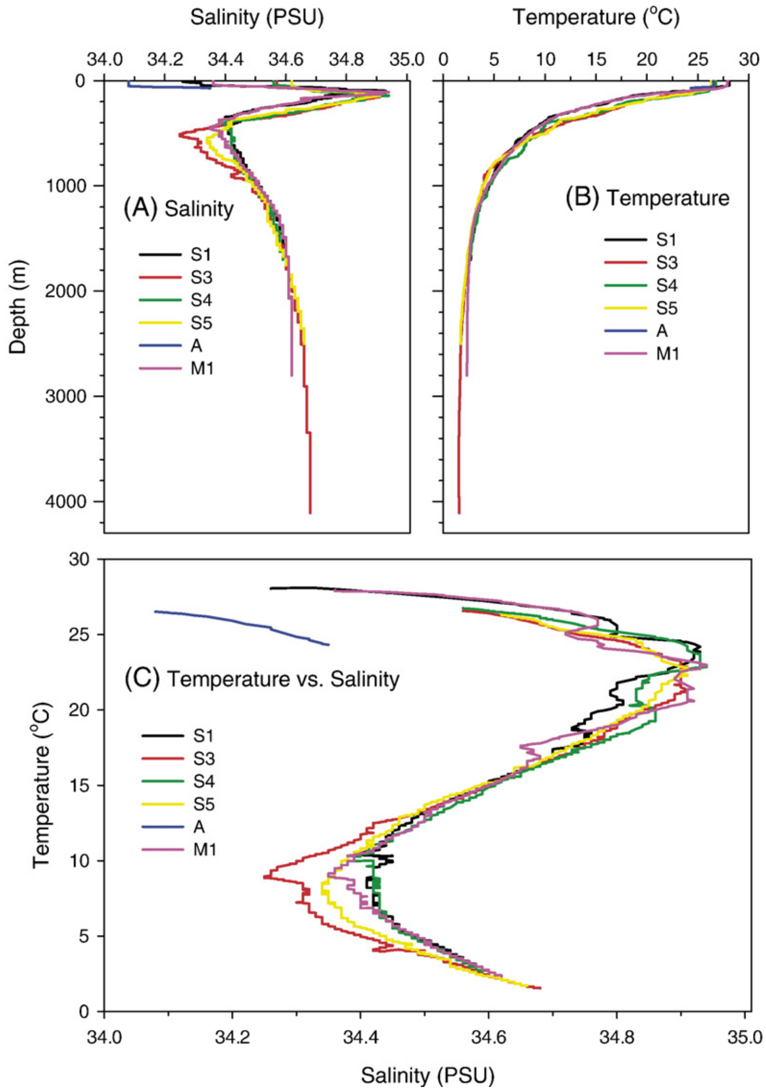

Fig. 2. Graph of (A) salinity, (B) temperature and (C) temperature *vs*. salinity at each sampling station.

we calculated different similarity values between stations and their associated centroid. From the obtained similarity vector, the mean and 130 standard deviations of the similarities were calculated and used for an estimation of spatial heterogeneity.

Geometric class plots are generated to understand the composition of copepod communities at different localities. First, we calculated the average density for each species in the different groups under comparison. Then, we ranked the copepod species number according to the geometric results (e.g. 2^0, 2^1, 2^2, $2^3 \ldots 2^n$.). The calculation of species number percentages of different geometric rank depends on the number of identified copepods.

2.2.2. Cluster and IndVal analysis

In order to obtain the symmetric normal distribution of species abundance data, a transformation power was generated by regression coefficients that were estimated simultaneously using the method of maximized log likelihood function (Box and Cox, 1964). According to this calculation, an index value of 0.93 very close to 1 was obtained. This way a matrix of abundances composed of 30 samples and 101 species was log transformed ($\log(x+1)$) before similarity coefficients between samples were computed using Bray–Curtis similarity coefficients and clustering strategies of flexible links. These were obtained from the Plymouth Routine In Multivariate Ecological research (PRIMER, version IV; Clarke and Warwick, 1994) software package. The species characterizing each cluster were further identified using the Indicator Value Index (IndVal) proposed by Dufrêne and Legendre (1997).

3. Results

3.1. Hydrography and water circulation

Salinity (Fig. 2A) showed minimum levels at the surface of about 34.3 PSU and reached a maximum

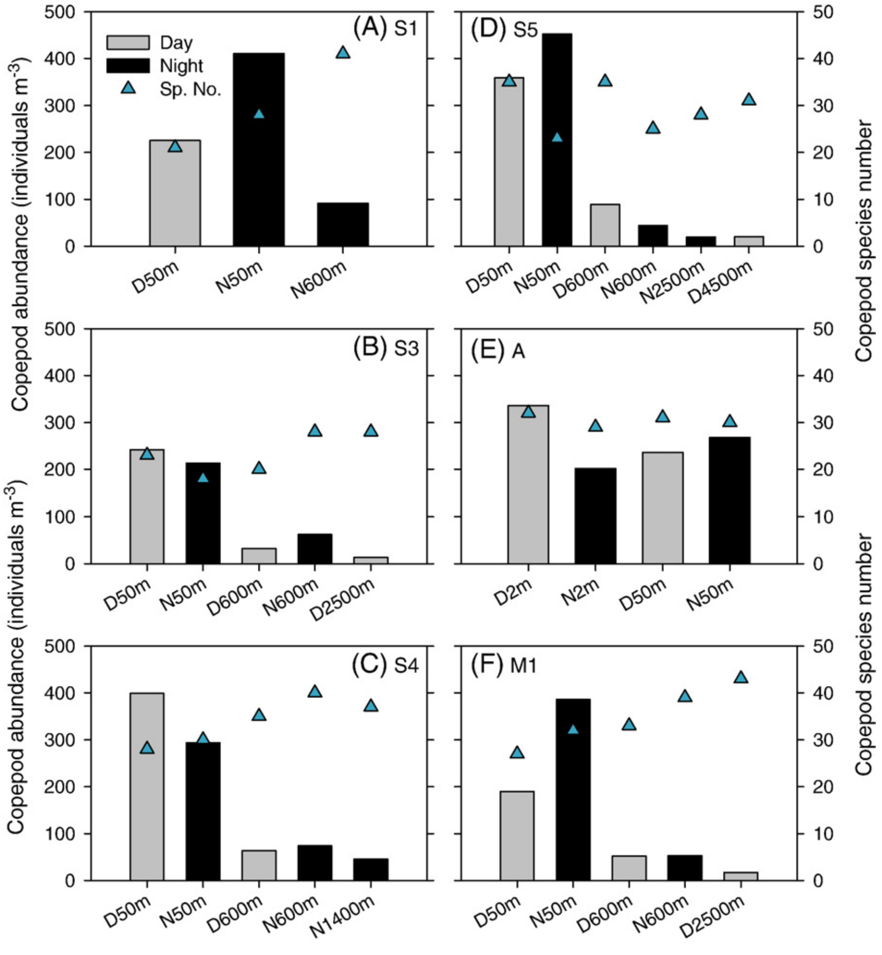

Fig. 3. Copepod abundance and species number at each station during day and night sampling.

concentration of 34.95 PSU at 200 m water depth. Another minimum of 34.25 PSU occurred at 450 m depth before salinity leveled off to 34.6 PSU at about 2000 m depth.

A temperature profile provided maximum temperatures of 28 °C at the surface and a temperature low of about 4 °C at 2000 m depth or deeper (Fig. 2B). This trend is similar for all stations. Sea surface temperatures to the east and southeast of Taiwan are >25 °C throughout the year due to the influence of the warmer KC and tropical SCS waters. In contrast, surface salinity varied widely among sampling stations and did not show a clear pattern.

3.2. Temperature versus salinity

The water mass at station A is different from other stations. Station A shows a relatively higher temperature and a low salinity, indicating water masses from the SCS. Station S1 and M1 comprise mixed water masses; surface waters show high temperatures and low salinities (SCS water masses). In deeper layers there is a shift to higher temperatures and salinities indicating an intrusion of the KC in deeper water layers. Stations S3, S4 and S5 have higher temperatures and higher salinities, indicating a water mass derived from the KC. The T–S diagram showed that the KC water mass intruded north to stations S1 and M1. Accordingly, station S1 and M1 comprised mixed waters from the SCS and the KC (Fig. 2C). Graph (C) shows that the water mass of station A is different from others stations. Station A shows high temperature and low salinity that indicate a water mass coming from the South China Sea. Station S1 and M1 belong to an area of mixed waters where surface waters show high temperature and low salinity (SCS water mass); deeper waters change to high temperature and high salinity (Kuroshio Current water masses). Stations S3, S4 and S5 are located in the Kuroshio Current area. These waters show high temperature and high salinity. Therefore, stations S1 and M1 belong to a boundary area with mixed waters.

3.3. Copepod assemblages

In the present study, 101 copepod species were found integrated over depth within the transect area of all

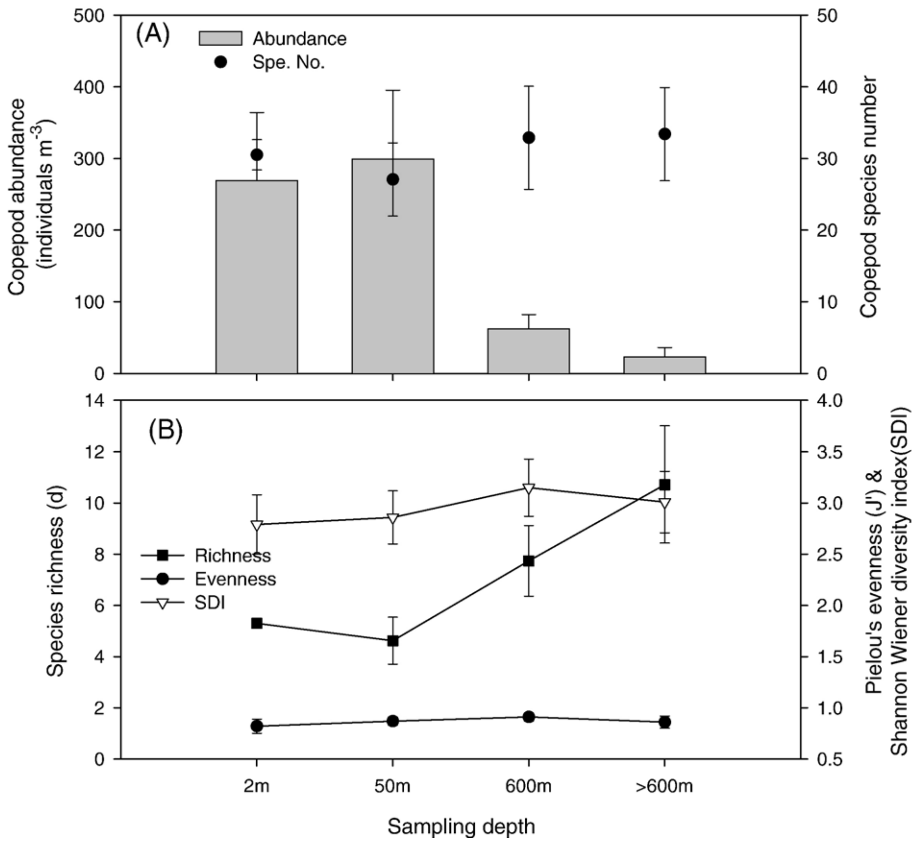

Fig. 4. Mean copepod abundance, species number, richness, Pielou's evenness and Shannon–Wiener diversity index for each sampling depth.

stations south of latitude 22.164°N and north of latitude 21.419°N. A total of 101 copepod species, including 70 representatives of the Calanoida, 25 Poecilostomatoida, 3 Cyclopoida and 3 Harpacticoida, were recorded during this study (see Appendix A).

Abundance appeared to vary among stations, but no clear trend between onshore and offshore stations was detected. Copepod species numbers at each station range from as low as 57 species at stations S1 and A (SCS water mass), and 61 to 67 species at stations S3, S4 and S5 (KC water mass), up to the highest number of 81 species at station M1 (where mixing of the SCS water masses and the KBC intrusion water masses take place). The density of copepods ranged from 134.2–262.3 individuals m^{-3}. The highest density occurred at stations S1 and A, whereas the lowest density occurred at station S3 (KC). Copepod assemblages were dominated by 17 species (belonging to the genera: *Acartia*, *Acrocalanus*, *Calanoides*, *Calocalanus*, *Canthocalanus*, *Clausocalanus*, *Corycaeus* (*Farranula*), *Lucicutia*, *Nannocalanus*, *Oithona*, *Paracalanus*, *Paracandacia*, *Pleuromamma*, and *Temora*—see Table 3) which comprised more than 50% of the copepod abundances of 4 copepod assemblages that were distinguished by a Bray–Curtis clustering approach comparing all stations and all depth samples. It should be noted that results covered depth layers from 2 m down to 4500 m.

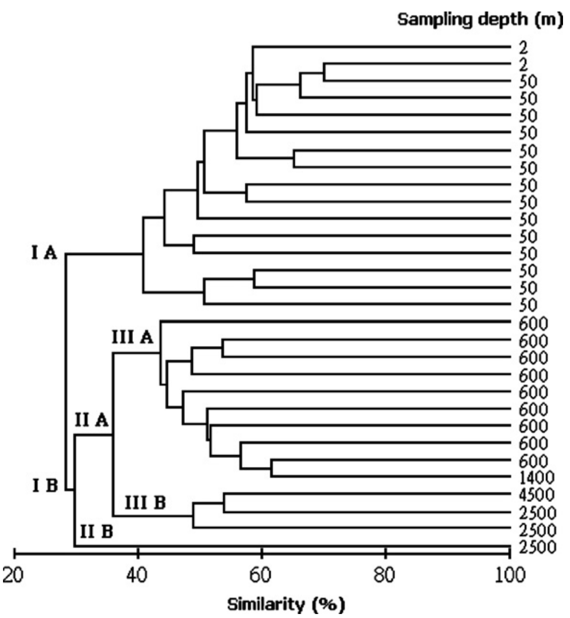

Fig. 5. Bray–Curtis similarity cluster analysis for all samples and depths.

Table 2
Copepod species contributing to more than 50% of the abundance of each group, resulting from a Bray–Curtis similarity analysis (Fig. 5)

Species\group	IA	IIB	IIIA	IIIB
Acartia (P.) negligens	8.39		6.56	
Acrocalanus gracilis	4.96			
Calanoides carinatus				11.58
Calocalanus pavoninus		3.53		
Canthocalanus pauper	4.57	5.88		
Clausocalanus arcuicornis	10.99		13.23	23.11
Clausocalanus furcatus	5.94	7.06	8.00	11.03
Corycaeus (F.) concinna	7.26		5.46	
Corycaeus (F.) gibbula	4.75		4.65	
Lucicutia flavicornis			4.73	
Nannocalanus minor		3.53		
Oithona attenuata		12.93		
Paracalanus nanus		12.93		
Paracandacia truncate	3.85			
Pleuromamma gracilis			5.76	
Pleuromamma xiphias			3.83	8.48
Temora discaudata		4.71		
Cumulative contribution (%)	50.71	50.57	52.22	54.20

3.4. Day/night shifts of copepod abundances and species numbers

Most day/night differences in copepod abundances were discernible only at shallower depths down to 50 m (Fig. 3). Stations where day night differences were significant at a depth above 600 m were S1, S5, S3 and A. There was no general trend for species numbers with day/night shifts. At stations S1, S3, S4 and M1, there was a trend of increasing species numbers with depth. Only at station S5 there was a consistent drop of species numbers discernible between day and night above 50 m and above 600 m depth.

Table 3
Copepod species found predominantly in between latitudes 22.164 °N and 21.419 °N

Latitude (°N)	Species name
22.164	*Calanopia elliptica*, *Candacia pachydactyla*, *Copilia quadrata*, *Corycaeus (Urocorycaeus) longistylis*, *Euchaeta concinna*, *Euchaeta spinosa*, *Labidocera acuta*, *Oncaea clevei*, *Sapphirina scarlata*
21.419	*Aetideus giesbrechti*, *Augaptilus longicaudatus*, *Calocalanus contractus*, *Eucalanus elongatus*, *Euchirella messinensis*, *Lucicutia bicornuta*, *Lucicutia ovalis*, *Metridia brevicauda*, *Microsetella norvegica*, *Neocalanus robustior*, *Pachyptilus eurygnathus*, *Sapphirina gemma*, *Scolecithricella* sp.

Over all stations (Fig. 4A), copepod abundances decreased with depth, showing some irregularities at the surface down to 50 m. Species numbers tentatively increased with depths. The average density of copepods at a water depth of 50 m was 284.12 individuals m^{-3} which was 13 times higher than above 600 m depth. Copepod abundances differed significantly between 50 m, 600 m and deeper samples (one-Way ANOVA, Tukey test $p<0.001$, $\alpha=0.01$). Species richness increased with depth from 50 m (average 4.56), to 600 m (average 7.74), and below 600 m (average 10.72) (one-way ANOVA Tukey test, $p<0.001$, $\alpha=0.01$) (Fig. 4B). Shannon–Wiener diversity indices show highest values above 600 m depth. Index values increase with sampling depth, reversing the trend of the richness index. Shannon–Wiener diversity indices at 600 m depth are significantly higher than samples above 50 m (one-way ANOVA Tukey test, $p=0.031$, $\alpha=0.05$). Evenness indices do not differ between samples from different depths (Fig. 4B).

3.5. Vertical patterns of copepod assemblages

The first hierarchical level of a cluster analysis separates a shallow (less than 50 m deep) water assemblage (cluster IA) from a deeper (than 50 m) assemblage (cluster IB) (Fig. 5). The second hierarchical level distinguishes an assemblage above 600 m depth and above 2500 m (cluster IIA) from another assemblage exclusively above 2500 m (cluster IIB). The next hierarchical level provides a cluster combining all stations above 600 m depth (cluster IIIA) as well as stations with samples above 2500 m depth and above 4500 m (cluster IIB) (Table 2).

The 17 key indicator species according to a SIMPER analysis, and their contribution to the total copepod abundance are provided in Table 3. These key indicator species contribute to more than 50% of the copepod abundance at each cluster. They include for cluster IA: *Acartia* (*P.*) *negligens*, *Acrocalanus gracilis*, *Canthocalanus pauper*, *Clausocalanus arcuicornis*, *Clausocalanus*

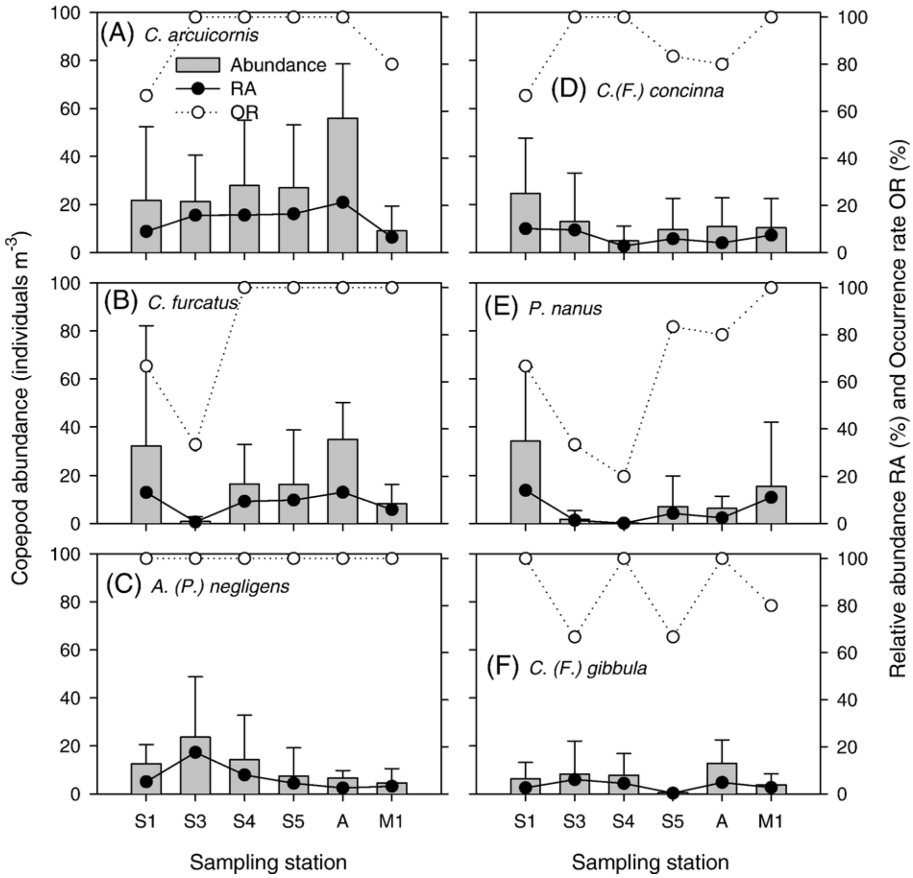

Fig. 6. Variation of mean abundance, relative abundance (RA) and occurrence rate (OR) of the six most abundant copepod species at each sampling station.

furcatus, *Corycaeus* (*Farranula*) *concinna*, *Corycaeus* (*Farranula*) *gibbula* and *Paracandacia truncata*. *Acartia* (*P.*) *negligens* does also belong to the group of most abundant copepods in Group IIA (all stations above 600–1400 m depth). *Clausocalanus pauper* is equally dominant in Group IIB (waters that are less than 2500 m deep). *C. arcuicornis* occurs in Group IA, IIIA, and IIIB, whereas *C. furcatus* occurs in all 4 clusters.

Copepod densities above 50 m depth were significantly higher than those of the water column above 600 m. The surface near species assemblage included: *Acartia* (*Planktacartia*) *negligens*, *Phyllopus helgae*, *Haloptilus longicornis*, *Calanoides carinatus*, *Canthocalanus pauper*, *Cosmocalanus darwini*, *Nannocalanus minor*, *Calocalanus pavo*, *P. truncata*, *Centropages calaninus*, *C. arcuicornis*, *C. furcatus*, *Subeucalanus crassus*, *A. gracilis*, *Acrocalanus monachus*, *Scottocalanus securifrons*, *Macrosetella gracilis*, *Corycaeus* (*Farranula*) *concinna*, *Corycaeus* (*Farranula*) *gibbula*, *Corycaeus* (*Onychocorycaeus*) *pacificus*, *Corycaeus* (*Urocorycaeus*) *lautus*. These species inhabit shallow warmer waters. We consider them as warm water indicator species.

3.6. Comparison of stations: copepod abundance, relative abundance and occurrence

The most abundant copepods occurred at all stations and are represented by the following taxa (Fig. 6): *C. arcuicornis* (most abundant at station A), *C. furcatus* (most abundant at station S1), *Corycaeus* (*Farranula*) *concinna* (most abundant at station S1), *Corycaeus* (*Farranula*) *gibbula*, *Paracalanus nanus* (most abundant at stations S1 and M1), *Acartia* (*Planktacartia*) *negligens* (most abundant at station S3). Relative abundances followed absolute abundances throughout. Occurrence rates show an irregular pattern (except for *Acartia* (*Planktacartia*) *negligens*). *Acartia* (*Planktacartia*) *negligens* was widely distributed in the present study with an occurrence rate (OR) of 100%.

3.7. Comparison of both latitudinal transects and the northern South China Sea (NSCS) and KC regions

The averaged copepod density along the northern transect is 203.12 individuals m^{-3} and is higher than 160.01 individuals m^{-3} along the southern transect.

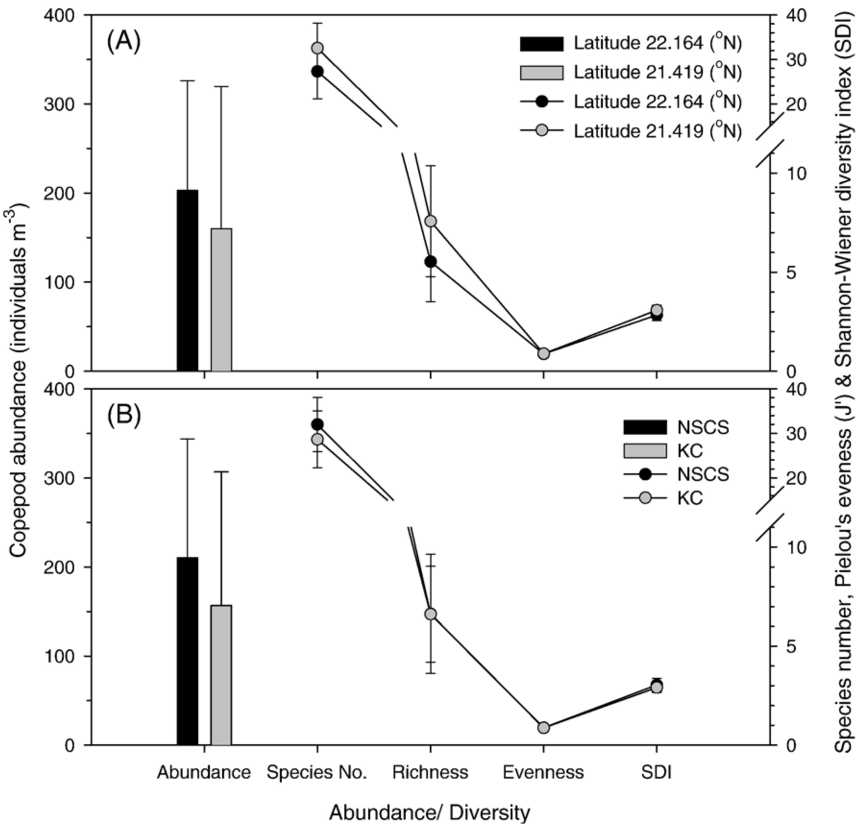

Fig. 7. Abundance, species number, richness, evenness and Shannon–Wiener diversity index variation of (A) latitude 22.164 (°N) and 21.419 (°N), (B) northern South China Sea (NSCS) and Kuroshio Current (KC) area.

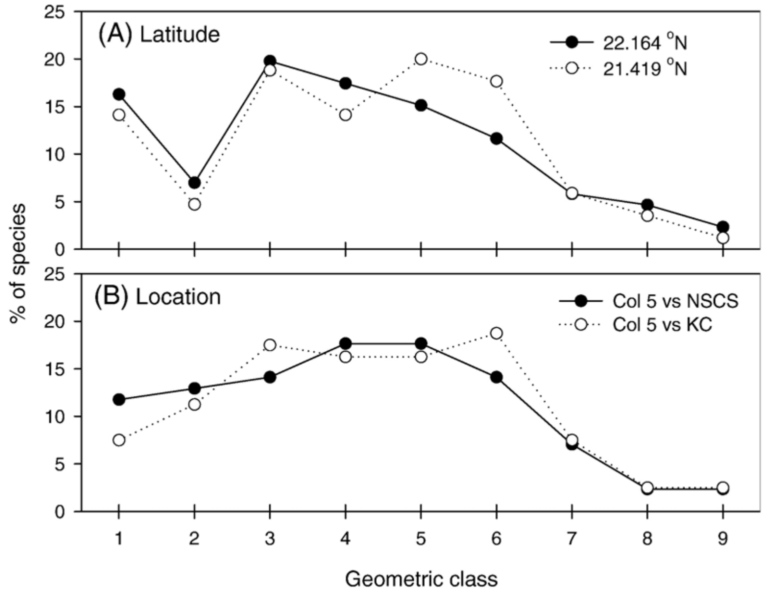

Fig. 8. Geometric class plots of the number of species in abundance of sampling area. Copepod species are ranked in the order of quantitative importance along the *X* axis. (A) latitudes 22.164 (°N) and 21.419 (°N), (B) northern South China Sea (NSCS) and Kuroshio Current (KC) area.

Whereas abundances were tentatively higher at the northern latitudinal transect, both, species number and species richness were lower there, and evenness and Shannon–Wiener index showed no difference (Fig. 7A).

As for regional differences, the average copepod density at NSCS is 210.63 individuals m^{-3} and is higher than in the KC region with 156.80 individuals m^{-3}. The copepod abundances and species numbers in the NSCS region are tentatively higher than in the KC region (Fig. 7B), whereas species richness, evenness and the Shannon–Wiener-Index are not remarkably different.

Geometric class plots of species numbers show no striking differences, neither with latitude nor with area (Fig. 8). There are 89 copepod species in samples of the northern transect and 93 copepod species in samples of the southern transect. There are 79 copepod species co-occurring at both latitudinal transect stations. However, 9 species occur only at the northern transect at 22.164 (°N), i.e., *Calanopia elliptica*, *Candacia pachydactyla*, *Copilia quadrata*, *Corycaeus* (*Urocorycaeus*) *longistylis*, *Euchaeta concinna*, *Euchaeta spinosa*, *Labidocera acuta*, *Oncaea clevei*, *Sapphirina scarlata*. On the other hand, 12 species occur only at the southern transect at 21.419 (°N). These are *Aetideus giesbrechti*, *Augaptilus longicaudatus*, *Calocalanus contractus*, *Eucalanus elongatus*, *Euchirella messinensis*, *Lucicutia bicornuta*, *Lucicutia ovalis*, *Metridia brevicauda*, *Microsetella norvegica*, *Neocalanus robustior*, *Pachyptilus eurygnathus*, *Sapphirina gemma*, *Scolecithricella* sp. In particular, there are 92 copepod species in samples of the NSCS region and 82 copepod species in samples of the KC region. In particular, there are 71 copepod species co-occurring in both NSCS and KC. However, only 19 copepod species occur in the NSCS area. These are: *A. longicaudatus*, *Candacia bipinnata*, *C. pachydactyla*, *Centropages furcatus*, *Corycaeus (Onychocorycaeus) pacificus*, *E. concinna*, *Euchaeta indica*, *E. spinosa*, *Euchirella curticauda*, *Euchirella maxima*, *E. messinensis*, *Euchirella pulchra*, *L. acuta*, *L. bicornuta*, *M. norvegica*, *O. clevei*, *P. eurygnathus*, *S. gemma*, *S. scarlata*, *Scolecithricella* sp. Only 10 copepod species were found exclusively in KC: *C. contractus*, *Candacia longimana*, *C. quadrata*, *Corycaeus* (*Agetus*) *flaccus*, *Corycaeus* (*Onychocorycaeus*) *catus*, *Corycaeus* (*Urocorycaeus*) *longistylis*, *Euchaeta longicornis*, *Mecynocera clausi*, *M. brevicauda*, *Subeucalanus subtenuis*. The same holds for the abundance and distribution of the 10 most abundant copepod species according to latitude and area. We find the same top five species along the two trsnsects: *C. arcuicornis*, *C. furcatus*, *A.(P.) negligens*, *C.(F.) concinna* and *P. nanus*. The proportion of species along the two transects were similar but not the same. The abundance of the northern transect of the top ten species is 62.36% but only 53.76% along the southern transect. The proportion of other species at the southern transect is higher than at the northern transect due to a higher species number than at the northern transect. The NSCS and KC regions shows the same dominant species in both regions that were, however, different in their rank and proportions. The top five species of NSCS were: *C. arcuicornis*, *C. furcatus*, *P. nanus*, *C.(F.) concinna* and *C. pauper*. The top five species of KC were: *C. arcuicornis*, *A.(P.) negligens*, *C. furcatus*, *C.(F.) concinna* and *A. gracilis*.

4. Discussion

A review of the literature on copepods in the ECS yielded 325 species (Shih and Young, 1995). Together with results presented in this study, it can be concluded that most copepod species in surface waters of the ECS region are rare species. Most species were found in low numbers (see Table 1). A recent study from an upwelling system in the southeastern TS showed that most copepod species stay in deeper waters (Lo et al., 2004b). Similarly, a study of copepods in the coral reef ecosystem of Ken-tin, southern Taiwan, demonstrated that several species never migrate to the surface (Kao, 2003).

It has to be emphasized that most common copepod species found during the present study do not belong to temperate-water species according to ecological classifications in other studies (Hirakawa et al., 1990; Takahashi and Hirakawa, 2001). Such copepods can provide suitable indicators for water mass movements such as the intrusion of Kuroshio Current waters that are otherwise characterized by different temperature and salinities (Hsieh et al., 2004).

Our results support the notion that some copepod species can be used as indicator-species of water masses. The present study in accordance with previous studies suggests that copepods have been transported from the Kuroshio Current into southwest Taiwan through the Luzon Strait based on similarity analyses (Hsiao, 2002; Hwang et al., 2000a,b, 2003, 2004a,b,c; Lo et al., 2004a). This intrusion has been evidenced by physical data before (Liu et al., 2003). The Kuroshio Current intrusion through the Luzon Strait into the northern South China Sea and southwest Taiwan may also in part explain why copepods show a very high diversity in adjacent waters of the intrusion areas (Hwang et al., 2000a,b, 2003, 2004a,b; Kao, 2003).

According to the present study, the dominant 10 copepod species were similar at both latitudes, 22.164 (°N) and 21.419 (°N). Such coincidence occurred also in the waters of the NSCS and the KC sampling stations. The similarity of dominant copepod species in these regions indicate long term water mixing. However, the dominant copepod species in the present study are very different from northern Taiwan (Hwang et al., 2004a,c; Hwang et al., 2006), indicating a separation of northern and southern water masses.

Table 4
Copepod species found predominantly at specific stations in the northern South China Sea (NSCS) and the Kuroshio Current (KC)

Location	Species name
NSCS	*Augaptilus longicaudatus*, *Candacia bipinnata*, *Candacia pachydactyla*, *Centropages furcatus*, *Corycaeus (Onychocorycaeus) pacificus*, *Euchaeta concinna*, *Euchaeta indica*, *Euchaeta spinosa*, *Euchirella curticauda*, *Euchirella maxima*, *Euchirella messinensis*, *Euchirella pulchra*, *Labidocera acuta*, *Lucicutia bicornuta*, *Microsetella norvegica*, *Oncaea clevei*, *Pachyptilus eurygnathus*, *Sapphirina gemma*, *Sapphirina scarlata, Scolecithricella* sp.
KC	*Calocalanus contractus*, *Candacia longimana*, *Copilia quadrata*, *Corycaeus (Agetus) flaccus*, *Corycaeus (Onychocorycaeus) catus*, *Corycaeus (Urocorycaeus) longistylis*, *Euchaeta longicornis*, *Mecynocera clausi*, *Metridia brevicauda*, *Subeucalanus subtenuis*

C. sinicus and *E. concinna*, two species with higher index values for winter (see Hwang et al., 2006), originate from the East China Sea (Chen, 1992; Hwang and Wong, 2005). A study by Hwang and Wong (2005) indicated that *C. sinicus* was transported by the China Coastal Current towards northern Taiwan and Hong Kong. *C. sinicus* did not occur at the present study sites, indicating a major influence of the Kuroshio Current intrusion with higher water temperatures (Chen, 1992; Hwang and Wong, 2005). Under the influence of the SW monsoon, the South China Sea Surface Current moves northwards during summer to the area of the Kuroshio Branch Current (Liang et al., 2003; Tseng and Shen, 2003). The zooplankton communities in the boundary waters are unique and diverse as a result of the collective impacts of these three water circulations (Chen et al., 1998; Hwang and Wong, 2005; Hwang et al., 1998, 2006; Shih and Chiu, 1998).

According to the present study, it is suggested that sampling stations in the NSCS have higher copepod densities as well as species numbers than those of the KC. Furthermore, lower latitudes show higher copepod species richness than higher latitudes, confirming a higher tropical diversity. In terms of the vertical profile

Appendix A

Species number, abundance, relative abundance (RA) and occurrence rate (OR) of copepods at each sampling station. (unit: individuals/m^3). *: indicates copepod abundances down to 50 m was significantly higher than that down to 600 m (α=0.05), **: indicates the copepod density in the water column above 50 m depth was significantly higher than that in the water column above 600 m (α=0.01)

Sampling station	S1	S3	S4	S5	A	M1	□	□	□
Filtered water (m^3)	342.91	1764.71	1182.90	2544.63	408.76	1673.01			
Species number	57	61	66	67	57	81	Total	RA	OR
Mean±SD abundance	242.5±160.6	134.2±117.3	175.3±161.1	164.1±191.2	262.3±80.6	139.9±152.9	□	(%)	(%)
Calanoida									
Acartiidae									
Acartia (*Planktacartia*) *negligens* (Dana, 1849)**	12.49±8	23.67±25.1	14.2±18.6	7.45±11.75	6.67±3.03	4.53±5.96	351.14	6.50	100.00
Aetideidae									
Aetideus giesbrechti (Cleve, 1904)	0	0	0.08±0.19	0	0	0.17±0.37	1.25	0.02	6.67
Euchirella amoena (Giesbrecht, 1888)	1.08±1.86	0.04±0.09	0.22±0.32	1.94±2.42	0	1.04±2.34	21.42	0.40	33.33
E. curticauda (Giesbrecht, 1888)	0.36±0.62	0	0	0	0	1.04±2.34	6.30	0.12	6.67
E. maxima (Wolfenden, 1905)	0.36±0.62	0	0	0	0	0.04±0.09	1.28	0.02	6.67
E. messinensis (Claus, 1863)	0	0	0	0	0	0.04±0.09	0.20	<0.01	3.33
E. pulchra (Lubbock, 1856)	0.36±0.62	0	0	0	0	0.19±0.43	2.03	0.04	6.67
Gaetanus miles (Giesbrecht, 1888)	0.36±0.62	0.56±1.38	0	0	0	0.23±0.41	5.61	0.10	13.33
Undeuchaeta plumosa (Lubbock, 1856)	2.29±2.37	0.72±1.45	0.14±0.31	3.83±7.4	0	1.21±2.27	40.94	0.76	36.67
Arietellidae									
Phyllopus helgae (Farran, 1908)**	0	0.04±0.09	0	0.04±0.1	0	0.04±0.09	0.69	0.01	10.00
Augaptilidae									
Augaptilus longicaudatus (Claus, 1863)	0	0	0	0	0	0.04±0.09	0.20	<0.01	3.33
Pachyptilus eurygnathus (Sars, 1920)	0	0	0	0	0	0.04±0.09	0.20	<0.01	3.33
Haloptilus longicornis (Claus, 1863)**	0.36±0.62	0	0.34±0.48	0.24±0.37	0	0.27±0.42	5.54	0.10	26.67
Calanidae									
Calanoides carinatus (Krøyer, 1849)**	0.36±0.62	0.27±0.66	1.1±1.36	0.51±0.57	0	0.19±0.43	12.18	0.23	30.00
Canthocalanus pauper (Giesbrecht, 1888)*	9.79±5.79	0.84±1.75	9.68±12.04	5.12±8.22	8.71±9.09	6.03±8.8	187.23	3.46	70.00
Cosmocalanus darwini (Lubbock, 1860)*	3.51±5.17	0.64±1.47	6.25±6.68	1.47±2.47	13.61±7.81	1.63±3.2	130.66	2.42	60.00
Neocalanus robustior (Giesbrecht, 1888)	0	0	0	0.16±0.39	0	0.04±0.09	1.16	0.02	6.67
Undinula vulgaris (Dana, 1849)	2.29±2.37	0	0.56±1.26	0.16±0.39	6.98±5.51	0.77±1.61	49.39	0.91	36.67
Nannocalanus minor (Claus, 1863)*	4.67±4.14	0.45±0.81	4.18±4.78	2.87±4.9	5.21±4.17	0.29±0.4	82.32	1.52	66.67
Neocalanus gracilis (Dana, 1849)	0	0	0.31±0.42	0.09±0.21	1.87±3.15	0.52±0.76	14.01	0.26	23.33
Calocalanidae									
Calocalanus contractus (Farran, 1926)	0	0	0.17±0.37	0	0	0	0.84	0.02	3.33
C. pavo (Dana, 1849)*	8.57±6.17	3.69±5.91	1.21±2.48	0.79±1.27	3.71±3.61	2.68±1.98	90.59	1.68	56.67
C. pavoninus (Farran, 1936)	2.65±2.41	0.76±1.76	1.78±2.02	3.75±7.5	0.7±1.57	0.85±1.59	51.75	0.96	46.67
C. plumulosus (Claus, 1863)	3.17±2.75	3.02±2.81	0	6.14±12.45	2.61±3.04	0.56±0.73	80.32	1.49	56.67
Candaciidae									
Candacia bipinnata (Giesbrecht, 1892)	0.36±0.62	0	0	0	0	0.04±0.09	1.28	0.02	6.67
C. catula (Giesbrecht, 1889)	4.35±6.63	2.08±2.3	1.6±2.33	0.32±0.78	0.78±1.07	0.21±0.36	40.40	0.75	43.33
C. ethiopica (Dana, 1849)	0	0	1.11±2.25	0	1.11±1.65	0	11.06	0.20	13.33
C. longimana (Claus, 1863)	0	0.15±0.27	0	1.05±2.56	0	0	7.19	0.13	10.00
C. pachydactyla (Dana, 1849)	0	0	0	0	0.74±1.65	0	3.69	0.07	3.33
Paracandacia bispinosa (Claus, 1863)	0	0.11±0.28	0.08±0.19	0.14±0.35	0.73±1.63	0	5.60	0.10	13.33
P. truncata (Dana, 1849)*	2.73±1.85	1.75±1.81	5.08±8.65	0.58±0.73	7.13±2.17	2.99±4.43	98.12	1.82	83.33

(continued on next page)

Appendix A (*continued*)

Sampling station	S1	S3	S4	S5	A	M1	□	□	□
Filtered water (m^3)	342.91	1764.71	1182.90	2544.63	408.76	1673.01			
Species number	57	61	66	67	57	81	Total	RA	OR
Mean±SD abundance	242.5±160.6	134.2±117.3	175.3±161.1	164.1±191.2	262.3±80.6	139.9±152.9	□	(%)	(%)
Calanoida									
Centropagidae									
Centropages calaninus (Dana, 1849)*	2.37±2.36	0.83±1.48	1.95±2.05	1.09±2.67	3.23±3.18	0.96±1.55	49.37	0.91	50.00
C. furcatus (Dana, 1849)	0	0	0	0	0.74±1.65	1.04±2.34	8.91	0.16	6.67
Clausocalanidae									
Clausocalanus arcuicornis (Dana, 1849)**	21.77±30.55	21.24±19.27	27.88±27.23	26.97±26.13	55.98±22.54	9.03±10.34	819.04	15.16	93.33
C. furcatus (Brady, 1883)*	32.07±50.06	0.9±1.89	16.5±16.17	16.3±22.45	34.86±15.36	8.29±8.02	497.67	9.21	83.33
C. mastigophorus (Claus, 1863)	0	0	0.4±0.89	3.26±5.41	0.74±1.65	0.17±0.37	26.06	0.48	20.00
Eucalanidae									
Eucalanus elongatus (Dana, 1849)	0	0	0.2±0.45	0	0	0.19±0.43	1.95	0.04	6.67
Pareucalanus attenuatus (Dana, 1849)	0	0.11±0.28	1.02±2.29	0.54±1.33	2.95±0.91	0.04±0.09	24.01	0.44	30.00
Rhincalanus nasutus (Giesbrecht, 1888)	0.36±0.62	0.04±0.09	0.14±0.31	0.73±1.29	0	0.23±0.41	7.55	0.14	26.67
R. rostrifrons (Dana, 1852)	0.36±0.62	0.19±0.3	0.2±0.45	0.22±0.34	0	3.89±6.64	23.97	0.44	36.67
Subeucalanus crassus (Giesbrecht, 1888)**	0	0.08±0.19	0	0.31±0.4	0	0.04±0.09	2.50	0.05	16.67
S. subcrassus (Giesbrecht, 1888)	1.93±2.48	0.11±0.28	0	0	3.36±0.89	4.11±6.62	43.85	0.81	40.00
S. subtenuis (Giesbrecht, 1888)	0	0.11±0.27	0	0.04±0.1	0	0	0.92	0.02	6.67
Euchaetidae									
Euchaeta concinna (Dana, 1849)	0	0	0	0	4.16±4.67	0	20.80	0.38	10.00
E. indica (Wolfenden, 1905)	0	0	0	0	1.51±1.54	0.17±0.37	8.38	0.16	13.33
E. longicornis (Giesbrecht, 1888)	0	0.04±0.09	0.28±0.62	0	0	0	1.63	0.03	6.67
E. rimana (Bradford, 1973)	0	0.64±1.47	0.34±0.48	0.54±1.33	0.73±1.63	0.19±0.43	13.42	0.25	23.33
E. spinosa (Giesbrecht, 1892)	0.36±0.62	0	0.2±0.45	3.34±7.6	1.24±2.78	0.19±0.43	29.31	0.54	23.33
Heterorhabdidae									
Heterorhabdus papilliger (Claus, 1863)	0.36±0.62	0.11±0.28	0.22±0.32	0.62±1.4	0.7±1.57	0.74±1.24	13.79	0.26	30.00
Lucicutiidae									
Lucicutia bicornuta (Wolfenden, 1905)	0	0	0	0	0	0.04±0.09	0.20	<0.01	3.33
L. clausi (Giesbrecht, 1889)	0	0.75±1.83	0	0.04±0.1	0	0.19±0.43	5.69	0.11	10.00
L. flavicornis (Claus, 1863)	5.8±7.43	1.28±1.4	8.17±12.84	3.53±7.54	2.31±3.36	4.74±9.05	122.34	2.26	66.67
L. ovalis (Giesbrecht, 1889)	0	0	0	1.59±2.64	0	0.17±0.37	10.38	0.19	10.00
Mecynoceridae									
Mecynocera clausi (Thompson, 1888)	0	0.73±1.78	0.14±0.31	0.54±1.33	0	0	8.32	0.15	10.00
Metridinidae									
Metridia brevicauda (Giesbrecht, 1889)	0	0	0.14±0.31	0.04±0.1	0	0	0.95	0.02	6.67
Pleuromamma abdominalis (Lubbock, 1856)	0.72±1.24	0.52±1.07	3.18±4.63	4.74±7.27	2.2±3.3	0.57±1.28	63.51	1.18	46.67
P. gracilis (Claus, 1863)	2.29±2.37	1.77±1.77	5.11±5.38	0.14±0.35	1.4±3.13	3.95±6.64	70.71	1.31	53.33
P. xiphias (Giesbrecht, 1889)	0.72±1.24	1.55±2.85	3.07±4.69	5.09±9.85	0	0.75±0.95	61.15	1.13	50.00
Paracalanidae									
Acrocalanus gracilis (Giesbrecht, 1888)**	12.69±10.99	5.15±8.07	8.82±15.14	3.99±5.65	6.94±7.55	2.88±3.24	186.07	3.44	66.67
A. monachus (Giesbrecht, 1888)*	3.95±4.91	0.61±1.48	1.02±2.29	1.75±2.56	4±3.28	1.78±2.49	59.98	1.11	43.33
Paracalanus nanus (Sars, 1907)	34.13±30.81	1.83±3.59	0.25±0.56	6.99±12.71	6.34±5.1	15.51±26.44	265.85	4.92	63.33
Pontellidae									
Calanopia elliptica (Dana, 1849)	0	0.73±1.78	0	0	0.37±0.82	0	6.19	0.11	6.67
C. minor (A. Scott, 1902)	1.57±2.73	0.04±0.09	0.65±1.23	0.72±1.29	1.83±2.59	3.51±6.83	39.20	0.73	40.00
Labidocera acuta (Dana, 1849)	0	0	0	0	0.37±0.82	0	1.84	0.03	3.33

L. detruncata (Dana, 1849)	0	0	0	1.18±1.84	0.37±0.82	0.92±1.58	13.54	0.25	16.67
Pontellina plumata (Dana, 1849)	1.57±2.73	0	0	0.54±1.33	1.14±1.66	0	13.70	0.25	13.33
Scolecithricidae									
Scolecithricella sp.	0	0	0	0	0	0.19±0.43	0.95	0.02	3.33
S. danae (Lubbock, 1856)	0.36±0.62	1.32±2.93	1.59±2.32	0.19±0.38	2.66±1.73	1.4±2.18	38.43	0.71	46.67
Scottocalanus securifrons (T. Scott, 1893)*	0.36±0.62	0	0.2±0.45	0.51±1.03	0	0.19±0.43	6.08	0.11	20.00
Temoridae									
Temora discaudata (Giesbrecht, 1889)	4.72±8.18	0	1.98±2.14	1.09±2.67	2.55±2.93	4.03±6.68	63.52	1.18	36.67
Cyclopoida									
Oithonidae									
Oithona attenuata (Farran, 1913)	5.18±5.39	3±3.37	0.81±0.78	3.14±7.69	2.95±6.6	2.72±1.92	84.86	1.57	53.33
O. plumifera (Baird, 1843)	0	0	1.02±2.29	0	0.7±1.57	0.17±0.37	9.45	0.17	10.00
O. setigera (Dana, 1849)	1.6±2.77	2.63±5.14	1.98±2.66	1.08±1.28	1.14±1.66	5.22±11.68	68.82	1.27	53.33
Harpacticoida									
Clytemnestridae									
Clytemnestra scutellata (Dana, 1847)	1.57±2.73	0.04±0.09	1.02±2.29	0	0	0	10.07	0.19	10.00
Ectinosomatidae									
Microsetella norvegica (Boeck, 1846)	0	0	0	0	0	0.17±0.37	0.83	0.02	3.33
Miraciidae									
Macrosetella gracilis (Dana, 1847)*	3.47±3.6	2.6±4.44	4.76±5.97	0.39±0.77	7.67±4.22	3.05±4.38	105.77	1.96	70.00
Poecilostomatoida									
Corycaeidae									
Corycaeus (Agetus) flaccus (Giesbrecht, 1891)	0	2.81±3.52	1.91±2.54	1.28±2.6	0	0	34.05	0.63	30.00
C. (Corycaeus) speciosus (Dana, 1849)	0.36±0.62	0.38±0.54	2.35±2.8	2.32±5.27	1.87±3.15	2.02±2.29	48.47	0.90	50.00
C. (Ditrichocorycaeus) dahli (Tanaka, 1957)	0.8±1.38	0.83±1.48	0.99±1.09	2.33±3.18	2.47±4.57	0.19±0.43	39.57	0.73	46.67
C. (D.) erythraeus (Cleve, 1901)	2.73±1.85	5.81±10.51	1.55±1.31	0.54±1.33	1.84±1.79	3.44±4.71	80.53	1.49	60.00
C. (Farranula) concinna (Dana, 1847)**	24.62±22.98	12.85±20.22	4.87±6.19	9.58±13	10.86±11.93	10.32±12.12	338.63	6.27	90.00
C. (F.) gibbula (Giesbrecht, 1891)*	6.24±6.87	8.2±13.82	7.82±8.99	0.52±0.43	12.72±9.79	3.78±4.54	192.65	3.56	83.33
C. (Onychocorycaeus) agilis (Dana, 1849)	0	6.46±6.66	2.39±4.41	4.26±9.14	2.14±3.15	1.63±3.2	95.05	1.76	46.67
C.(O.) catus (F. Dahl, 1894)	0	0.11±0.28	2.27±4.46	0	0	0	12.03	0.22	13.33
C.(O.) pacificus (M. Dahl, 1912)*	0.36±0.62	0	0	0	0	0.36±0.49	2.86	0.05	10.00
C.(O.) pumilus (M. Dahl, 1912)	0	1.49±3.66	0.14±0.31	0	0	0.9±1.58	14.14	0.26	13.33
C.(Urocorycaeus) lautus (Dana, 1849)*	0	2.19±2.19	1.73±2.22	0.16±0.39	2.17±1.98	0.73±1.63	37.22	0.69	40.00
C.(U.) longistylis (Dana, 1849)	0	1.35±2.11	0	0	0	0	8.12	0.15	6.67
Oncaeidae									
Lubbockia squillimana (Claus, 1849)	0.36±0.62	0	1.11±2.25	0.16±0.39	0	0.17±0.37	8.40	0.16	16.67
Oncaea clevei (Fruhtl, 1863)	0.36±0.62	0	0	0	0	0	1.08	0.02	3.33
O. conifera (Giesbrecht, 1891)	0.8±1.38	0	0.31±0.42	0.16±0.39	0.7±1.57	1.38±2.27	15.27	0.28	23.33
O. dentipes (Giesbrecht, 1891)	0	0.72±1.45	1.79±2.19	0.72±1.29	1.87±3.15	1.09±2.31	32.35	0.60	40.00
O. media (Giesbrecht, 1891)	1.93±2.48	0	2.08±3.6	0.14±0.35	1.48±3.3	0.98±1.53	29.34	0.54	33.33
O. mediterranea (Claus, 1861)	0	0.98±1.4	0.85±1.17	10.87±22.51	0	1.54±2.32	83.07	1.54	43.33
O. minuta (Giesbrecht, 1892)	0	0.04±0.09	1.45±2.09	0.22±0.34	1.14±1.66	2.13±4.65	25.15	0.47	40.00
O. venusta (Philippi, 1843)	1.57±2.73	0.72±1.45	0.14±0.31	1.79±2.52	4.8±4.66	0.23±0.41	45.66	0.84	43.33
Sapphirinidae									
Copilia mirabilis (Dana, 1849)	0.8±1.38	0	0.2±0.45	1.09±2.67	0	0.04±0.09	10.13	0.19	13.33
C. quadrata (Dana, 1852)	0	0.75±1.83	0	0	0	0	4.48	0.08	3.33
Sapphirina gemma (Dana, 1849)	0	0	0	0	0	1.09±2.31	5.43	0.10	6.67
S. nigromaculata (Claus, 1863)	0	0.73±1.78	0	0	1.43±1.96	0.73±1.63	15.15	0.28	13.33
S. scarlata (Giesbrecht, 1891)	0.8±1.38	0	0	0	1.07±1.58	0	7.73	0.14	10.00

of the water column, copepod abundances are generally higher in the upper 50 m than in deeper strata of the water column. Several species have been suggested to be associated with water masses in that region (Table 4).

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