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# Spatial Distribution of Copepods in Surface Waters of the Southeastern Taiwan Strait

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**Wen-Tseng Lo, Jiang-Shiou Hwang and Qing-Chao Chen. (2004).** Spatial distributions of copepod assemblages relative to hydrological conditions in the southeastern Taiwan Strait. *Zoological Studies* **43**(2): 218-228. Those were investigated during 16-19 June 1998. In all, 90 species of copepods were identified. The mean numerical abundance of copepods was 37.9 ± 12.7 individuals $m^{-3}$. Among these species, *Acrocalanus gracilis*, with an occurrence rate of 86%, was the most dominant taxon, contributing 37% to the numerical total of copepods. Other dominant copepods included *Undinula vulgaris* (11%), *Oncaea venusta* (7%), and *Farranula gibbula* (6%). The numerical abundance and species richness of copepods were higher in the waters south of the Penghu Islands. This area is affected by topographical upwelling due to the northward-flowing Kuroshio Current and South China Sea waters meeting the shallower shelf of the Taiwan Strait. Meanwhile, the lowest abundance and species richness of copepods were found at stations near the center of the Strait. Distribution patterns varied with different species, e.g., *Acrocalanus gracilis*, *Undinula vulgaris*, and *Oncaea venusta* had higher abundances in waters southwest of the Penghu Islands, while *Farranula gibbula* had higher abundance in coastal waters. Other dominant copepods exhibited higher abundances in coastal waters associated with either topographic or hydrographic conditions. Three station groups were defined using cluster analysis: southern stations off the Penghu Islands, stations near the center of the Taiwan Strait, and stations in the Penghu Channel. The last station group was particularly distinct from the others. Three copepod species groups were also distinguished and are herein discussed.
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**Key words:** Copepod composition, Spatial distribution, Taiwan Strait, South China Sea, Upwelling.

The Taiwan Strait is located at 22°~25.5°N and 117°~121.5°E and is sandwiched between mainland China on the west and the Is. of Taiwan on the east, with a length of 350 km, width of 180 km, and average depth of 60 m. It connects the East China Sea (ECS) to the north with the South China Sea (SCS) to the south. The Strait has complex bottom topography, including the very shallow Taiwan Banks (20 m depth) at the southern end, the Penghu Channel (100 m depth) on the east, and the Yunchang Rise which crosses the Strait north of the Penghu Is. (also known as the Penghu Archipelago and the Pescadores ) (Fig. 1). The SCS surface waters usually intrude into the Strait and pass northward through the Penghu Channel, dominating the Strait from early summer to early autumn during the southwesterly monsoon. After the end of autumn in the beginning of the northeasterly monsoon, a branch of the Kuroshio Current (KC), a warm and highly saline North Pacific current, which originates from the North Equatorial Current east of the Philippines, dominates the area and flows northward through the same pathway. As it approaches the Yunchang Rise, it turns westward and accumulates in the area west of the Penghu Is. (Wang and Chern 1987, Shaw 1992). In the meantime, the southerly flowing China Coastal Current (CCC), enforced now by the northeasterly monsoon in winter, invades the northern Strait and often forms

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cyclonic cold-core rings north of the Yunchang Rise. Both the northerly flowing KC (warm and highly saline) and the southerly flowing CCC (cold and nutrient rich) are obstructed by the Yunchang Rise and usually develop an east-west-oriented thermohaline front. The complex hydrological conditions, therefore, greatly influence the distribution patterns and succession of copepod communities as well as the ecosystems of the Strait.

This study is a part of a multidisciplinary oceanographic investigation in the South China Sea (SCS) and the Taiwan Strait. A number of reports on the SCS, including biology (Morton 1996, Huang and Qi 1997), physics (Shaw 1989, Shaw and Chao 1994, Chen 1996, Hwang 1998, Li et al. 1998), chemistry (Chung et al. 1997, Chen 1998), and geology (Fang et al. 1998, Wei et al. 1998) have recently been published. Information on copepods is, however, still rather sparse despite their dominance in the zooplankton, both in terms of species diversity and numerical abundance. Past studies on planktonic copepods in the waters around Taiwan have been limited, with a few exceptions (Tan 1967, Tseng 1972), and were mainly concerned with biomass and productivity (Chen and Chen 1992). Since the mid-1990s,

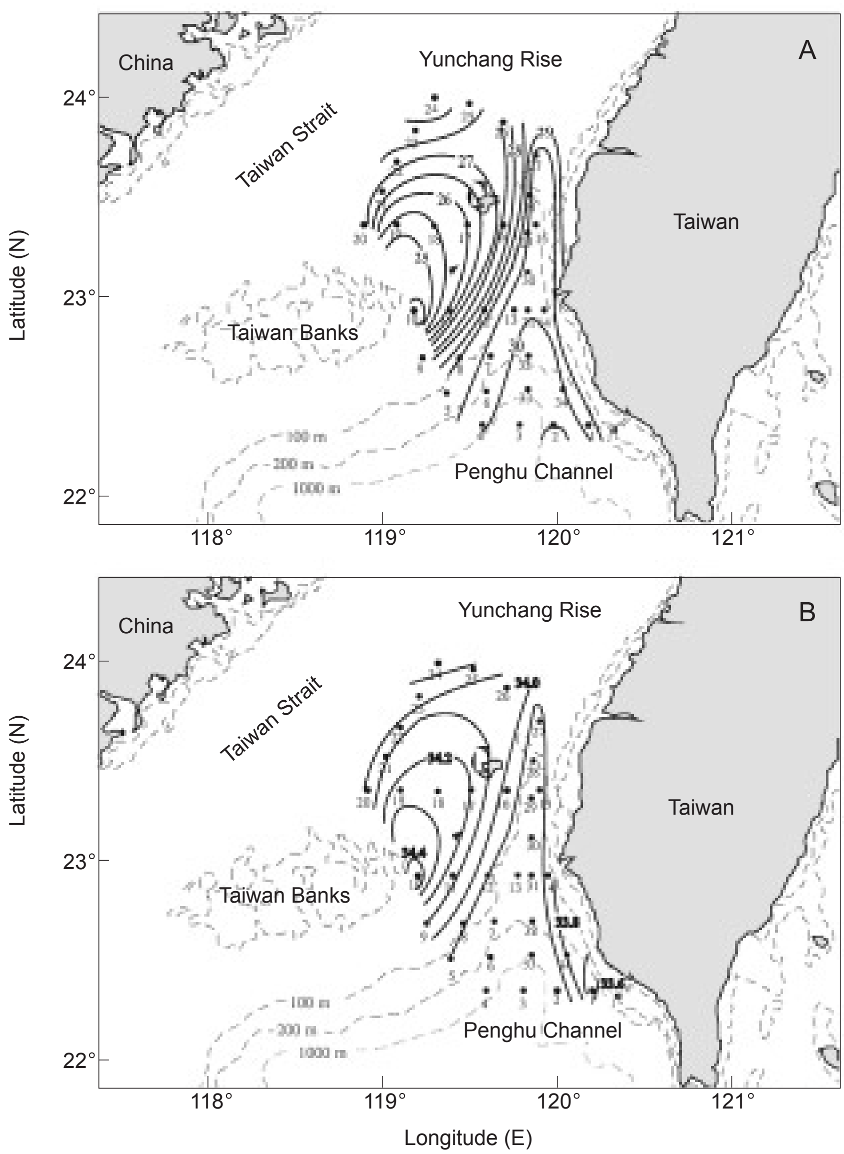



**Fig. 1.** Map of waters of the southeastern Taiwan Strait showing sampling stations. Solid lines represent contours of (A) sea surface temperature (°C) and (B) salinity (‰), while dashed lines indicate isobaths.

copepod studies have gradually become the main subject, focusing on taxonomy (Shih and Chiu 1998), behavior (Hwang and Turner 1995), diurnal migration (Su 1996), feeding (Hwang et al 1998), estuarine distribution (Hsieh and Chiu 1998, Lo et al 2001), diversity, and relation to water masses (Shih and Chiu 1998, Hsieh and Chiu 2002). These studies, however, were mainly conducted in the waters off northern Taiwan. In this work, we studied the species composition and spatial distribution of planktonic copepods in the waters of the southeastern Taiwan Strait. Our objectives were to document the distribution patterns of planktonic copepods related to hydrological conditions and topography and to examine associations of stations and species.

## MATERIALS AND METHODS

Zooplankton samples were taken from 34 stations in waters in the southeastern Taiwan Strait during cruise 455 of the *Ocean Researcher III* in June 1998 (Fig. 1). We collected samples with a net having a 1-m opening and 333-μm mesh. A flow meter was mounted in the center of the mouth opening. The net was towed horizontally near the surface (0-5 m) at a mean speed of 2 m $s^{-1}$ for 10 min at each station during both day and night. Zooplankton samples were preserved in 5%-10% buffered formalin-seawater on board, immediately after collection. At each station, prior to the plankton tow, temperature and salinity as functions of depth were obtained using a SeaBird conductivity-temperature-depth (CTD) instrument lowered from the surface to near the bottom.

In the laboratory, each sample was divided by a Folsom plankton splitter until the subsample contained about 500 specimens. Copepods were then sorted for identification and counting. To compare differences in copepod groups with station samples, the logarithmic abundances of the 59 most common species (those with occurrence rates of > 20%) were standardized, then cluster analysis (CA) was used to place species with similar distributions into groups or clusters using minimum variance (or Ward) linkages. To identify groups of copepod species that co-varied in logarithmic

**Table 1.** Mean density, relative abundance, and occurrence rate of the 20 dominant copepod species in waters southwest of Taiwan during the cruise of 16-19 June 1998

| Species | Mean density (individuals $m^{-3}$) | Relative abundance (%) | Occurrence rate (%) |
|---|---|---|---|
| *Acrocalanus gracilis* | 14.16 ± 60.89 | 37.31 | 85.71 |
| *Undinula vulgaris* | 4.17 ± 15.66 | 10.99 | 80.00 |
| *Oncaea venusta* | 2.47 ± 4.45 | 6.51 | 74.29 |
| *Farranula gibbula* | 2.29 ± 6.39 | 6.03 | 74.29 |
| *Canthocalanus pauper* | 1.43 ± 2.21 | 3.77 | 68.57 |
| *Labidocera detruncata* | 0.99 ± 2.03 | 2.60 | 71.43 |
| *Cosmocalanus darwini* | 0.98 ± 2.03 | 2.58 | 60.00 |
| *Clausocalanus arcuicornis* | 0.95 ± 1.82 | 2.50 | 68.57 |
| *Calanopia elliptica* | 0.91 ± 3.18 | 2.40 | 48.57 |
| *Centropages calaninus* | 0.83 ± 1.92 | 2.18 | 74.29 |
| *Temora turbinata* | 0.69 ± 2.14 | 1.82 | 57.14 |
| *Clausocalanus mastigophorus* | 0.61 ± 1.51 | 1.60 | 42.86 |
| *Subeucalanus subtenuis* | 0.48 ± 2.07 | 1.28 | 8.57 |
| *Temora discaudata* | 0.45 ± 0.97 | 1.18 | 65.71 |
| *Nannocalanus minor* | 0.40 ± 0.84 | 1.06 | 37.14 |
| *Acrocalanus monachus* | 0.38 ± 0.64 | 1.01 | 62.86 |
| *Calocalanus pavo* | 0.37 ± 0.61 | 0.97 | 77.14 |
| *Paracalanus nanus* | 0.35 ± 1.90 | 0.92 | 17.14 |
| *Scolecithrix danae* | 0.33 ± 0.62 | 0.88 | 34.29 |
| *Candacia catula* | 0.32 ± 0.56 | 0.83 | 45.71 |
| Other copepods | 3.95 ± 14.29 | 12.39 | - |
| Total copepods | 37.95 ± 126.71 | 100.00 | - |

abundance, the data matrix was transposed so that samples became variables, and then cluster analysis was used to determine the co-varying species groups. The numerical abundances of all copepod species in each group were integrated and averaged to display their distribution patterns.

## RESULTS

The sea surface water temperature and salinity contours, isobaths, and sampling stations are shown in fig. 1. The temperature and salinity contours, ranged from 24.5°C at Stn. 10 to 30.6°C at Stn. 2 and from 33.6‰ at Stn. 1 to 34.4‰ at Stn. 10, respectively. These seemed to be coincident with the local topography but in reverse order between temperature and salinity. A warmer and fresher water tongue (> 29°C, < 33.9‰) was found to be pushing northward along the southwestern coast of Taiwan and through the Penghu Channel, finally reaching the Yunchang Rise. Furthermore, a topographical upwelling or the so-called "cold-core ring", having the coldest temperature (24.5°C) and highest salinity at the center of the ring (at Stn. 10), was found in the area between the Taiwan Banks and the Penghu Islands.

In total, 90 species of copepods were identified in this study with a mean numerical abundance of 37.9 ± 12.7 individuals (ind.) $m^{-3}$. Among these copepods, *Acrocalanus gracilis* was the most dominant species, comprising 37% of the numerical total of copepods, with an occurrence rate of 86%. Other dominant copepods included *Undinula vulgaris* (11%), *Oncaea venusta* (7%), and *Farranula gibbula* (6%), and their occurrence rates were all > 74% (Table 1). The species richness of copepods at each station was between 6 (at Stn. 20) and 41 (at Stn. 17). Higher species richness was generally found in waters south of the Penghu Is., and in the center of the Penghu Channel, while lower species richness was always found at offshore stations near the center of the Taiwan Strait (i.e., Stns. 20~24 in Fig. 2). The numerical abundance of copepods varied greatly through 3 orders of magnitude among stations, and had a peak (413 ind. $m^{-3}$) at Stn. 10 located in waters of the eastern Taiwan Banks with a low surface temperature (24.5°C). Higher abundance was also found in waters south of the Penghu Islands (Stns. 15~19) (Fig. 3). However, an extremely low abundance of copepods was found at stations (Stns. 20~24) near the center of the Taiwan Strait. Various dominant species had different distributions. *Acrocalanus gracilis*, *U. vulgaris*, *O. venusta*, *Calanopia elliptica*, and *Temora turbinata* had higher abundances in waters southwest of the Penghu Is. and near the eastern

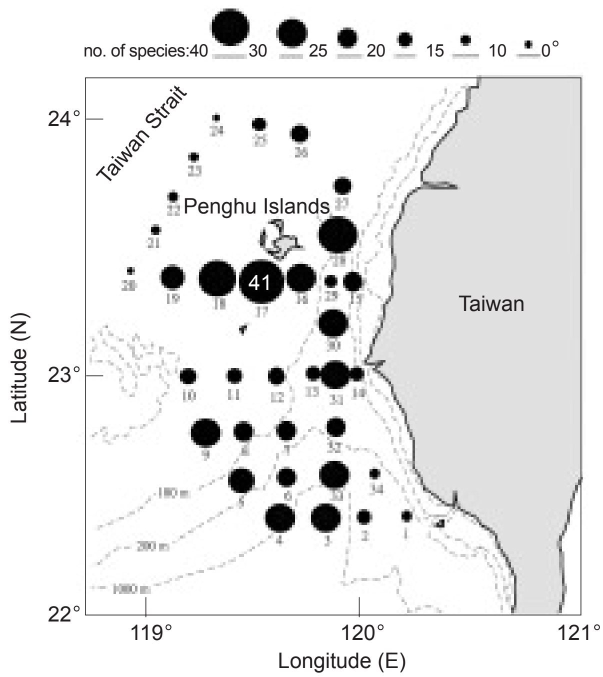



**Fig. 2.** Species richness of copepod in waters of the southeastern Taiwan Strait during the cruise of 16-19 June 1998.

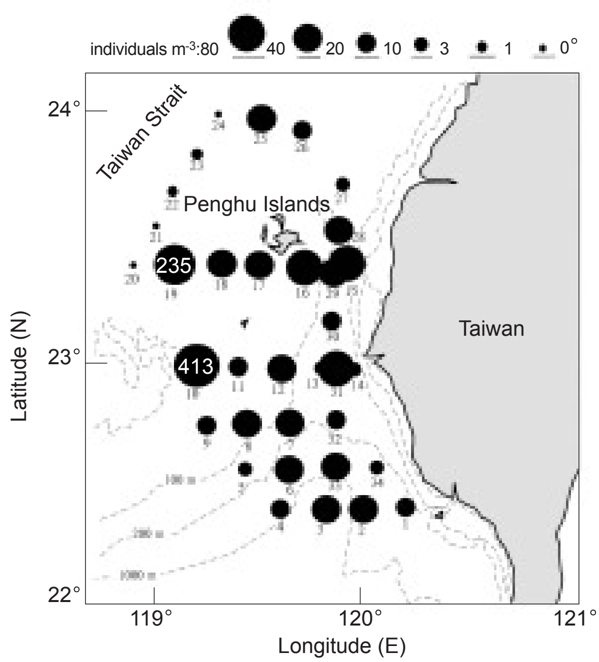
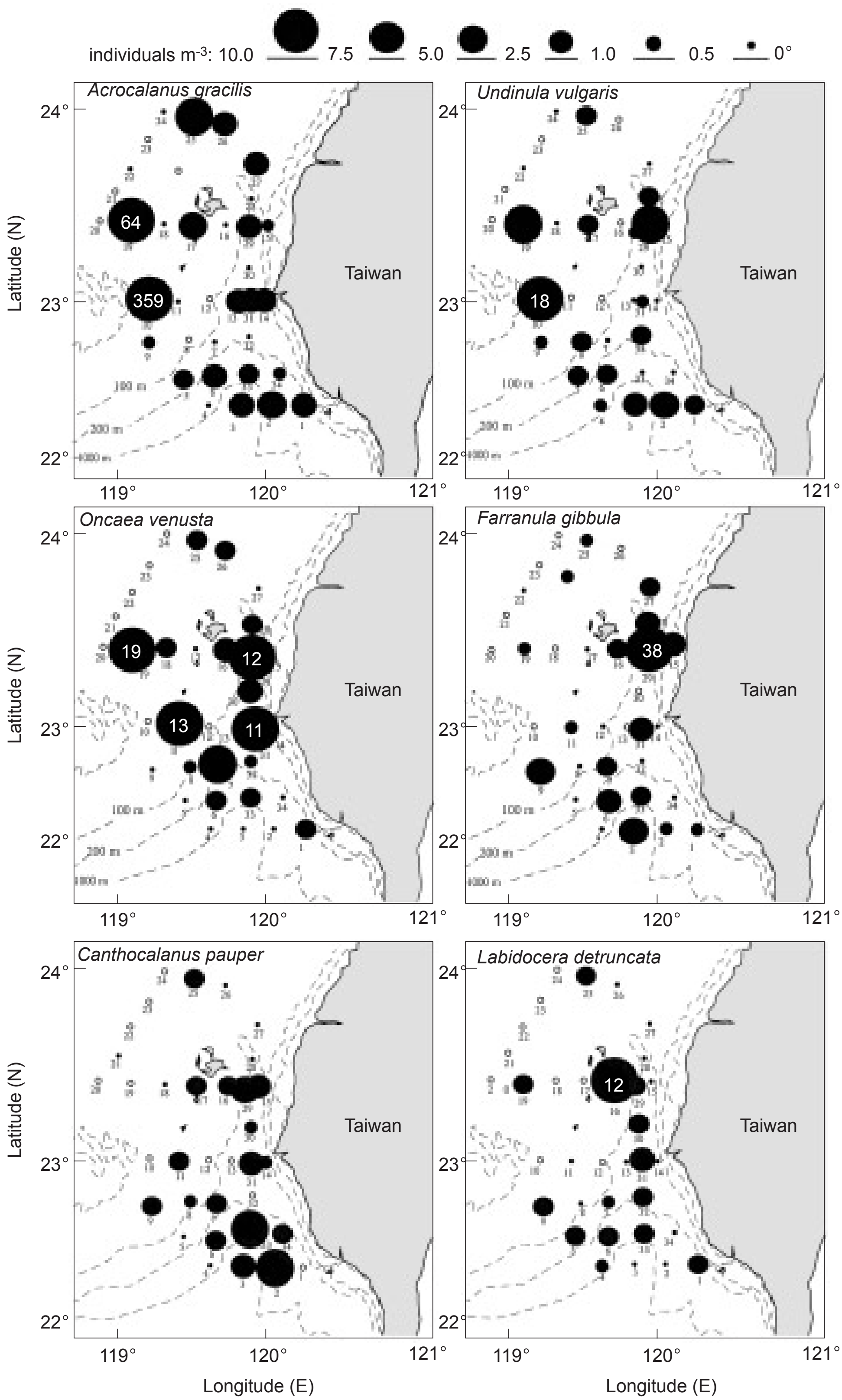



**Fig. 3.** Numerical abundance of copepods in waters of the southeastern Taiwan Strait during the cruise of 16-19 June 1998.


individuals m-3: 10.0
7.5
5.0
2.5
1.0
0.5
0°
Acrocalanus gracilis
Undinula vulgaris
Oncaea venusta
Farranula gibbula
Canthocalanus pauper
Labidocera detruncata
64
359
18
19
12
13
11
38
12
Taiwan
100 m
200 m
1000 m
24°
23°
22°
119°
120°
121°
Latitude (N)
Longitude (E)

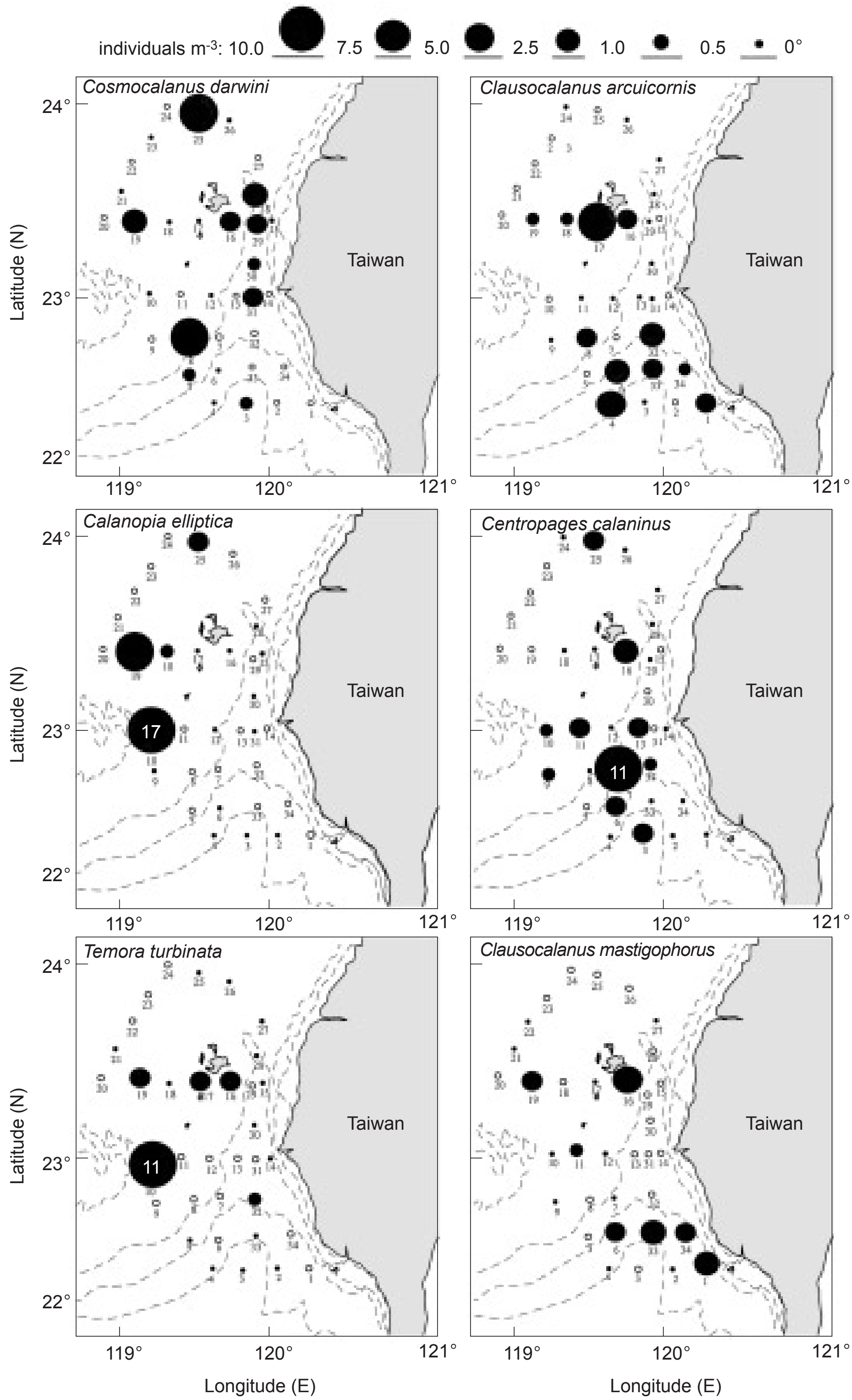



**Fig. 4.** Numerical abundance of the 12 dominant copepod species in waters of the southeastern Taiwan Strait during the cruise of 16-19 June 1998.

Taiwan Banks, particularly at Stn. 10. There the abundance of *A. gracilis* was up to 359 ind. $m^{-3}$ and comprised 87% of the total copepods. *Farranula gibbula*, *Canthocalanus pauper*, and *Labidocera detruncata* were common in the Penghu Channel and had higher abundances at the northern end of the Channel (Fig. 4). *Clausocalanus arcuicornis*, *Centropages calaninus*, and *Clausocalanus mastigophorus* showed higher abundances in waters south of the Penghu Is. and in the southern Penghu Channel, but were relatively scarce or even totally absent at the northern and the far offshore stations near the center of the Strait. The distribution patterns of these dominant copepod species were somewhat associated with either local topographic or hydrographic conditions.

Three station groups were defined using cluster analysis with Ward's linkage method and are delineated on the map (Fig. 5). The first group included 7 stations which were mostly in waters south of the Penghu Is. This group seemed to be the link between the 2nd and 3rd groups, and exhibited close relations with the hydrographical conditions of shallower depth and higher production. The 2nd group was mostly composed of the far offshore stations (Stns. 20~26) near the center of the Taiwan Strait and was characterized by the lowest species richness and the lowest abundance of copepods. The last group contained 20 stations located mainly in the Penghu Channel and was correlated with local topography. This group was particularly distinct from the others according to the cluster linkage. Three copepod species groups were also distinguished (Fig. 6). The 1st group contained 22 species, which had higher abundances in the central core of the Penghu Channel. The 2nd group included 9 dominant species which displayed higher abundances in waters south of the Penghu Is. and the Penghu Channel, particularly at Stn. 10 that was characterized by colder surface water. In contrast, this species group was rather scarce or absent from stations (20~26) near the center of the Strait. The 3rd group included 28 species which were not common but had higher abundances in waters southwest of the Penghu Islands near the Taiwan Banks.

## DISCUSSION

Results of this study show that copepods are patchily distributed, and that the distribution patterns match both local isobaths and hydrographic conditions. The 3rd station group (Fig. 5) covered almost the entire Penghu Channel, which is dominated by warm waters of the South China Sea during summer (Fang and Yu 1981). This station group displayed higher abundances and species richness at the northern end of the Penghu Channel (Figs. 2, 3), where the northward flow becomes faster and more turbulent when confronting the narrower channel and shallower shelf, and finally becomes impeded by the Yunchang Ridge. The deeper and colder subsurface water, when blocked by the shallower shelf and the Penghu Islands, may rise and turn northwestward south of the Penghu Is. and induce a cyclone (cold-core ring in the north hemisphere) in the area of station group I. This is probably due to the combined effects of the Coriolis force and Ekman transport driven by the southwesterly monsoon (Jan et al. 1994). This area (station group I) seemed to be the transition zone between the areas of station groups II and III, had shallower depths and coral reefs, and was characterized by lower surface temperatures and occasional peaks of abundance and species richness. Station group II represents the Taiwan Strait center water that always had the lowest abundance and species richness of copepods but with abundant tunicates (*Thalia democratica*). These results confirm previous observations made by Jan et al. (1995) as to physical factors and the current model and of Young et al. (1995) as to the distribution pattern of larval anchovy in the Taiwan Strait. They imply that the distribution patterns of planktonic organisms in the strait are mainly seasonally influenced by at least 3 water masses: the Kuroshio Current, the South China Sea waters, and the China Coastal Current. Upwelling generated by the local topographical front can also be an important factor. Similar phenomena related to water masses were reported by Chiu (1991) for fish egg and larvae, by Shiah et al. (1995) for primary productivity, by Chen and Chen (1992) for zooplankton biomass in the northern waters of Taiwan, and by Hsieh and Chiu (2002) for copepods and fish larvae in the northern Taiwan Strait.

Numerous studies on planktonic copepods of the waters adjacent to Taiwan have recently been reported (e.g., Hwang and Turner 1995, Shih and Young 1995, Su 1996, Chen and Hwang 1998, Chen et al. 1998, Cheng 1998, Hwang 1998, Hwang et al. 1998, Shih and Chiu 1998, Wong et al. 1998, Hwang et al. 2000, Shih et al. 2000). In total, 502 species of planktonic copepods have been recorded in the marginal seas of China (Shih's unpubl. data) and about 280 have been reported in the waters around Taiwan (Hwang and Turner 1995, Chen and Hwang 1998, Hwang et al. 1998, Shih and Chiu 1998, Wong et al 1998, Shih et al 2000). In this study, we identified 90 species of copepod. This is higher than that recorded in the northern South China Sea (78 species) by Hwang et al. (2000), and much higher than that in coastal waters off the northern tip of Taiwan (25 species) by Hwang et al. (1998), near the northern nuclear power plant (37 species) by Wong et al. (1998), and in coastal waters southwest of Taiwan (67 species) by Lo et al. (2001), but lower than that of Hsieh and Chiu (2002) in the northern Taiwan Strait (122 species). Differences in species richness among these studies may have resulted in part from different sampling frequencies over different temporal and spatial scales, and the different levels of identification used. The Taiwan Strait is influenced by many adjacent water masses and currents with strong seasonal influences by the monsoons. With more sampling and identification effort, we expect that additional copepod species will be recorded in this subtropical water in our future work. Unfortunately, it must be pointed out that the use of a 333-μm mesh net may have under-sampled smaller copepods such as *Oithona* spp., *Paracalanus* spp., etc. (Turner 2004).

The abundance of copepods in the southeastern coastal waters of Taiwan in our previous work (Lo et al. 2001) is about 3 times higher than that of the present study. This probably is because the present sampling stations were mostly located far away from land, particularly the stations (20~24) near the center of the Taiwan Strait which always showed the lowest abundances. For instance, *Acrocalanus gracilis* was the most dominant species in this study, with a mean numerical abundance of 14.2 ± 60.9 ind. m$^{-3}$, comprising 37% of the numerical total of copepods, but it comprised only 30% in our previous study (Lo et al. 2001), with a similar trend also for *Oncaea venusta*. In general, *A. gracilis* is widely distributed in the subtropical western North Pacific according to records of many reports. In the northern South China Sea (south of Taiwan), it was the most dominant copepod (Hwang et al. 2000), and in the northern Taiwan Strait as well as the East China Sea, it was more abundant in the east than in the west (Hsieh and Chiu 2002). In the southern East China Sea north of Taiwan (Shih and Chiu 1998) and in the southern Sea of Japan (Takahashi and Hirakawa 2001), this species was found but was less important as to abundance. Takahashi and Hirakawa (2001) defined *A. gracilis* as being a warm-water species. Comparing with other reports in adjacent waters of Taiwan, we also confirm that *A. gracilis* usually displays higher abundances in inshore waters and its degree of abundance declines from subtropical to temperate waters. Other dominant copepods, such as *Undinula vulgaris* and *O. venusta*, were also very common in the waters around Taiwan. *Oncaea venusta* showed equal importance in abundance in most waters adjacent to Taiwan, while *U. vulgaris* seemed to be less important in the East China Sea and was not recorded in the southern Sea of Japan. However, from our results, we found that the effect of local hydrographic conditions on copepod patchiness seemed to be more significant than that of any geographic gradient. For instance, the 3 most dominant species (as mentioned above) displayed peak abundance (particularly *A. gracilis*) at or near Stn. 10 located at the eastern Taiwan Banks where surface temperature was lowest (Fig. 3). Abundance was also affected by topographical upwelling due to interception of the northward-flowing SCS waters by the shallower shelf of the Taiwan Strait. The distribution characteristics of the epipelagic copepod community in this study also reflected the distinct hydrographic conditions in the Strait during the southwesterly monsoon. Therefore, the present study has not only expanded our understand-

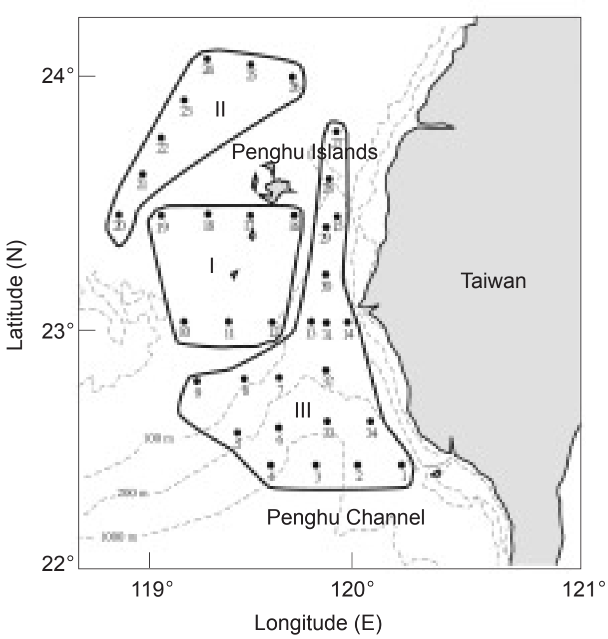



**Fig. 5.** Station groups delineated from the result of PCA using the 59 dominant copepod species.

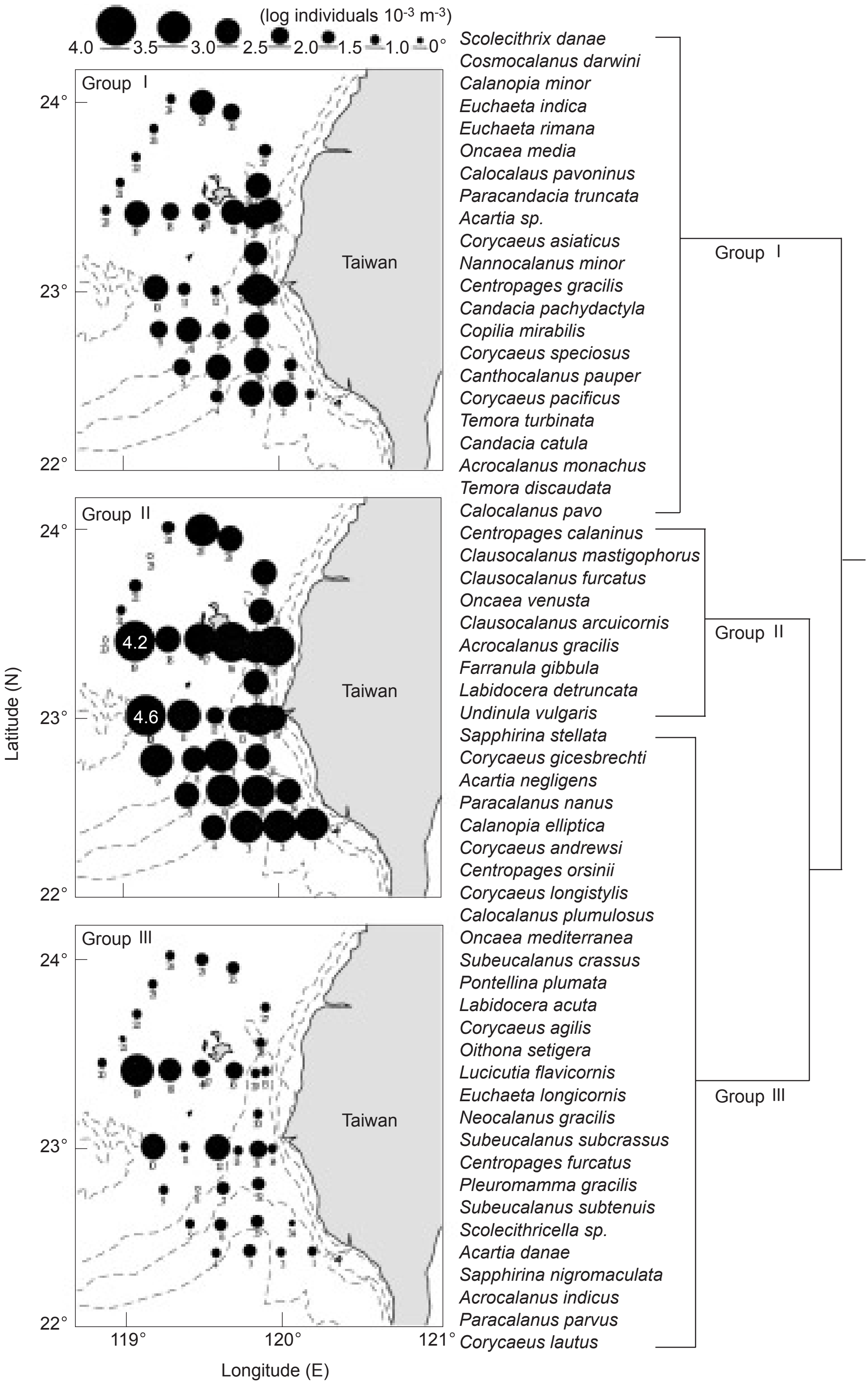



**Fig. 6.** Copepod assemblages and their distribution patterns in waters of the southeastern Taiwan Strait during the cruise of 16-19 June 1998.

ing on the copepods in the southeastern Taiwan Strait, but also provided good evidence of biotic responses to the hydrological situation and interactions among water masses in the Taiwan Strait.

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