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# Effects of the Kuroshio Current on Copepod Assemblages in Taiwan

Shih Hui Hsiao[1,2,5], Tien-Hsi Fang[2], Chang-tai Shih[3,4], and Jiang-Shiou Hwang[5,*]

[1] *Department of Science Education, National Taipei University of Education, Taipei 106, Taiwan*
[2] *Department of Marine Environmental Informatics, National Taiwan Ocean University, Keelung 202, Taiwan*
[3] *Institute of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung 202, Taiwan*
[4] *Canadian Museum of Nature, Ottawa K1P 6P4, Canada*
[5] *Institute of Marine Biology, National Taiwan Ocean University, Keelung 202, Taiwan*

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**Shih Hui Hsiao, Tien-Hsi Fang, Chang-tai Shih, and Jiang-Shiou Hwang (2011)** Effects of the Kuroshio Current on copepod assemblages in Taiwan. *Zoological Studies* **50**(4): 475-490. The Kuroshio Current (KC) is a northerly flowing warm-water current, which has major effects on the hydrography and faunal assemblages along the east coast of Taiwan. We studied the abundance and diversity of copepods at 5 stations for 3 consecutive years (2000-2002). Copepod samples were collected with a plankton net with a 1-m mouth opening and a mesh size of 333 μm deployed in oblique tows from 200 to 0 m in depth. In total, 174 copepod species including 6 orders, 31 families, and 68 genera (111 calanoids, 11 cyclopoids, 4 harpacticoids, 2 mormonilloids, 44 poecilostomatoids, and 2 siphonostomatoids) were identified at the species level. Spatial variations in copepod abundances among these 5 stations were not significant. The composition of the indicator species and cluster analysis varied seasonally, indicating seasonal succession. We suggest that copepod species of *Acartia negligens*, *Clausocalanus mastigophorus*, *Cosmocalanus darwini*, and *Lucicutia flavicornis* are indicator species of the KC in winter when the northeast monsoon (NEM) prevails; in contrast, *Acrocalanus* spp. and *Canthocalanus pauper* are indicator species in summer. Furthermore, *Acr.* cf. *gracilis* and *Oncaea venusta* served as indicator species on all investigated cruises. We thus concluded that the KC carries a wide range of warm-water copepods to the east coast of Taiwan and western Pacific Ocean year round. The NEM did not transport *Calanus sinicus* into the Kuroshio main current, indicating a boundary of the distribution of *Cal. sinicus* in the western Pacific Ocean. http://zoolstud.sinica.edu.tw/Journals/50.4/475.pdf

**Key words:** Kuroshio Current, Copepod assemblages, Copepod distribution, Western Pacific Ocean, Indicator species.

Copepods are the most abundant and diverse group of zooplankton in marine environments (Hwang et al. 2004a, Souissi et al. 2007, Hwang et al. 2009, Tseng et al. 2011), forming about 50% of the biomass of all plankton, ranging from 70% in polar to 35% in tropical seas (Longhurst 1985). In addition, they contain about 1/3 of the mean plankton carbon biomass and 1/2 of the mean zooplankton abundance (Longhurst 1985, Hsiao et al. 2011). Thus, when studying food webs and energy pathways of producers and consumers in marine environments, understanding their species assemblages, abundances, distribution patterns, and diversity is important. Such knowledge is well established in the eastern Pacific Ocean and northern Atlantic Ocean, such as by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys of the south-central California Current system (Chen 1986, Saltzman and Wishner 1997, Rebstock 2002, Fernández-Álamo and Färber-Lorda 2006), Canadian and Japanese sampling in the oceanic subarctic northeastern Pacific (Yamaguchi et al. 2002, Hooff and Peterson 2006),

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*To whom correspondence and reprint requests should be addressed. Fax: 886-2-24629464. E-mail:Jshwang@mail.ntou.edu.tw and the Continuous Plankton Recorder (CPR) surveys of the eastern North Atlantic (Allison and Wishner 1986, Bonnet and Frid 2004). Systematic sampling has been carried out in these long-term surveys for more than 4 decades (Mackas et al. 2004).

However, several long-term studies indicated that only a few copepod species dominate seawater. For example, the survey results for CalCOFI from 1951 through 1999 indicated that 3 species dominated the southern California region in spring, *Calanus pacificus*, *Metridia pacificus*, and *Pleuromamma borealis*, which together accounted for 77% of the total on average; the 4 other categories each accounted for 3%-7% of the total (Rebstock 2001). A similar result was also observed in Northumberland coastal seawater during the entire time period of 1969-1999, where 7 species of copepods dominated (Bonnet and Frid 2004). Chen (1986) identified 63 of the 140 known species of copepods in the eastern tropical Pacific Ocean. *Eucalanus subtenuis* and *Euc. subcrassus* were most dominant, with mean relative abundances of 33.5% and 12.8%, respectively.

Compared to areas of the eastern Pacific Ocean and Atlantic Ocean, knowledge of copepod diversity and abundance in the western Pacific Ocean, especially in the tropical Kuroshio Current (KC), is relatively scant.

Three major water masses affect the copepod communities of Taiwan's surrounding waters, the South China Sea (SCS), the China Coastal Current (CCC), and the KC (Hwang et al. 2000b 2007 2010a b, Hsieh et al. 2004, Lan et al. 2004, Dur et al. 2007). Several studies showed that up to 116 species of copepods, belonging to 47 genera and 25 families, were identified, and amounts of copepods ranged 100-200 individuals (ind.)/m$^3$ along the northern coast of Taiwan (Hsieh and Chiu 1998 2002, Hwang et al. 1998, Lo et al. 2004b). Moreover, the most abundant species of copepods were *Temora turbinata*, *Paracalanus parvus*, *Canthocalanus pauper*, *Acrocalanus gibber*, and *Euchaeta* sp. Lee et al. (2009) reported 7 copepod species, i.e., *Cal. sinicus*, *Clausocalanus furcatus*, *Cla. minor*, *Lucicutia flavicornis*, *Paracalanus aculeatus*, *Oithona plumifera,* and *Oncaea venusta*, which were the dominant species in Ilan Bay and adjacent Kuroshio waters off northeastern Taiwan. This area was adjacent to waters we examined in this study.

The KC originates in the equatorial region east of the Philippines and diverges from the North Equatorial Current in the area east of the Philippines, forming a western boundary current flowing along the gyre margin (Nitani 1972, Kawai 1998). It flows northward along the east coast of Taiwan where the current's speed and width are approximately 100-150 cm/s and 100-140 km, respectively (Su et al. 1990, Liang et al. 2003). The upper waters (0-500 m) of this boundary current flow northward into the Okinawa Trough through the Yonaguni Depression and pass along the outer edge of the continental shelf of the East China Sea (ECS), forming the main track of the KC (Ujiié et al. 2003). High salinities and temperatures characterize the Kuroshio waters as well as low nutrients in the surface layer. A maximum salinity of > 34.7 psu and potential temperatures of > 25°C were observed in the surface layer adjacent to the Okinawa Trough (Hung et al. 2000). This salinity maximum corresponds to North Pacific subtropical waters (Nitani 1972). The Kuroshio Branch Current runs into the continental shelf-break off the northeastern coast of Taiwan and forms year-round upwelling. Information regarding the copepod community structure in the main stream of the KC, which flows along the east coast of Taiwan, is very limited. In the past decade, few copepod studies were conducted on the Kuroshio main currents (Hwang et al. 2000a 2003 2004b 2006 2010b, Hwang and Wong 2005, Hsiao et al. 2011, Kâ and Hwang 2011). Four seasonal cruises were carried out in the main KC region to study the distribution, abundance, and biodiversity of copepods, and species associations among the copepods in the KC off the east coast of Taiwan.

## MATERIALS AND METHODS

### Zooplankton sampling

Zooplankton samples were taken from the *R/V Ocean Research-II* and *Fishery Researcher I* during 4 cruises (Dec. 2000, May/June 2001, July 2001, and Jan. 2002) at 5 stations in eastern Taiwan (Fig. 1). A conical plankton net with a 100-cm mouth diameter and 333 μm mesh size was used to collect samples. At the center of the mouth opening, a flow meter (Hydro-Bios, model 438 110, Kiel, Germany) was mounted. The net was towed obliquely at 0-200 m below the sea surface. The sampling time was approximately 30 min at a vessel speed of 2 knots (nm/h). Zooplankton samples were immediately preserved in 5%-10% buffered formalin-seawater on board. A CTD instrument (SeaBird, SBE 9/11 CTD and

SBE 19-01 CTD, Washington, USA) on board simultaneously recorded the temperature and salinity at each station. The abundance of each species was calculated. Copepods in the samples were identified in the laboratory according to methods and classifications of Zheng et al. (1989), Huys and Boxshall (1991), Hattori et al. (1997), and Shih (unpubl. data).

### Statistical analyses

In order to reduce the heteroscedasticity observed in the original species abundance data, a transformation power was generated by regression coefficients that were estimated by maximizing the log likelihood function (Box and Cox 1964). Accordingly, a matrix of copepod abundance data was used in conjunction with Bray-Curtis similarity indices after logarithmic transformation (log (X + 1)) (vers. IV; Clarke and Warwick 1994).

Species characterizing each cluster were further identified using the indicator value (IndVal) index proposed by Dufrene and Legendre (1997). This index is obtained by multiplying the product of 2 independently computed values by 100:

$$\mathrm{IndVal}(j,s) = 100\mathrm{SP}(j,s)\,\mathrm{FI}(j,s); \qquad (1)$$

where SP(j,s) is the specificity, and FI(j,s) is the fidelity of species s toward a group of samples (j). These were calculated by:

$$\mathrm{SP}(j,s) = \frac{\mathrm{NI}(j,s)}{\Sigma\mathrm{NI}(s)} \text{ and } \mathrm{FI}(j,s) = \frac{\mathrm{NS}(j,s)}{\Sigma\mathrm{NS}(s)}; \qquad (2)$$

where NI(j,s) is the mean abundance of

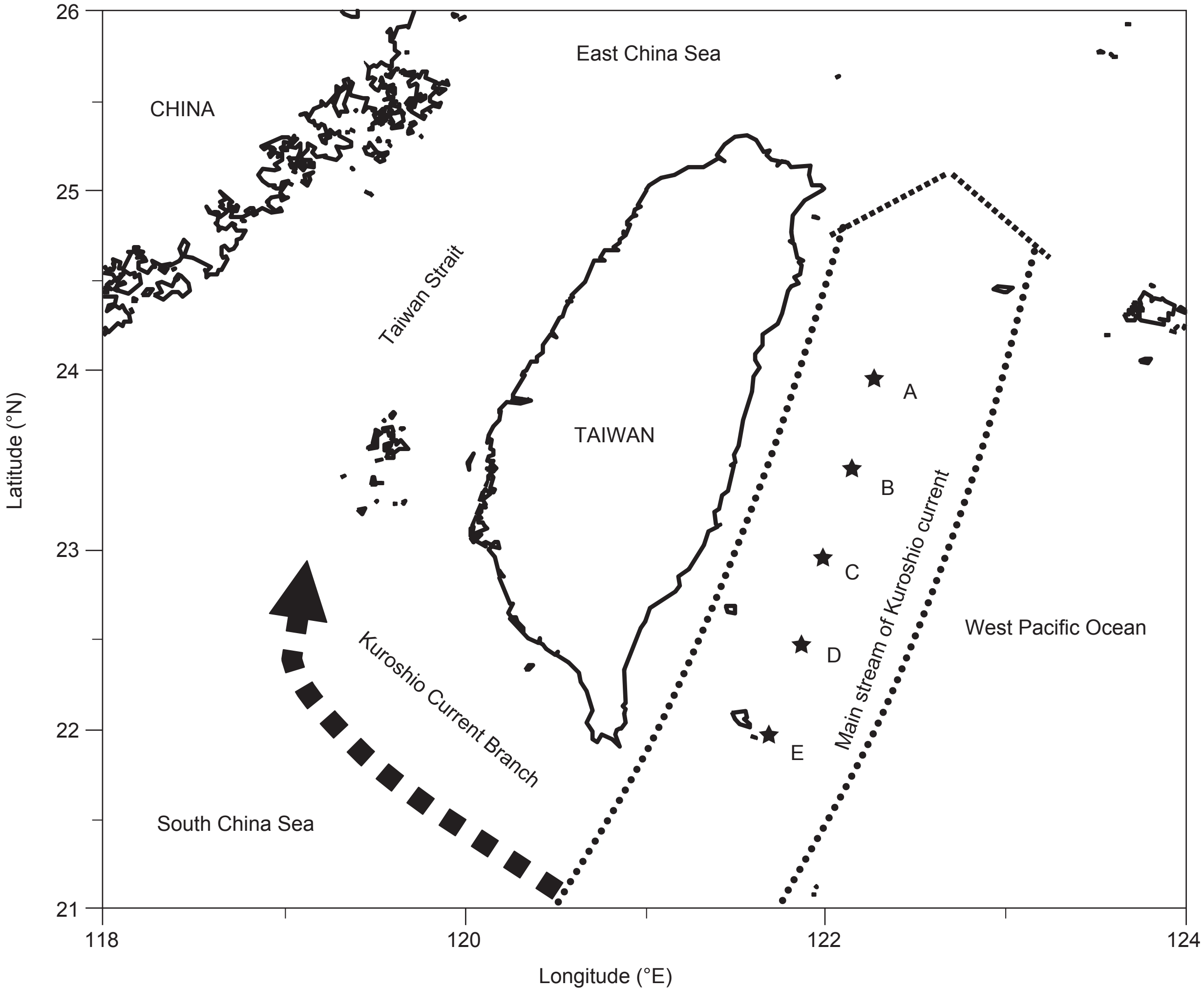

**Fig. 1.** Sampling stations.

species s across samples pertaining to j, ΣNI(s) is the sum of the mean abundances of species s within the various groups in the partition, NS(j,s) is the number of samples in j where species s is present, and ΣNS(s) is the total number of samples in that group. The specificity of a species within a group is greatest if a particular species is found only in a particular group, whereas the fidelity of a species to a group is greatest if the species is present in all samples of the group considered. In order to evaluate copepod assemblages for the entire sampling period, indicator species were separately analyzed for each sampling cruise.

## RESULTS

### Hydrography and water circulation

Throughout the study period, surface water temperatures ranged 23.5°C in Jan. to 29.2°C in July, and at a depth of 200 m, water temperatures ranged 14.6°C in July to 19.0°C in May and Jan. Salinity followed an opposite trend with a maximum value of 34.6 psu in Jan. and a minimum value of 33.4 psu in July (Fig. 2). Wide ranges of temperature were recorded in May and July between waters at a depth of 200 m and waters at the surface, with smaller ranges recorded in Dec. and Jan. In contrast, salinity ranges were similar throughout the year. Generally, temperatures and salinities from the surface to a depth of 100 m in the main stream of the KC in eastern Taiwan were mainly affected by seasonal variations.

### Copepod assemblages

Figure 3 plots the abundances of copepods observed at each station during the survey periods. With a few exceptions, abundances of copepods found at most stations were approximately 90 ± 10 ind./m$^3$. However, abundances of copepods found in the May 2001 cruise were relatively lower than those of the other cruises. On the other hand, copepod species numbers of 50-79 were identified at different stations, and higher numbers of copepod species were found in May and July (Fig. 3). In total, 174 copepod species, including 111 calanoids, 11 cyclopoids, 4 harpacticoids, 2 mormonilloids, 44 poecilostomatoids, and 2 siphonostomatoids, were identified in the present study, comprising more than 50% of the copepod abundances of calanoid assemblages. Appendix I lists all copepod species recorded. Copepod species belonged to 6 orders, 31 families, and 67 genera. The 10 most abundant species were *Oncaea venusta*, *Cosmocalanus darwini*, *Acrocalanus* cf. *gracilis*, *Lucicutia flavicornis*, *Acartia negligens*, *Clausocalanus mastigophorus*, *Cla. minor*, *Canthocalanus pauper*, *Oithona setigera*, and *Corycaeus* (*Corycaeus*) *speciosus*. Abundances varied among stations, but no clear trend between month and stations was detected. Average relative abundances ranged < 0.1%-7.4% of total copepod abundances. In addition, 35 copepod species had a average relative abundance of > 1% (Appendix I).

In total, 14 copepod species, including *Aca. negligens, Cos. darwini, Nannocalanus minor, Cla. mastigophorus, Cla. minor, Luc. flavicornis, Acr.* cf. *gracilis*, *Oit. setigera, Cor.* (*Agetus*) *typicus, Cor.* (*Corycaeus*) *crassiusculus, Cor.* (*Corycaeus*) *speciosus, Farranula gibbula, Onc. mediterranea*, and *Onc. venusta*, were consistently discovered at all stations during the investigation on 4 cruises. In contrast, 36 copepod species were recorded only once (Appendix I). The species *Acr.* cf. *gracilis* of the study has similar morphological characters to *Acr.* cf. *gracilis*, but female copepod specimens had an obvious P5 that was observed under a microscope (Fig. 4). Among the 174 identified copepod species, 6 were new record species for waters of the northwestern Pacific. (Appendix I).

### Hierarchical classification and indicator species

The cluster analysis revealed a high correlation in the cruise (Fig. 5). The 1st hierarchical level separated the winter cruise assemblages with a mean temperature of 23.54°C and mean salinity of 34.62 psu (cluster I) from summer assemblages with a mean temperature of 24.28°C and mean salinity of 34.42 psu (cluster II). The 2nd hierarchical level separated only 1 sample (cluster Ib) that had the least abundance from winter cruise assemblages (cluster Ia). In sum, the assemblages of each cruise (clusters IIa, IIb, IIIa, and IIIb) and seasonal variations (clusters I and II) distinguished hierarchical levels.

Table 1 gives the 8 key indicator species (IndVal), and their contributions to the total copepod assemblage. These key indicator species contributed > 5% to the IndVal index of the copepod assemblage of each group. *Acrocalanus* cf. *gracilis*, and *Onc. venusta* were the indicator species for all groups. Basically, *Cla. mastigophorus*, *Cos. darwini,* and *Luc. flavicornis*

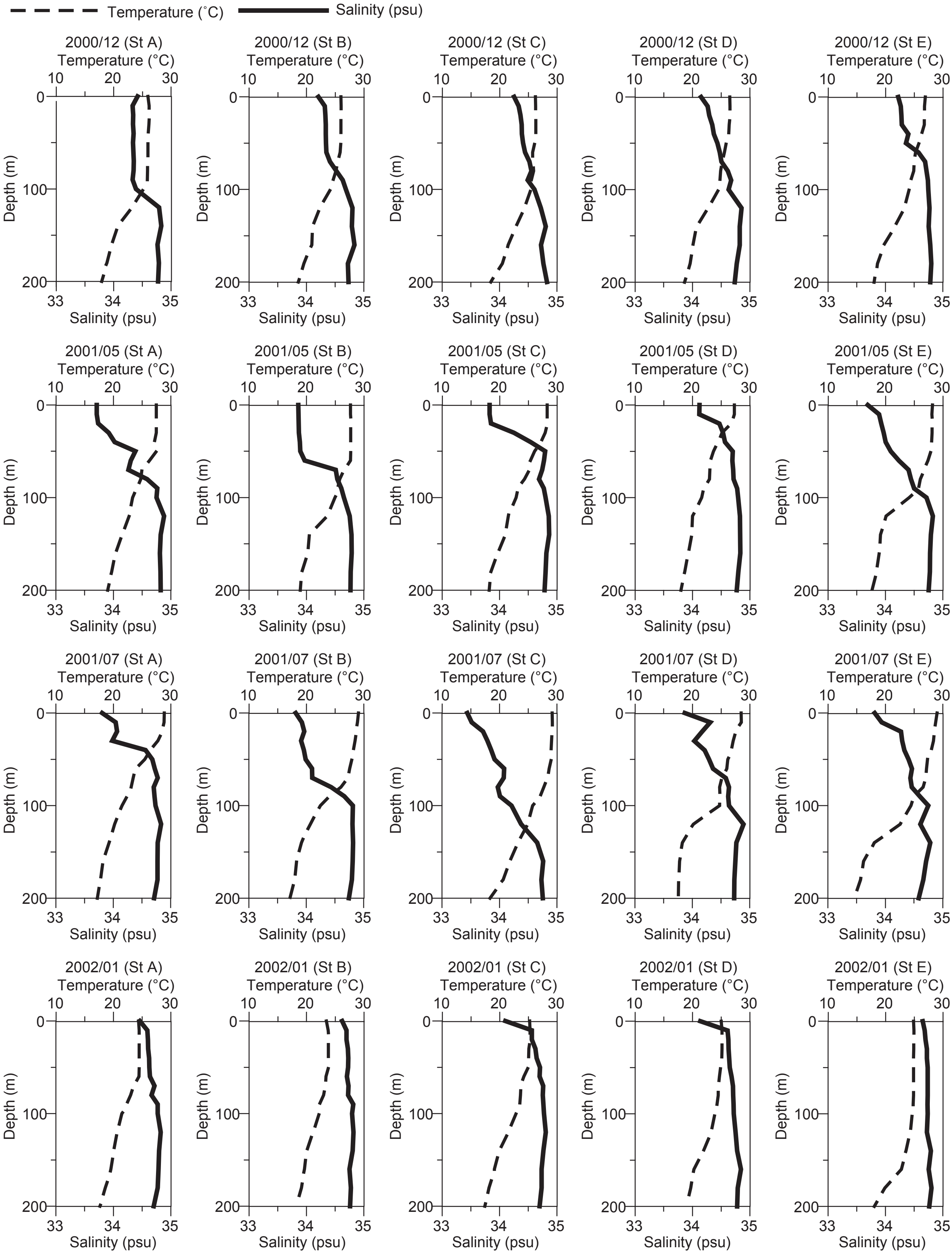

**Fig. 2.** Temperature and salinity for each cruise and station.

were indicator species for clusters I, IIa, and IIb, respectively, while *Aca. negligens* was the indicator species for clusters I and IIa; this indicated a separation of the group in winter. In contrast, *Can. pauper* was the indicator species for clusters II and IIIb, and *Acrocalanus* spp. was the indicator species for cluster IIIa, indicating a separation of the group in summer. The complex of *Acrocalanus* spp. involved *Acr*. *gibber* and *Acr*. cf. *gracilis* that had broken legs and could not be identified to the species level.

## DISCUSSION

The hydrography of the KC changes seasonally in the upper 100 m in depth. An increase in temperature and decrease in salinity were recorded in summer. These phenomena also occurred in the SCS (Randall et al. 1991, Morton and Blackmore 2001).

The KC originates in northern Pacific equatorial water and flows in a northwesterly direction along the east coast of Taiwan and the Okinawa Trough towards the east coast of Japan. In addition, branches of the KC flow into marginal seas, such as the SCS, the Taiwan Strait, the ECS, and the Tsushima Strait (Farris and Wimbush 1996, Hwang et al. 2000b 2006, Jan et al. 2002, Liang et al. 2003, Liu et al. 2003b, Chen and Wang 2006). Very little is known about copepod abundances and distributions in eastern Taiwan, particularly along the main stream of the KC. The most extensively studied area of copepods in the major KC is along the western Pacific coast in Japanese waters (Motoda and Maruno 1963, Nakata et al. 2001). Motoda and Marumo (1963) showed that the dominant species of copepods in Kuroshio waters off the eastern coast of Japan were **Nan.*

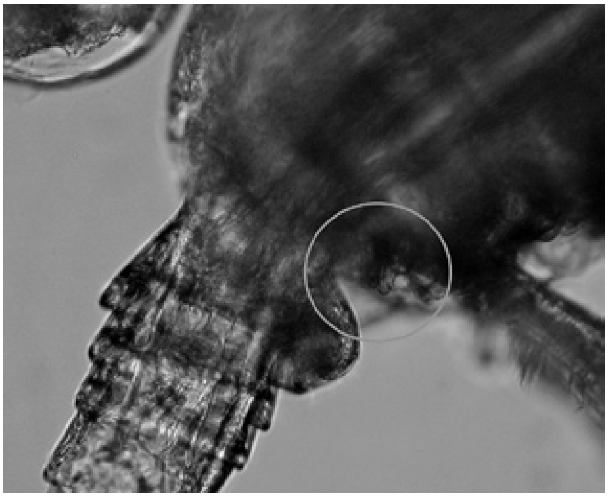

**Fig. 4.** Evident P5 of *Acrocalanus* cf. *gracilis*, observed under a microscope.

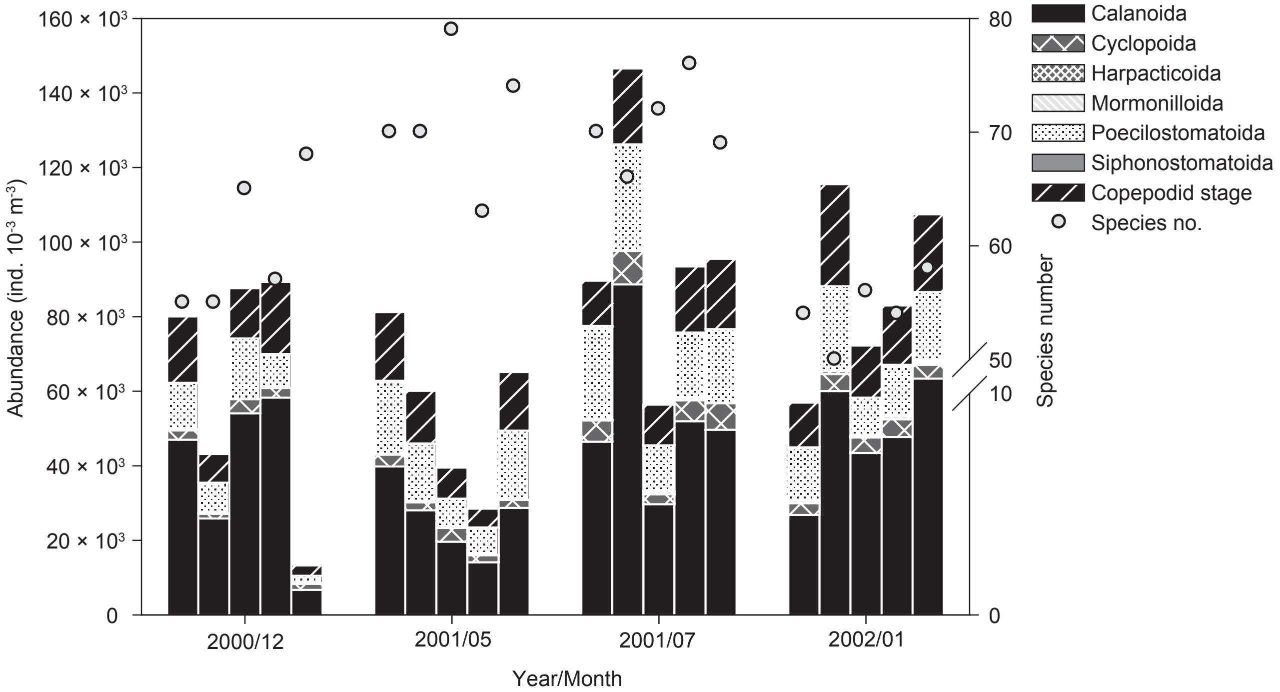

**Fig. 3.** Abundance (individuals (ind.)/1000 m$^3$), species number and composing of copepod orders and their unripe stage in samples.

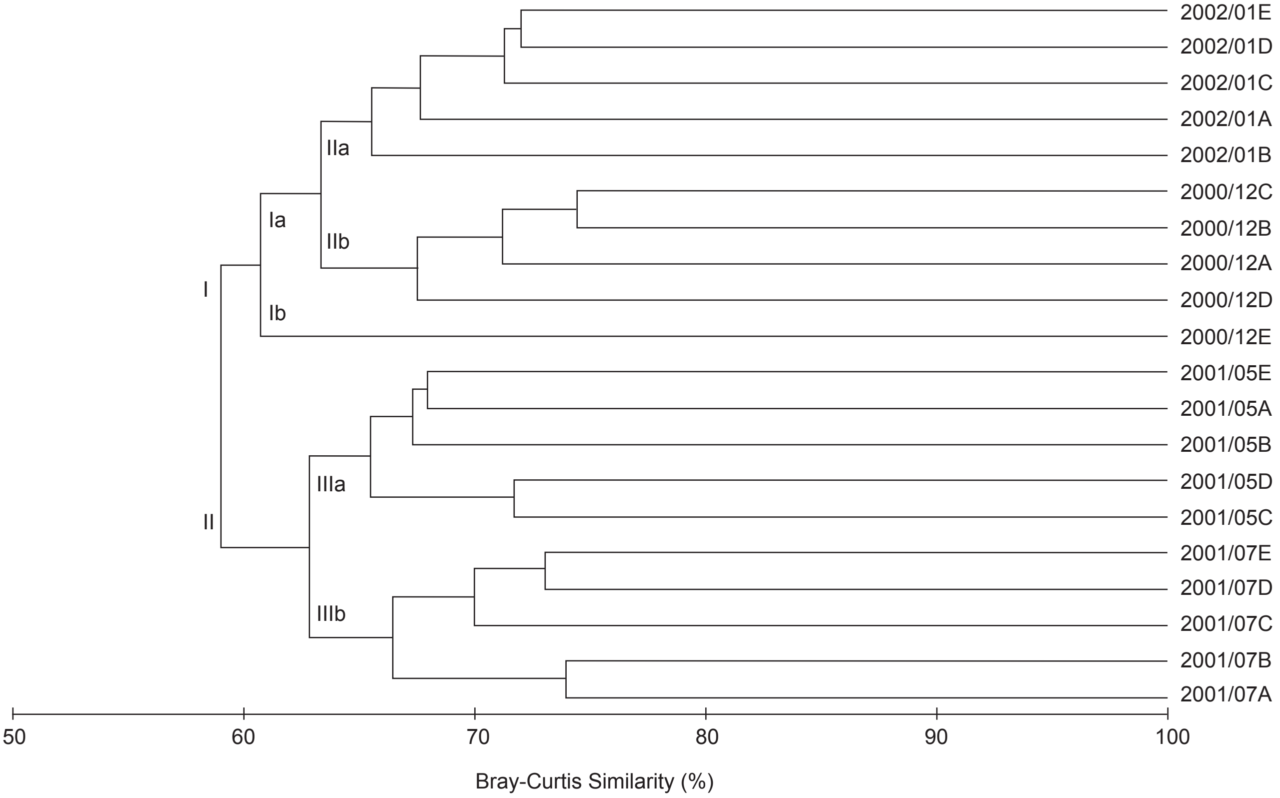

**Fig. 5.** Classification of samples collected from all stations on each sampling date using Bray-Curtis similarity and clustering strategies with flexible links. Newly obtained groups in the 1st 4 hierarchical levels are marked by discontinuous lines and labeled.

**Table 1.** Temperature and salinity (mean ± S.D., at 0-200 m). Indicator species and indicator values (indicator value, %) for each cluster are identified in the cluster figure

| Cluster level | Temperature (°C) | Salinity (psu) | Indicator species |
|---|---|---|---|
| I | 23.54 ± 2.58 | 34.62 ± 0.19 | *Cos. darwini* (7.58), *Cla. mastigophorus* (7.12), *Onc. venusta* (6.99), *Luc. flavicornis* (6.30), *Acr.* cf. *gracilis* (5.88), *Aca. negligens* (5.17) |
| II | 24.28 ± 3.89 | 34.42 ± 0.39 | *Onc. venusta* (8.42), *Acr.* cf. *gracilis* (5.85), *Can. pauper* (5.76) |
| IIa | 22.94 ± 2.3 | 34.7 ± 0.12 | *Cla. mastigophorus* (8.58), *Onc. venusta* (8.28), *Cos. darwini* (6.94), *Aca. negligens* (6.66), *Acr.* cf. *gracilis* (5.02), *Luc. flavicornis* (5.00) |
| IIb | 24.17 ± 2.66 | 34.52 ± 0.21 | *Cos. darwini* (8.62), *L. flavicornis* (8.19), *Acr.* cf. *gracilis* (7.06), *Onc. venusta* (5.37), *Cla. mastigophorus* (5.12) |
| IIIa | 24.14 ± 3.45 | 34.46 ± 0.39 | *Onc. venusta* (9.82), *Acrocalanus* spp. (5.70), *Acr.* cf. *gracilis* (5.16) |
| IIIb | 24.42 ± 4.31 | 34.39 ± 0.38 | *Can. pauper* (7.68), *Onc. venusta* (7.68), *Acr.* cf. *gracilis* (6.22) |

Abbreviations used of copepods species: *Aca. negligens*, *Acartia negligens*; *Acr.* cf. *gracilis*, *Acrocalanus* cf. *gracilis*; *Can. pauper*, *Canthocalanus pauper*; *Cos. darwini*, *Cosmocalanus darwini*; *Cla. mastigophorus*, *Clausocalanus mastigophorus*; *Luc. flavicornis*, *Lucicutia flavicornis*; *Onc. venusta*, *Oncaea venusta*.

*minor*, **Subeucalanus subtenuis*, **Mecynocera clausi*, **Aca. negligens*, **Onc. venusta*, *Cos. darwini*, *Cla. furcatus*, *Euchaeta longicornis*, *Euc. rimana*, *Scolecithrix danae*, *Luc. flavicornis*, and *Copilia mirabilis*. They also indicated that the former 5 species of copepods (with an asterisk) represent indicator species of the main stream of the KC. An investigation by Nakata et al. (2001) showed that the biomass of Oncaeidae copepods, such as *Onc. media*, *Onc. venusta* f. *venella,* and *Onc. venusta* f. *typical*, reached a maximum in spring and remained at about 14% of the total copepod biomass throughout the year. In the present study, some indicator species of copepods were the same as those reported by Motoda and Maruno (1963) and Nakata et al. (2001), including *Aca. negligens*, *Cos. darwini*, *Luc. flavicornis*, and *Onc. venusta*; the 4 species may originate from the main KC of Taiwan and are transported northward into the Sea of Japan.

Grice (1962) extensively investigated the calanoid copepod compositions in northern Pacific equatorial water where the KC originates. He identified 108 species of calanoid copepods. The most dominant were *Sub. subtenuis* (20.50%), *Cos. darwini* (10.94%), *Cla. arcuicornis* (9.09%), *Haloptilus longicornis* (7.85%), and *Nan. minor* (6.52%). Surprisingly, he also reported 59% of the copepods species identified in our study. These species may mainly originate from northern Pacific equatorial waters, and are further transported along the main KC near eastern Taiwan. In western Taiwan, the copepods are dominated by *Aca. negligens*, *Acr. gibber*, *Acr.* cf. *gracilis*, *Can. pauper*, *Cla. arcuicornis*, *Cla. furcatus*, *Cla. minor*, *Cla. mastigophorus,* and *Far. concinna* (Hwang et al. 2006 2007, Lan et al. 2009). Most copepod species in our study showed high values of either abundance or occurrence rate. Hwang et al. (2007) proposed that intrusions of the KC into the Taiwan Strait may affect copepod assemblages in western Taiwan. For several decades, copepodologists from Taiwan did not pay much attention to research on copepod assemblages in the main stream of the KC. They mainly focused on the ecology of copepods in the Taiwan Strait (Hwang et al. 1998, Hsieh and Chiu 2002, Lan et al. 2004 2009, Lo et al. 2004a b, Hwang and Wong 2005, Dur et al. 2007, Tseng et al. 2008a b).

Based on our research, we propose that the KC plays a major role in the copepod community structure in waters surrounding Taiwan. Specifically, it continuously transports significant numbers of copepods from northern Pacific equatorial waters to waters surrounding Taiwan year-round and shapes the specific copepod assemblages in waters surrounding Taiwan. To the east of Taiwan, the KC transports copepods northwards that eventually reach Japan, affecting the copepod assemblages in Japanese waters. In addition, the KC introduces copepod populations to western Taiwan (Liang et al. 2003, Hwang et al. 2007, Jan et al. 2010).

Among those copepods, *Cal. sinicus* has a broad geographical distribution in the marginal seas of the northwestern Pacific Ocean, such as the Sea of Japan, Bohai Sea, Yellow Sea, and ECS, that extends southward to northeastern Taiwan (Chen 1964 1992, Chen and Zhang 1965, Huang et al. 1993, Hulsemann 1994, Sun et al. 2002, Liu et al. 2003b, Wang et al. 2003, Hsieh et al. 2004, Hwang and Wong 2005, Lee et al. 2006, Dur et al. 2007). *Calanus sinicus* was abundantly recorded along western and northeastern Taiwan; on the other hand, it is also an indicator species of the CCC (Liu et al. 2003a, Hsieh et al. 2004, Hwang et al. 2004b 2006, Hwang and Wong 2005, Lee et al. 2006 2009, Dur et al. 2007). It was interesting to determine the distribution of *Cal. sinicus* in waters east of Taiwan.

Surprisingly, our study did not find *Cal. sinicus*, which may have been due to the high temperature of the Kuroshio water. Throughout the study period, the surface water temperature ranged 23.5°C in Jan. to 29.2°C in July. Laboratory experiments revealed that the lower and upper thermal limits for embryonic development of *Cal. sinicus* are 5 and 23°C, respectively (Uye 1988). At temperatures above 23°C, the population of *Cal. sinicus* may be thermally stressed. A field study by Lin and Li (1984) also supported this result, by showing that *Cal. sinicus* was found in winter and spring, but disappeared in June when the seawater temperature warmed to 24°C in Xiamen Harbor, China. Meanwhile, Uye (2000) investigated a *Cal. sinicus* population along the continental shelf of the eastern Inland Sea of Japan and adjacent Pacific Ocean. His results indicated that the *Cal. sinicus* population was centered in shelf waters and declined inshore and offshore, conclusively suggesting that the surface water temperature near the KC was lethally or sublethally high for *Cal. sinicus*. Lee et al. (2006 2009) observed a similar phenomenon in Ilan Bay and adjacent Kuroshio waters off northeastern Taiwan. *Calanus sinicus* was recorded at stations of shelf waters throughout the year, but at significantly lower frequencies at stations with intermediate Kuroshio

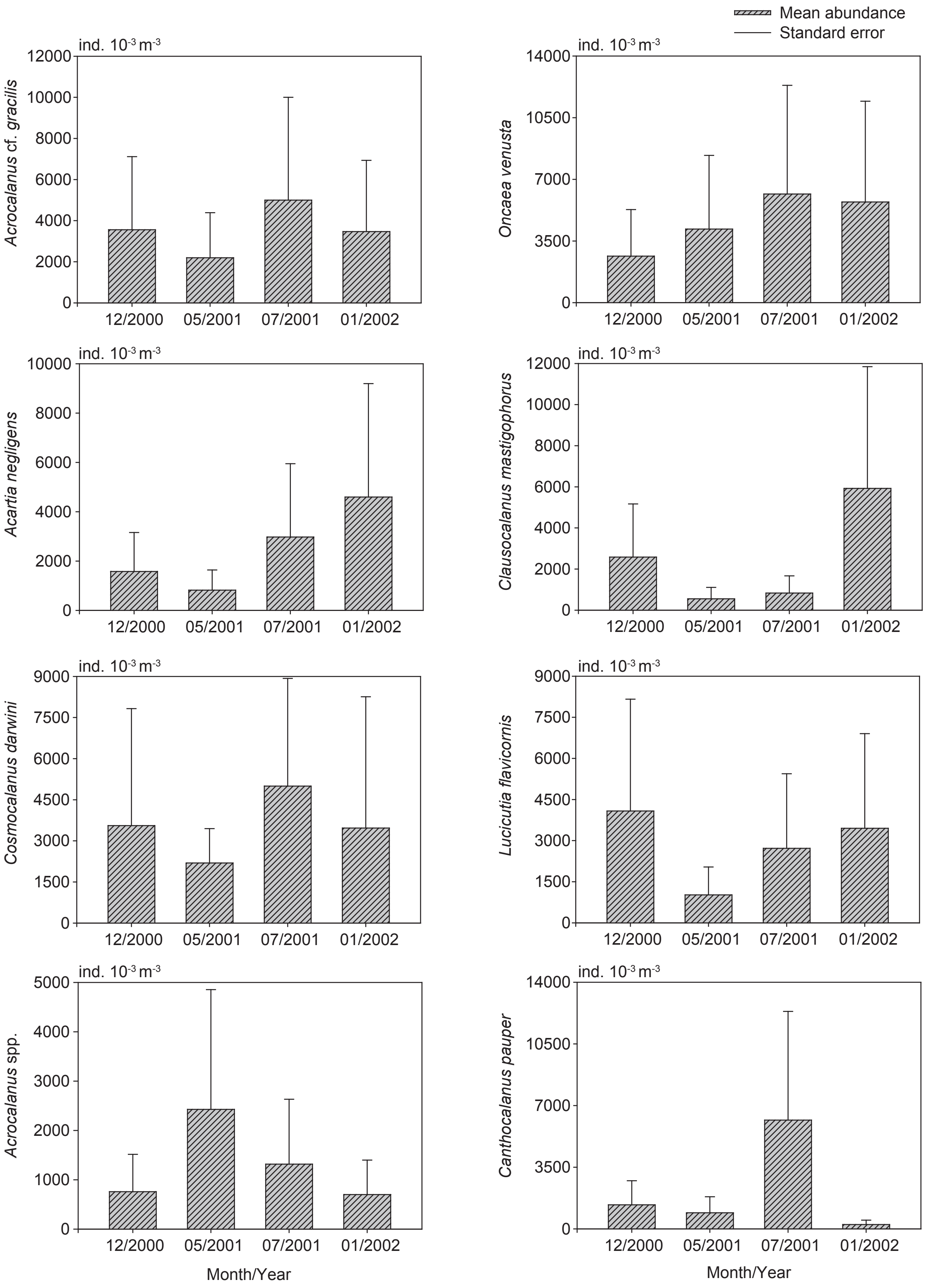

**Fig. 6.** Variations in the mean abundances of the 8 indicator species for each cruise.

waters in their investigations. These phenomena may explain why *Cal. sinicus* was never found in this study. Furthermore, *Cal. sinicus* was reported to vertically migrate in summer when the surface water temperature reaches a lethally high level. Nevertheless, *Cal. sinicus* showed no vertical migratory behavior even in samples collected down to 200 m in depth in our study and down to 800 m in depth in a previous study in an adjacent region (Hsiao et al. 2004).

Hwang et al. (2006) originally proposed several indicator species from the KC. The combined effect of the southwestern monsoon (SWM) and the KC during summer may transport the copepods *Acr. gibber*, *Acr. gracilis,* and *Can. pauper* into northwestern Taiwan from southern Taiwan. These results were confirmed by the present study (Fig. 6). Among 8 indicator species of copepods, *Acrocalanus* spp. and *Can. pauper* were indicator species in summer when the SWM prevails. *Acrocalanus* cf. *gracilis* and *Onc. venusta* were indicator species of 4 cruises (Table 1, Fig. 6). These results were recorded in our present study and proposed by Hwang et al. (2006) and Hsiao et al. (2011). Hsiao et al. (2011) suggested that *Acrocalanus* spp. were associated with warm waters of the Kuroshio Branch Current in northeastern Taiwan. Very little is known of copepod assemblages in the KC in winter. The mean abundances of *Aca. negligens*, *Cla. mastigophorus*, *Cos. darwini,* and *Luc. flavicornis* in winter were generally higher than those in summer, being particularly low in May (Fig. 6). We propose that these 4 copepod species be considered indicator species of the KC in winter when the NEM prevails (Table 1, Fig. 6). Furthermore, among the 174 copepod species collected in this study, 6 species were not reported by Shih and Young (1995) and their recent research in Taiwan (Hsieh and Chiu 2002, Hsieh et al. 2004, Lo et al. 2004a b, Dur et al. 2007, Hwang et al. 2007 2010b, Tseng et al. 2008a b, Lan et al. 2009, Lee et al. 2009, Hsiao et al. 2011). These 6 copepod species are new to Taiwan and include *Cal. jashnovi*, *Heterorhabdus subspinifrons*, *Paraheterorhabdus vipera*, *Paroithona pulla*, *Lubbockia minuta*, and *Onc. gracilis*. This study recommends further ecological research.

In conclusion, the KC affects the distribution and assemblages of copepods in the waters of eastern Taiwan, and also the copepod assemblages in western Taiwan. Furthermore, the KC may affect copepod distributions and assemblages in many parts of the western Pacific Ocean. Further studies should describe this influence in greater detail.

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**Appendix I.** Copepod species and their occurrence, relative abundance, mean abundance, and standard deviation values found in the Kuroshio Current off eastern Taiwan

| Species | Occurrence (%) | Relative abundance (%) | Mean ± S.D. (ind./1000 $m^3$) |
|---|---|---|---|
| CALANOIDA | | | |
| *Acartiidae* | | | |
| *Acartia bifilosa* (Giesbrecht 1881) | 25 | 0.86 | 157 ± 614 |
| *Aca. danae* Giesbrecht 1889 | 75 | 0.63 | 300 ± 231 |
| *Aca. negligens* Dana 1849 | 100 | 3.84 | 2492 ± 1901 |
| *Aca. omorii* Bradford 1976 | 15 | 0.17 | 21 ± 103 |
| *Aca. pacifica* Giesbrecht 1888 | 25 | 0.30 | 60 ± 175 |
| Aetideidae | | | |
| *Aetideopsis* sp. | 5 | 0.07 | 4 |
| *Aetideus acutus* Farran 1929 | 65 | 0.46 | 211 ± 179 |
| *Aet. giesbrechti* Cleve 1904 | 10 | 0.23 | 21 ± 69 |
| *Chirundina streetsii* Giesbrecht 1892 | 5 | 0.21 | 13 |
| *Euchirella amoena* Giesbrecht 1888 | 5 | 0.54 | 33 |
| *Euc. curticaudata* Giesbrecht 1888 | 10 | 0.30 | 28 ± 60 |
| *Euc. indica Vervoort* 1949 | 5 | 0.22 | 13 |
| *Undeuchaeta major* Giesbrech 1888 | 5 | 0.15 | 9 |
| *Und. plumosa* (Lubbock 1856) | 15 | 0.77 | 94 ± 346 |
| Augaptilidae | | | |
| *Euaugaptilus elongatus* (Sars 1905) | 5 | 0.07 | 4 |
| *Eua. hecticus* (Giesbrech 1892) | 10 | 0.28 | 25 ± 93 |
| *Haloptilus acutifrons* (Giesbrech 1892) | 10 | 0.45 | 41 ± 272 |
| *Hal. austini* Grice 1959 | 5 | 0.51 | 31 |
| *Hal. longicirrus* (Claus 1863) | 90 | 0.95 | 576 ± 406 |
| *Hal. ornatus* (Giesbrech 1892) | 50 | 0.41 | 138 ± 187 |
| *Hal. oxycephalus* (Giesbrech 1892) | 10 | 0.24 | 22 ± 49 |
| *Hal. paralongicirrus* Park 1970 | 75 | 0.70 | 334 ± 157 |
| *Hal. spiniceps* (Giesbrech 1892) | 5 | 0.17 | 10 |
| Calanidae | | | |
| *Calanoides carinatus* (Kroeyer 1849) | 20 | 0.18 | 27 ± 78 |
| *_Calanus jashnovi_ Hulsemann 1994 | 5 | < 0.01 | 14 |
| *Canthocalanus pauper* (Giesbrech 1888) | 90 | 3.88 | 2174 ± 3407 |
| *Cosmocalanus darwini* (Lubbock 1860) | 100 | 5.21 | 3559 ± 2364 |
| *Mesocalanus tenuicornis* (Dana 1863) | 45 | 1.15 | 343 ± 545 |
| *Nannocalanus minor* (Claus 1863) | 100 | 2.38 | 1515 ± 994 |
| *Neocalanus gracilis* (Dana 1849) | 90 | 0.83 | 467 ± 402 |
| *Neo. robustior* (Giesbrech 1888) | 35 | 0.20 | 49 ± 93 |
| *Undinula vulgaris* (Dana 1849) | 90 | 1.21 | 700 ± 697 |
| Calocalanidae | | | |
| *Calocalanus pavo* (Dana 1849) | 80 | 0.75 | 385 ± 416 |
| *Cal. plumulosus* (Claus 1863) | 35 | 0.46 | 111 ± 197 |
| Candaciidae | | | |
| *Candacia bipinnata* (Giesbrecht 1892) | 10 | 0.17 | 16 ± 106 |
| *Can. catula* (Giesbrecht 1889) | 60 | 0.72 | 284 ± 376 |
| *Can. curta* (Dana 1849) | 10 | 0.16 | 15 ± 111 |
| *Can. discaudata* A. Scott 1902 | 15 | 0.24 | 29 ± 99 |
| *Can. ethiopica* (Dana 1849) | 35 | 0.32 | 78 ± 97 |
| *Can. longimana* (Claus 1863) | 15 | 0.22 | 27 ± 84 |
| *Paracandacia bispinosa* (Claus 1863) | 85 | 0.68 | 368 ± 295 |
| *Par. simplex* (Giesbrecht 1888) | 20 | 0.49 | 74 ± 124 |
| *Par. truncata* (Dana 1849) | 75 | 0.94 | 443 ± 331 |
| Centropagidae | | | |
| *Centropages calaninus* (Dana 1849) | 65 | 0.55 | 244 ± 250 |
| *Cen. elongatus* Giesbrecht 1896 | 5 | 0.10 | 6 |
| *Cen. furcatus* (Dana 1849) | 30 | 0.49 | 104 ± 208 |

**Appendix I.** (continued)

| Species | Occurrence (%) | Relative abundance (%) | Mean ± S.D. (ind./1000 $m^3$) |
|---|---|---|---|
| *Cen. gracilis* (Dana 1849) | 20 | 0.26 | 45 ± 184 |
| *Cen. orsinis* Giesbrecht 1889 | 5 | 0.38 | 23 |
| Clausocalanidae | | | |
| *Clausocalanu* sp. | 15 | 0.68 | 82 ± 707 |
| *Cla. arcuicornis* (Dana 1849) | 70 | 1.64 | 780 ± 908 |
| *Cla. farrani* Sewell 1929 | 85 | 1.24 | 651 ± 677 |
| *Cla. furcatus* (Brady 1883) | 70 | 1.01 | 454 ± 523 |
| *Cla. mastigophorus* (Claus 1863) | 100 | 3.85 | 2474 ± 3043 |
| *Cla. minor* Sewell 1929 | 100 | 3.80 | 2456 ± 1620 |
| *Cla. lividus* Frost&Fleminger 1968 | 20 | 0.79 | 120 ± 656 |
| *Cla. pergens* Farran 1926 | 5 | 0.21 | 13 |
| Eucalanidae | | | |
| *Eucalanus elongatus* (Dana 1849) | 20 | 0.35 | 53 ± 158 |
| *Paraeucalanus attenuatus* (Dana 1849) | 40 | 0.49 | 147 ± 353 |
| *Par. langae* Fleminger 1973 | 25 | 0.23 | 42 ± 100 |
| *Rhincalanus nasutus* Giesbrecht 1888 | 5 | 0.07 | 4 |
| *Rhi. rostrifrons* (Dana 1852) | 60 | 0.72 | 316 ± 493 |
| *Subeucalanus crassus* (Giesbrecht 1888) | 20 | 0.48 | 73 ± 81 |
| *Sub. mucronatus* (Giesbrecht 1888) | 85 | 1.31 | 742 ± 630 |
| *Sub. subcrassus* (Giesbrecht 1888) | 60 | 1.13 | 447 ± 1277 |
| *Sub. subtenuis* (Giesbrecht 1888) | 20 | 0.31 | 47 ± 166 |
| Euchaetidae | | | |
| *Euchaeta concinna* (Dana 1849) | 10 | 0.12 | 21 ± 91 |
| *Euc. indica* Wolfenden 1905 | 20 | 0.31 | 47 ± 119 |
| *Euc. longicornis* Giesbrecht 1888 | 20 | 0.22 | 34 ± 54 |
| *Euc. media* Giesbrecht 1888 | 10 | 0.29 | 27 ± 71 |
| *Euc. rimana* Bradford 1973 | 75 | 0.58 | 304 ± 277 |
| *Pararucheata* sp. | 5 | 0.21 | 13 |
| Heterorhabdidae | | | |
| *Heterorhabdus abyssalis* (Giesbrecht 1889) | 5 | 0.07 | 4 |
| *Het. papilliger* (Claus 1863) | 85 | 0.85 | 477 ± 444 |
| *Het. spinifrons* (Claus 1863) | 20 | 0.38 | 57 ± 236 |
| **Het. subspinifrons* Tanaka 1964 | 25 | 0.33 | 60 ± 112 |
| **Paraheterorhabdus vipera* (Giesbrecht 1889) | 5 | 0.21 | 13 |
| Lucicutiidae | | | |
| *Lucicutia* sp. | 5 | 0.19 | 12 |
| *Luc. clausi* (Giesbrecht 1889) | 20 | 0.37 | 56 ± 67 |
| *Luc. curta* Farran 1905 | 5 | 0.19 | 11 |
| *Luc. flavicornis* (Claus 1863) | 100 | 4.28 | 2817 ± 1858 |
| *Luc. gaussae* Grice 1963 | 45 | 0.34 | 102 ± 110 |
| *Luc. gemina* Farran 1936 | 60 | 0.68 | 270 ± 300 |
| *Luc. ovalis* (Giesbrecht 1889) | 15 | 0.23 | 28 ± 103 |
| Mecynoceridae | | | |
| *Mecynocera clausi* Thompson 1888 | 20 | 0.41 | 62 ± 132 |
| Metridicidae | | | |
| *Pleuromamma abdominalis* (Lubbock 1856) | 45 | 1.88 | 571 ± 1545 |
| *Ple. gracilis* (Claus 1863) | 65 | 2.55 | 1081 ± 1624 |
| *Ple. robusta* (Dahl 1893) | 35 | 0.44 | 107 ± 136 |
| *Ple. xiphias* (Giesbrecht 1889) | 25 | 1.26 | 230 ± 794 |
| Paracalanidae | | | |
| *Acrocalanus* spp. | 95 | 2.23 | 1300 ± 1028 |
| *Acr.* cf. *gracilis* | 100 | 5.57 | 3555 ± 2362 |
| *Acr. gibber* Giesbrecht 1888 | 40 | 0.51 | 139 ± 94 |
| *Acr. gracilis* Giesbrecht 1888 | 40 | 0.35 | 97 ± 109 |
| *Acr. longicornis* Giesbrecht 1888 | 25 | 0.40 | 72 ± 136 |
| *Acr. monachus* Giesbrecht 1888 | 65 | 1.36 | 549 ± 704 |

**Appendix I.** (continued)

| Species | Occurrence (%) | Relative abundance (%) | Mean ± S.D. (ind./1000 m$^3$) |
|---|---|---|---|
| *Paracalanus aculeatus* Giesbrecht 1888 | 85 | 2.16 | 1184 ± 1104 |
| *Par. parvus* (Claus 1863) | 90 | 1.21 | 704 ± 549 |
| *Par. serrulus* Shen & Lee 1963 | 20 | 0.35 | 84 ± 367 |
| Phaennidae | | | |
| *Phaenna spinifera* Claus 1863 | 35 | 0.33 | 81 ± 184 |
| Pontellidae | | | |
| *Calanopia elliptica* (Dana 1849) | 15 | 0.29 | 35 ± 86 |
| *Cal. minor* A. Scott 1902 | 55 | 0.65 | 237 ± 358 |
| *Labidocera acuta* (Dana 1849) | 30 | 0.44 | 93 ± 251 |
| *Pontella danae* Giesbrecht 1889 | 5 | 0.10 | 6 |
| *Pontellina morii* Fleminger & Huylsemann 1974 | 5 | 0.25 | 15 |
| *Pon. plumata* (Dana 1849) | 30 | 0.34 | 72 ± 146 |
| Scolecitrichidae | | | |
| *Lophothrix* sp. | 5 | 0.03 | 2 |
| *Scaphocalanus brevicornis* Sars 1900 | 5 | 0.38 | 23 |
| *Scolecithricella dentata* (Giesbrecht 1892) | 10 | 0.18 | 16 ± 132 |
| *Sco. longispinosa* Chen & Zhan 1965 | 65 | 0.44 | 200 ± 157 |
| *Sco. minor* (Brady 1963) | 20 | 0.26 | 39 ± 136 |
| *Sco. tenuiserrata* (Giesbrecht 1892) | 80 | 1.33 | 686 ± 486 |
| *Sco. vittata* (Giesbrecht 1892) | 15 | 0.08 | 21 ± 119 |
| *Scolecithrix bradyi* Giesbrecht 1888 | 50 | 0.39 | 132 ± 150 |
| *Sco. danae* (Lubbock 1856) | 65 | 0.52 | 218 ± 196 |
| *Scottocalanus securifrons* (T. Scott 1893) | 5 | 0.18 | 11 |
| Spinocalanidae | | | |
| *Monacilla gracillis* (Wolfenden 1911) | 5 | 0.19 | 12 |
| Temoridae | | | |
| *Temora discaudata* (Giesbrecht 1889) | 70 | 1.38 | 628 ± 741 |
| *Tem. stylifera* (Dana 1849) | 35 | 0.55 | 132 ± 312 |
| *Tem. turbinate* (Dana 1849) | 35 | 0.39 | 94 ± 292 |
| *Tomoropia mayumbaensis* T. Scott 1894 | 15 | 0.19 | 23 ± 102 |
| CYCLOPOIDA | | | |
| Oithonidae | | | |
| *Oithona atlantica* Farran 1908 | 5 | 0.10 | 6 |
| *Oit. attenuata* Farran 1908 | 5 | 0.07 | 4 |
| *Oit. fallax* Farran 1913 | 15 | 0.35 | 42 ± 88 |
| *Oit. nana* Giesbrecht 1892 | 5 | 0.10 | 6 |
| *Oit. plumifera* Baird 1843 | 90 | 2.70 | 1513 ± 1550 |
| *Oit. robusta* Giesbrecht 1891 | 65 | 0.53 | 223 ± 206 |
| *Oit. setigera* (Dana 1849) | 100 | 3.04 | 1911 ± 763 |
| *Oit. similis* Claus 1866 | 5 | 0.03 | 2 |
| *Oit. simplex* Farran 1913 | 5 | 0.19 | 11 |
| *Oit. vivida* Farran 1913 | 10 | 0.29 | 26 ± 163 |
| **Paroithona pulla* Farran | 5 | 0.19 | 12 |
| HARPACTICOIDA | | | |
| Aegisthidae | | | |
| *Aegisthus mucronatus* Giesbrecht 1991 | 10 | 0.17 | 15 ± 160 |
| Clytemnestridae | | | |
| *Clytemnestra scuteillata* Dana 1847 | 10 | 0.29 | 26 ± 170 |
| Ectinosomatidae | | | |
| *Microsetella norvegica* (Boeck 1846) | 15 | 0.28 | 34 ± 150 |
| Miraciidae | | | |
| *Macrosetella gracilis* (Dana 1847) | 15 | 0.16 | 19 ± 120 |
| MORMONILLOIDA | | | |
| Mormonillidae | | | |
| *Mormonilla minor* Giesbrecht 1891 | 25 | 0.27 | 50 ± 109 |
| *Mor. phasma* Giesbrecht 1891 | 40 | 0.68 | 179 ± 223 |

**Appendix I.** (continued)

| Species | Occurrence (%) | Relative abundance (%) | Mean ± S.D. (ind./1000 $m^3$) |
|---|---|---|---|
| POECILOSTOMATOIDA | | | |
| Corycaeidae | | | |
| *Corycaeus* (*Agetus*) *flaccus* Giesbrecht 1891 | 90 | 1.36 | 783 ± 599 |
| *Cor.* (*A.*) *limbatus* Brady 1883 | 95 | 1.55 | 904 ± 600 |
| *Cor.* (*A.*) *typicus* (Kroeyer 1849) | 95 | 1.38 | 837 ± 915 |
| *Corycaeus*(*Corycaeus*) *clausi* F. Dahl 1894 | 25 | 0.29 | 53 ± 226 |
| *Cor.* (*C.*) *crassiusculus* Dana 1849 | 100 | 1.08 | 698 ± 570 |
| *Cor.* (*C.*) *speciosus* Dana 1849 | 100 | 2.43 | 1626 ± 821 |
| *Corycaeus* (*Ditrichocorycaeus*) *affinis* McMurrich 1916 | 15 | 0.38 | 46 ± 277 |
| *Cor.* (*D.*) *andrewsi* Farran 1911 | 40 | 0.87 | 225 ± 547 |
| *Cor.* (*D.*) *asiaticus* F. Dahl 1894 | 55 | 0.71 | 258 ± 393 |
| *Cor.* (*D.*) *erythraeus* Cleve 1901 | 10 | 0.56 | 51 ± 414 |
| *Corycaeus* (*Monocorycaeus*) *robustus* Giesbrecht 1891 | 35 | 0.40 | 127 ± 223 |
| *Corycaeus* (*Onychocorycaeus*) *agilis* Dana 1849 | 25 | 0.30 | 55 ± 91 |
| *Cor.* (*O.*) *catus* F. Dahl 1894 | 70 | 0.66 | 323 ± 317 |
| *Cor.* (*O.*) *giesbrechti* F. Dahl 1894 | 5 | 0.19 | 11 |
| *Cor.* (*O.*) *pacificus* M. Dahl 1912 | 60 | 0.50 | 198 ± 208 |
| *Corycaeus* (*Urocorycaeus*) *furcifer* Claus 1863 | 55 | 0.54 | 223 ± 299 |
| *Cor.* (*U.*) *lautus* Dana 1849 | 40 | 0.34 | 93 ± 149 |
| *Farranula carinata* (Dana 1847) | 20 | 0.28 | 43 ± 205 |
| *Far. concinna* (Dana 1847) | 5 | 0.77 | 47 |
| *Far. gibbula* Giesbrecht 1891 | 100 | 1.67 | 1029 ± 1013 |
| Oncaeidae | | | |
| *Lubbockia* sp. | 10 | 0.24 | 22 ± 23 |
| *Lub. aculeata* Giesbrecht 1891 | 25 | 0.22 | 40 ± 95 |
| *Lub. marukawai* Mori 1937 | 30 | 0.24 | 58 ± 72 |
| **Lub. minuta* Wolfenden 1905 | 5 | 0.25 | 15 |
| *Lub. squillimana* Claus 1849 | 15 | 0.18 | 30 ± 77 |
| *Oncaea clevei* Fruhtl 1863 | 5 | 0.26 | 16 |
| *Onc. conifera* Giesbrecht 1891 | 60 | 0.96 | 378 ± 371 |
| **Onc. gracilis* (Dana) | 25 | 0.46 | 84 ± 199 |
| *Onc. media* Giesbrecht 1891 | 10 | 0.33 | 30 ± 115 |
| *Onc. mediterranea* Claus 1861 | 95 | 1.80 | 1091 ± 862 |
| *Onc. venusta* Philippi 1843 | 100 | 7.44 | 4676 ± 2137 |
| *Pachos* (*Pachysoma*) *punctatum* Claus 1893 | 5 | 0.06 | 3 |
| Sapphirinidae | | | |
| *Copilia lata* Giesbrecht 1891 | 5 | 0.19 | 11 |
| *Cop. mirabilis* Dana 1849 | 85 | 1.06 | 575 ± 484 |
| *Cop. quadrata* Dana 1852 | 15 | 0.27 | 33 ± 134 |
| *Cop. vitrea* Haeckel 1864 | 5 | 0.06 | 3 |
| *Sapphirina angusta* Dana 1849 | 5 | 0.22 | 13 |
| *Sap. auronitens* Claus 1863 | 5 | 0.03 | 2 |
| *Sap. gastrica* Giesbrecht 1891 | 10 | 0.18 | 16 ± 54 |
| *Sap. gemma* Dana 1849 | 15 | 0.19 | 23 ± 86 |
| *Sap. intestinata* Giesbrecht 1891 | 5 | 0.21 | 12 |
| *Sap. metallina* Dana 1849 | 20 | 0.38 | 57 ± 119 |
| *Sap. nigromaculata* Claus 1863 | 5 | 0.07 | 4 |
| *Sap. ovatolanceolata* Dana 1849 | 5 | 0.23 | 14 |
| *Sap. stellata* Giesbrecht 1891 | 50 | 0.45 | 150 ± 201 |
| SIPHONOSTOMATOIDA | | | |
| Rataniidae | | | |
| *Ratania flava* Giesbrecht 1892 | 5 | 0.21 | 13 |
| Pontoeciellidae | | | |
| *Pontoeciella abyssicola* T. Scott 1904 | 15 | 0.16 | 19 ± 60 |

*New record for Taiwan.