Zoological Studies **48**(2): 151-161 (2009)

Zoological Studies

Seasonal and Spatial Variations in the Planktonic Copepod Community of Ilan Bay and Adjacent Kuroshio Waters off Northeastern Taiwan

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(Accepted July 14, 2008)

Chun-Yein Lee, Don-Chung Liu, and Wei-Cheng Su (2009) Seasonal and spatial variations in the planktonic copepod community of Ilan Bay and adjacent Kuroshio waters off northeastern Taiwan. *Zoological Studies* **48**(2): 151-161. Knowledge of seasonal fluctuations in the planktonic copepods in waters off northeastern Taiwan is rather limited. To construct certain preliminary information, the investigation of marine copepods is necessary and important. Plankton samples for copepod studies were seasonally collected by a single vertical haul at each station with a ring trawl net of 335 μm mesh size at 5 fixed stations along a transect extending eastward from Ilan Bay to about 40 nautical miles (approx. 72 km) offshore in 2005. In total, 128 species of copepods belonging to 4 orders, 24 families, and 49 genera were identified. Twenty-three dominant species contributed to the main components of seasonal abundance of the copepod community. Four of these, i.e., *Paracalanus aculeatus*, *Corycaeus* (*Agetus*) *typicus*, *Oncaea mediterranea*, and *O. venusta*, were the most widely distributed species that occurred at all stations in each season. We found copepod abundances to be higher on the continental shelf waters and lower in Kuroshio waters, but the number of species was higher in Kuroshio waters than on the continental shelf. Obvious seasonal fluctuations in the composition of dominant species were observed based on replacement rates (25.0%-61.9%) at all stations. Geographical variations in distributional associations of the copepod community occurred over a seasonal scale, and the intermediate region was mainly influenced by the Kuroshio Current. *Calanus sinicus* might be considered an indicator species for the intrusion of eddy waters from the East China Sea into Ilan Bay and adjacent waters.
http://zoolstud.sinica.edu.tw/Journals/48.2/151.pdf

Key words: Geographical distribution, Biodiversity parameter, Indicator species, Biological oceanography.

Planktonic copepods are of prime importance in marine ecosystems because many are herbivorous and feed on phytoplankton, thus forming a direct link between primary producers and higher trophic consumers (Mauchline 1998). Marine copepod communities are characterized by a high diversity of species that form the basis of food webs (Huys and Boxshall 1991). Their grazing plays a key role in the recycling of all biogenic elements in the oceans. For example, the abundance of copepods can dramatically affect the structure of oceanic food webs because of their regulation of material and energy fluxes. The role of copepods as secondary producers in marine ecosystems makes their potential influence on fishery resources critical. However, copepod communities may change in response to hydrographic conditions. This has been the primary reason researchers have attempted to determine how hydrographic factors affect the seasonal and/or long-term community dynamics of copepods (Clark et al. 2003). Seasonal fluctuations in the abundance and distribution of planktonic copepods are highly related to the hydrographic characteristics of the marine environment (Kang and Hong 1995, Yang et al. 1999a, Lin 2007). Certain copepod species are also known to be indicators of specific water masses and oceanic

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currents (Yang et al. 2000, Li et al. 2003).

Ilan Bay is located on the Ilan Shelf which is the seaward continuation of the Ilan Plain along the northeastern coast of Taiwan. The Ilan Shelf is morphologically regarded as the southern end of the East China Sea Shelf (Yu and Song 2000). Moreover, hydrographic characteristics of the bay and the eastern adjacent waters are mainly influenced by the Kuroshio Current as well as shelf water off northeastern Taiwan (Chern and Wang 1989, Lee and Hu 1998). A relatively explicit explanation from the analysis of the temperature-salinity diagrams in Ilan Bay was reported by Lee and Hu (1998). They supposed that the water mass properties of the bay from the shelf water northeast of Taiwan were basically consistent during the period of Apr. to Oct., and were from the Kuroshio water in winter. Since the warm Kuroshio Current has significant influence on the oceanography of offshore regions of eastern/northeastern Taiwan, this study was carried out to confirm the seasonal movement of the Kuroshio Current by providing biological evidence that was previously lacking.

The primary objectives of this research were to illustrate the relationship between copepod distribution and hydrographic factors, especially the Kuroshio Current (Nitani 1972), in the waters of our study area, and to monitor the marine planktonic copepod fauna in Ilan Bay and adjacent waters off northeastern Taiwan. The present study is able to present some preliminary information on these important organisms and their seasonal community dynamics, such as the species composition, abundances, distributional patterns, parameters of biodiversity, community structure, and other issues of biological oceanography.

MATERIALS AND METHODS

The research vessel *Hai-Chien* of the Fisheries Research Institute was commissioned to conduct the seasonal sampling surveys in 2005. Plankton samples were collected by a single vertical haul at each station at a speed of 0.5 m/s with a ring trawl net (1 m in mouth diameter, 335 μm mesh size, with a flow meter mounted at the center of the mouth) at 5 fixed stations along a latitudinal transect extending from Ilan Bay eastward to about 40 nautical miles (approx. 72 km) offshore of northeastern Taiwan (Fig. 1). Samples were immediately fixed in a 5% formalin-seawater solution. Detailed information of sampling dates, starting time of hauls, sampling depths, and coordinates is available (Table 1). The transect, located at the southern margin of the Okinawa Trough (Lee and Hu 1998, Yu and Song 2000), passes through different water masses and over various water depths from stations A (75 m) and B (140 m) on the continental shelf, via station KS (280 m, approx. 5.4 km east of Kuei-Shan I.) on the continental slope, to stations C (1066 m) and D (over 2000 m, the actual depth was beyond the range of the sonar equipment on the *Hai-Chien*). The hydrographic data, mainly temperature and salinity of the seawater, were taken simultaneously with a single conductivity-temperature-depth (CTD) cast (SBE 19, Sea-Bird Electronics, Bellevue, Washington, USA) at each station in all seasons. The depths of the CTD measurements were set to 70, 135, 250, 500, and 500 m of the surface at stations A, B, KS, C, and D respectively.

In the laboratory, all samples were preserved in 70% alcohol. Each sample was repeatedly divided on a Folsom splitter until the subsample contained about 300-500 copepods (Shih and Chiu 1998), then these copepods were identified to species level where possible, and the abundance of each species was recorded. Grice (1962), Chen and Zhang (1965), Frost and Fleminger (1968), Chen et al. (1974), Chihara and Murano (1997), and Mauchline (1998) were the general references used for identification. Species compositions were

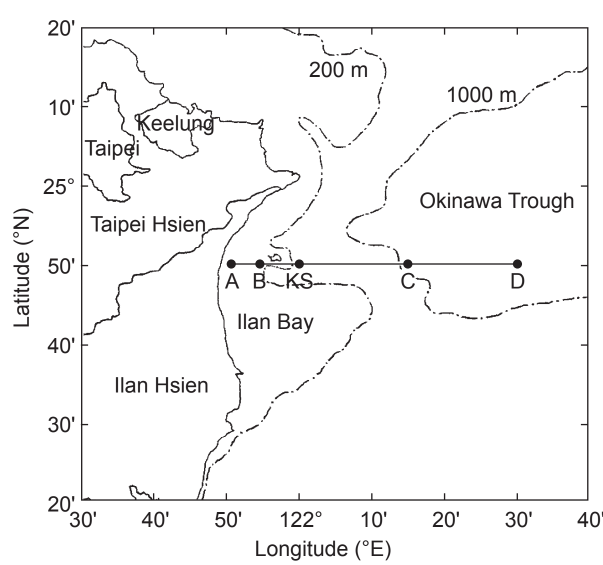

Fig. 1. Position of sampling stations along a transect extending eastward from Ilan Bay to 40 nautical miles (approx. 72 km) offshore of northeastern Taiwan.

compared among stations using the number of species and the Shannon-Wiener index of species diversity; the Jaccard coefficient of similarity was used between 2 communities when the stations were clustered on the basis of their similarity indices using the Unweighted Pair Group Method of Averages (UPGMA, Kang and Hong 1995).

For comparison of the dynamic values with other studies in the regions adjacent to this study area, the following formulae were used (Yang et al. 1999b):

$Y_i = (N_i / N) \times f_i$ and

$R = (a + b - 2c) / (a + b - c) \times 100\%$;

where Y_i is the dominance of species i, N_i is the number of individuals of species i at all stations, N is the number of individuals of all species at all stations, and f_i is the frequency of stations at which species i occurs. Species with a Y value of more than or equal to 0.02 were defined as dominant species. R is the seasonal replacement rate of dominant species, a and b are the numbers of dominant species occurring in 2 adjoining seasons, respectively, and c is the number of dominant species common to both seasons.

RESULTS

Hydrographic characteristics

Two types of water masses, especially in spring and summer, can readily be recognized by their seasonal temperature-salinity diagrams throughout the year (Fig. 2). Stations A and B, which had lower and narrower ranges of temperature and salinity, were characterized as shelf waters. Stations C and D were characterized as Kuroshio waters by exhibiting an intermediate temperature-salinity curve between the South China Sea and western Philippine Sea waters (Sawara and Hanzawa 1979, Lee and Hu 1998). Station KS has similar properties but with wider ranges of temperature than those at station B in all seasons.

Higher temperatures were found in the upper water layer at all stations, with an extreme of about 27°C at stations C and D in autumn. The relatively lower salinity of the upper water layer detected was influenced by the high precipitation of super typhoon Haitang in summer 2005. Seasonal hydrographic patterns of stations A, B, and KS were found to fluctuate considerably, while those at stations C and D were relatively stable.

Species composition

In total, 128 species of copepods belonging to 4 orders, 24 families, and 49 genera were identified (Table 2). There were 86 species of the Calanoida, 7 species of the Cyclopoida, 1 species of the Harpacticoida, and 34 species of the Poecilostomatoida. Fifty-six of these were common in all seasons, and 4 species, i.e., *Paracalanus aculeatus*, *Corycaeus* (*Agetus*) *typicus*, *Oncaea mediterranea*, and *O. venusta*, were the most

Table 1. Sampling dates (mm/dd) and starting time of hauls (hh:mm) of the collections of planktonic copepods at the various stations by vertical hauls with a ring trawl net in 2005

Station	A	B	KS	C	D
Latitude (°N)	24°50'	24°50'	24°50'	24°50'	24°50'
Longitude (°E)	121°51'	121°55'	122°00'	122°15'	122°30'
Water depth (m)	75	140	280	1,066	> 2,000
Sampling depth (m)	65	130	200	200	200
Winter	01/25	01/25	01/25	01/24	01/24
	11:36	12:20	14:00	16:54	14:27
Spring	04/22	04/22	04/22	04/21	04/21
	11:25	13:09	14:01	17:10	14:16
Summer	07/23	07/23	07/23	07/22	07/22
	11:10	11:53	14:06	17:41	14:36
Autumn	11/03	11/03	11/03	11/02	11/02
	11:31	12:15	14:01	18:10	15:00

widely distributed species that occurred at all stations in each season. In contrast, 25 species made only a single appearance throughout the year, and there were 3, 4, 4, 8, and 6 species at stations A, B, KS, C, and D, respectively, including 4 uncertain species in the genera *Eucalanus*, *Scolecithricella*, and *Farranula*.

Abundance and the dominant species

Seasonal fluctuations in the abundances of planktonic copepods distributed in the study area were noted. The greatest abundance occurred at station A with an average of 737 ± 168 individuals (ind.)/m^3, with the highest value of 949 ind./m^3 in

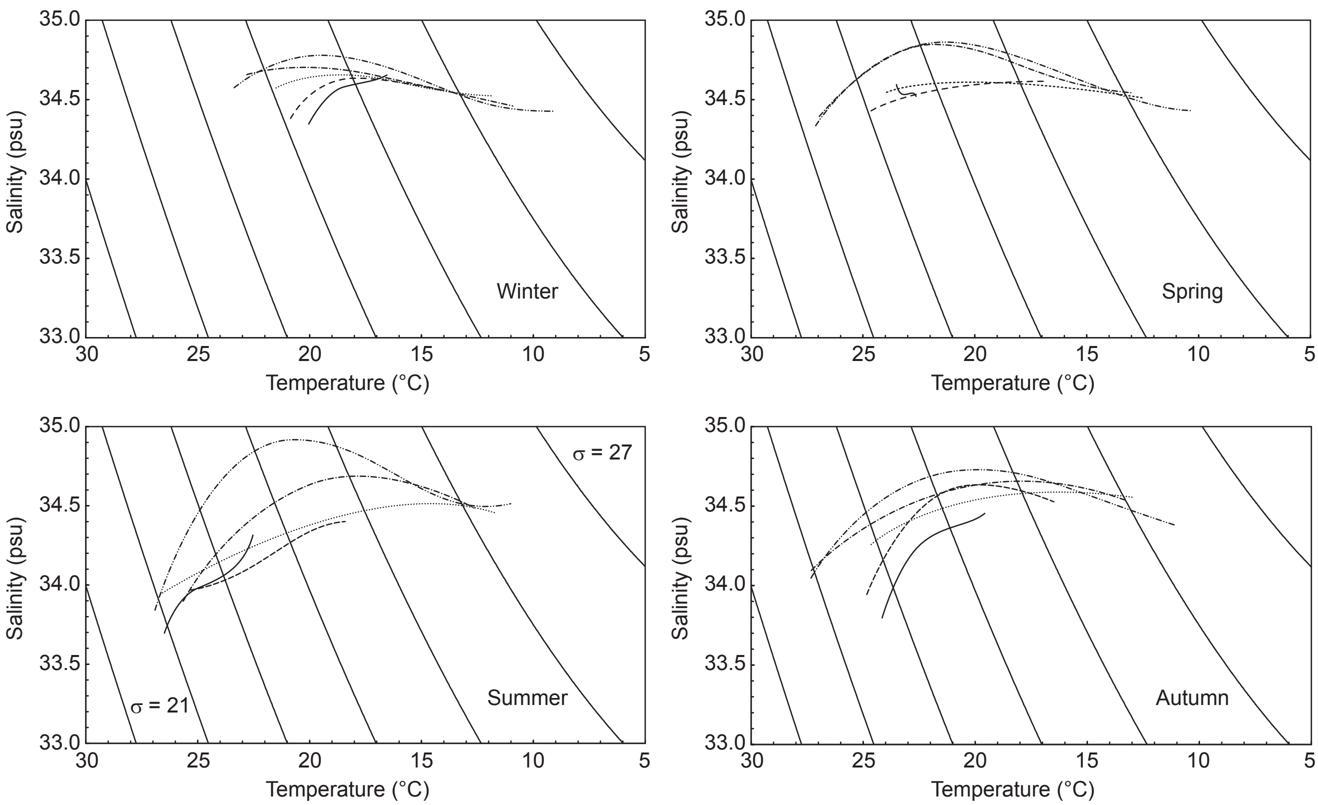

Fig. 2. Seasonal temperature-salinity diagrams at stations A (——), B (– –), KS (····), C (– · –), and D (– ·· –) in 2005.

Table 2. Species list of planktonic copepods collected in the study area in 2005. Species in boldface denote the dominant species, and those with an asterisk are the single-appearance species

CALANOIDA		
ACARTIIDAE	*Gaetanus minor* Farran, 1905	*Nannocalanus minor* (Claus, 1863)
Acartia danae **Giesbrecht, 1889**	AUGAPTILIDAE	*Neocalanus gracilis* (Dana, 1849)
Acartia negligens **Dana, 1849**	*Haloptilus longicornis* (Claus, 1863)	***Undinula vulgaris*** **(Dana, 1849)**
AETIDEIDAE	*Haloptilus spiniceps* (Giesbrecht, 1892) *	CALOCALANIDAE
Aetideopsis retusa Grice & Hulsemann, 1967	CALANIDAE	*Calocalanus pavo* (Dana, 1849)
	Calanoides philippinensis Kitou & Tanaka, 1969	*Calocalanus plumulosus* (Claus, 1863)
Aetideus acutus Farran, 1929		CANDACIIDAE
Aetideus giesbrechti Cleve, 1904 *	***Calanus sinicus*** **Brodsky, 1962**	*Candacia catula* (Giesbrecht, 1892)
Bradyidius angustus Tanaka, 1957 *	*Canthocalanus pauper* (Giesbrecht, 1888)	*Candacia curta* (Dana, 1849)
Bradyidius sp.	*Cosmocalanus darwini* (Lubbock, 1860)	*Candacia discaudata* A. Scott,1909 *

Table 2. (Cont.)

CALANOIDA

Candacia ethiopica (Dana, 1849)
Candacia longimana (Claus, 1863) *
Paracandacia bispinosa (Claus, 1863)
Paracandacia simplex (Giesbrecht, 1888)
Paracandacia truncata (Dana, 1849)
CENTROPAGIDAE
Centropages furcatus (Dana, 1849)
Centropages gracilis (Dana, 1849)
Centropages longicornis Mori, 1932 *
CLAUSOCALANIDAE
Clausocalanus arcuicornis (Dana, 1849)
Clausocalanus farrani Sewell, 1929
Clausocalanus furcatus (Brady, 1883)
Clausocalanus mastigophorus (Claus, 1863)
Clausocalanus minor Sewell, 1929
Clausocalanus parapergens Frost & Fleminger, 1968
Clausocalanus pergens Farran, 1926
Ctenocalanus vanus Giesbrecht, 1888
Ctenocalanus sp.
EUCALANIDAE
Eucalanus hyalinus (Claus, 1866)
Eucalanus sp. *
Pareucalanus attenuatus (Dana, 1849) *
Rhincalanus cornutus (Dana, 1849)
Rhincalanus nasutus Giesbrecht, 1888
Subeucalanus crassus (Giesbrecht, 1888)
Subeucalanus mucronatus (Giesbrecht, 1888)
Subeucalanus subcrassus (Giesbrecht, 1888)
EUCHAETIDAE
Euchaeta concinna (Dana, 1849)
Euchaeta indica Wolfenden, 1905
Euchaeta longicornis Giesbrecht, 1888
Euchaeta media Giesbrecht, 1888 *
Euchaeta rimana Bradford, 1973
HETERORHABDIDAE
Heterorhabdus papilliger (Claus, 1863)
Heterorhabdus tanneri (Giesbrecht, 1895) *
LUCICUTIIDAE
Lucicutia flavicornis (Claus, 1863)
METRIDINIDAE
Pleuromamma abdominalis (Lubbock, 1856)
Pleuromamma borealis (Dahl, 1893) *
Pleuromamma gracilis (Claus, 1863)
Pleuromamma robusta (Dahl, 1893) *
Pleuromamma xiphias (Giesbrecht, 1889)
PARACALANIDAE
Acrocalanus gibber Giesbrecht, 1888
Acrocalanus gracilis Giesbrecht, 1888
Acrocalanus longicornis Giesbrecht, 1888
Acrocalanus monachus Giesbrecht, 1888
Bestiolina similis (Sewell, 1914) *
Paracalanus aculeatus Giesbrecht, 1888
Paracalanus parvus (Claus, 1863)
PONTELLIDAE
Calanopia elliptica (Dana, 1849)
Calanopia minor A. Scott, 1902
Labidocera acuta (Dana, 1849) *
Pontellina plumata (Dana, 1849) *
SCOLECITRICHIDAE
Scaphocalanus longifurca (Giesbrecht, 1888) *
Scolecithricella ctenopus (Giesbrecht, 1888)
Scolecithricella dentata (Giesbrecht, 1892)
Scolecithricella minor (Brady, 1883)
Scolecithricella sp. *
Scolecithrix bradyi (Giesbrecht, 1888) *
Scolecithrix danae (Lubbock, 1856)
Scolecithrix nicobarica Sewell, 1929
Scottocalanus helenae (Lubbock, 1856)
TEMORIDAE
Temora discaudata (Giesbrecht, 1889)
Temora stylifera (Dana, 1849)
Temora turbinata (Dana, 1849)
Temoropia mayumbaensis T. Scott, 1894
THARYBIDAE
Tharybis sp.
TORTANIDAE
Tortanus (Atortus) digitalis Ohtsuka & Kimoto, 1989 *

CYCLOPOIDA
OITHONIDAE
Oithona fallax Farran, 1913
Oithona longispina Nishida, 1977 *
Oithona plumifera Baird, 1843
Oithona rigida Giesbrecht, 1896
Oithona robusta Giesbrecht, 1891
Oithona setigera (Dana, 1849)
Oithona tenuis Rosendorn, 1917 *

HARPACITICOIDA
MIRACIIDAE
Macrosetella gracilis (Dana, 1848)

POECILOSTOMATOIDA
CORYCAEIDAE
Corycaeus (*Agetus*) *flaccus* Giesbrecht, 1891
Corycaeus (*Agetus*) *limbatus* Brady, 1883
Corycaeus (_Agetus_) _typicus_ (Kroyer, 1849)
Corycaeus (*Corycaeus*) *clausi* F. Dahl, 1894
Corycaeus (*Corycaeus*) *crassiusculus* Dana, 1849
Corycaeus (_Corycaeus_) _speciosus_ Dana, 1849
Corycaeus (*Ditrichocorycaeus*) *affinis* McMurrich, 1916
Corycaeus (*Ditrichocorycaeus*) *andrewsi* Farran, 1911
Corycaeus (*Ditrichocorycaeus*) *asiaticus* F. Dahl, 1894
Corycaeus (*Ditrichocorycaeus*) *dahli* Tanaka, 1957
Corycaeus (*Onychocorycaeus*) *agilis* Dana, 1849 *
Corycaeus (*Onychocorycaeus*) *catus* F. Dahl, 1894
Corycaeus (*Onychocorycaeus*) *pacificus* M. Dahl, 1912 *
Corycaeus (*Onychocorycaeus*) *pumilus* M. Dahl, 1912
Corycaeus (*Urocorycaeus*) *furcifer* Claus, 1863
Corycaeus (*Urocorycaeus*) *longistylis* Dana, 1849
Farranula concinna (Dana, 1849)
Farranula gibbula (Giesbrecht, 1891)
Farranula sp. 1 *
Farranula sp. 2 *
ONCAEIDAE
Lubbockia marukawai Mori, 1937
Lubbockia squillimana Claus, 1863
Oncaea conifera Giesbrecht, 1891
Oncaea media Giesbrecht, 1891
Oncaea mediterranea Claus, 1863
Oncaea minuta Giesbrecht, 1892
Oncaea venusta Philippi, 1843
SAPPHIRINIDAE
Copilia lata Giesbrecht, 1891
Copilia mediterranea (Claus, 1863)
Copilia mirabilis Dana, 1849
Copilia recta Giesbrecht, 1891
Sapphirina metallina Dana, 1849
Sapphirina nigromaculata Claus, 1863
Sapphirina stellata Giesbrecht, 1891

winter (Fig. 3). By contrast, the abundances in Kuroshio waters, i.e., at stations C and D, were lower than those in shelf waters. The result of a 2-way analysis of variance (ANOVA, Table 3) indicated significant differences both among stations ($p < 0.05$, $F = 50.50$) and among seasons ($p < 0.05$, $F = 4.89$).

There were 23 dominant species that contributed to the main components of seasonal abundances of copepods (Table 4). Seven of these, i.e., *Calanus sinicus*, *Clausocalanus furcatus*, *Clausocalanus minor*, *Lucicutia flavicornis*, *Paracalanus aculeatus*, *Oithona plumifera*, and *Oncaea venusta*, were dominant species that occurred in all seasons (Fig. 4). Eight species, including *Corycaeus* (*Agetus*) *typicus* and *Oncaea mediterranea*, were usually less abundant and only dominated in a single season. Although *Cor. typicus* and *O. mediterranea* were both collected at all stations in each season, their abundances in most seasons were not high enough to regard them as defined dominant species. This rendered them quite different from the 7 dominant species which usually had higher abundances and thus dominated the copepod community in each season in the study area.

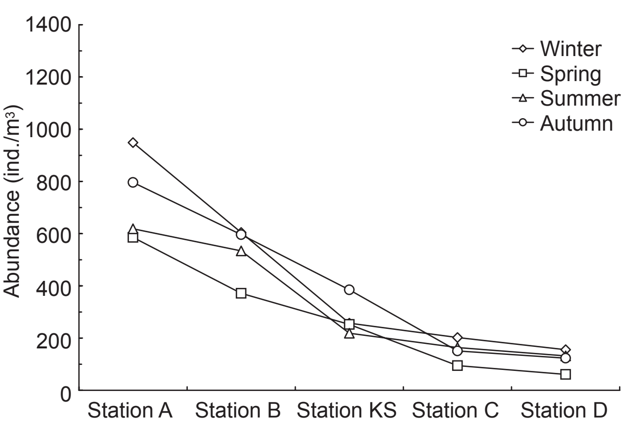

Fig. 3. Seasonal fluctuations in the abundance of planktonic copepods collected at the various stations in 2005.

Particularly, *Cal. sinicus* reached a maximal Y value of 0.1744 in spring, among all species throughout the year. Its geographical distribution pattern of seasonal abundance clearly fluctuated (Fig. 5). High abundances occurred in the shelf region during autumn, winter, and spring, with extreme values of 126 and 102 ind./m^3 at station A in autumn and winter, respectively. There were a few individuals at stations A, B, KS, and C in summer. *Calanus sinicus* never occurred at station D throughout the year.

None of the dominant species was the most abundant in all seasons. Actually, the supremacy of these dominant species fluctuated seasonally. According to the replacement rates between 2 adjoining seasons in table 4, values of the winter-spring, spring-summer, summer-autumn, and autumn-winter interchanges were 55.6%, 33.3%, 25.0%, and 61.9%, respectively.

Biodiversity parameters

According to seasonal variations in 2 important indices of copepod species diversity at each station (Fig. 6), the number of species tended to show significant differences among seasons (Table 3, ANOVA result: $p < 0.05$, $F = 13.78$) and an increasing trend from coastal waters to the open sea ($p < 0.05$, $F = 4.27$), except for an irregular condition in winter. The total number of species in each season ranged between 76 and 107. Presenting a similar geographical trend as the number of species, the Shannon-Wiener index ranged from 3.41 at station KS in spring to 5.13 at station D in autumn. The results of ANOVA (Table

Table 3. The results of 2-way analysis of variance without replication on the abundance, number of species, and diversity index (Shannon-Wiener index) respectively. The critical values are for alpha = 0.05

Item	Source of variation	SS	*d.f.*	MS	*F*	*p*-value	*F*-crit
Abundance	Season	80941	3	26981	4.8945	0.0190	3.4903
	Station	1113544	4	278386	50.5017	2.07E-07	3.2592
Number of species	Season	960	3	320	13.7846	0.0003	3.4903
	Station	397	4	99	4.2733	0.0223	3.2592
Diversity index	Season	1.1978	3	0.3993	7.3594	0.0047	3.4903
	Station	1.8190	4	0.4547	8.3821	0.0018	3.2592

3) indicated significant differences both among stations ($p < 0.05$, $F = 8.38$) and among seasons ($p < 0.05$, $F = 7.36$).

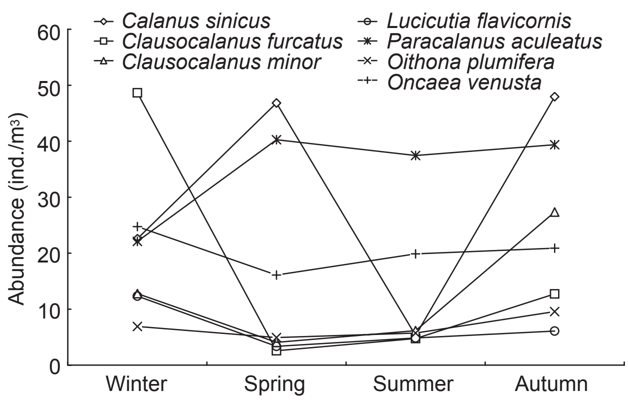

Fig. 4. Seasonal fluctuations in the abundances of the 7 most dominant copepods collected in 2005.

Distributional association

The cluster analysis of season-station associations based on the Jaccard coefficient shows the degree of similarity in the geographical distribution of the copepod faunas in the study area (Fig. 7). There were 2 major groups, i.e., the 1st group dominated containing all C and D samples, while the 2nd group contained A, B, and KS samples; but interestingly, there was 1 exception to this pattern of winter A and B which grouped together with C and D. That is, spatial differences were lower and the faunal composition resembled the C-D fauna during winter. KS grouped normally together with A and B, but winter KS was another exception. This sample could not be grouped in either of the 2 major groups. Briefly, spatial separation clearly existed between the shelf and open-ocean faunas, but not during winter.

Table 4. The seasonal dominance (Y) and abundance (X, ind./m^3) of dominant species of planktonic copepods in 2005; # denotes Y < 0.02 and / denotes species was not found. The data are for all stations together

	Winter		Spring		Summer		Autumn	
Dominant species	Y	X	Y	X	Y	X	Y	X
Calanus sinicus Brodsky, 1962	0.0342	22.59	0.1744	46.83	0.0211	5.29	0.0996	47.95
Clausocalanus furcatus (Brady, 1883)	0.1002	48.65	0.0209	2.57	0.0253	4.74	0.0344	12.72
Clausocalanus minor Sewell, 1929	0.0262	12.77	0.0362	4.06	0.0415	6.16	0.0776	27.35
Lucicutia flavicornis (Claus, 1863)	0.0672	12.33	0.0399	3.35	0.0387	4.85	0.0417	6.09
Paracalanus aculeatus Giesbrecht, 1888	0.0615	22.10	0.1665	40.26	0.1308	37.44	0.1018	39.37
Oithona plumifera Baird, 1843	0.0285	6.91	0.0393	4.93	0.0331	5.73	0.0359	9.56
Oncaea venusta Philippi, 1843	0.0923	24.75	0.0590	16.09	0.0724	19.87	0.0659	20.89
Acrocalanus gibber Giesbrecht, 1888	#		0.0418	5.77	0.0373	7.34	0.0278	8.04
Acrocalanus gracilis Giesbrecht, 1888	#		0.0369	10.51	0.0394	10.95	0.0410	13.81
Acartia negligens Dana, 1849	0.0661	11.28	#		#		0.0293	11.83
Clausocalanus farrani Sewell, 1929	#		#		0.0352	10.18	0.0388	12.80
Paracalanus parvus (Claus, 1863)	#		0.0498	8.82	0.0570	11.93	#	
Temora discaudata (Giesbrecht, 1889)	/		#		0.0605	25.09	0.0300	11.74
Temora turbinata (Dana, 1849)	#		#		0.0478	18.00	0.0205	6.09
Oithona setigera (Dana, 1849)	0.0547	14.95	0.0209	1.29	#		#	
Acartia danae Giesbrecht, 1889	0.0228	2.58	#		#		#	
Undinula vulgaris (Dana, 1849)	#		#		0.0457	13.70	#	
Clausocalanus arcuicornis (Dana, 1849)	0.0387	16.87	#		#		#	
Clausocalanus mastigophorus (Claus, 1863)	0.0672	14.10	#		#		#	
Pleuromamma gracilis (Claus, 1863)	0.0228	6.40	#		#		#	
Corycaeus (*Agetus*) *typicus* (Kroyer, 1849)	#		#		#		0.0220	4.12
Corycaeus (*Corycaeus*) *speciosus* Dana, 1849	0.0228	2.71	#		#		#	
Oncaea mediterranea Claus, 1863	0.0273	6.82	#		#		#	
Numbers of species	15		11		14		14	

DISCUSSION

Abundances of copepods vary greatly in coastal and shelf regions of the world (Mauchline 1998). For instance, the average annual abundance ranged from 150 to 2000 ind./m^3 in a 53 m water column sampled vertically by a 200 μm mesh net in the North Sea (Roff et al. 1988). Fluctuations of average seasonal abundances in this study ranged from 737 ± 168 ind./m^3 at station A to 118 ± 40 ind./m^3 at station D, and thus, apparently, showed a decreasing trend seaward. This trend is probably due to the high levels of nutrients carried by the freshwater runoff that, therefore, enrich the shelf waters (Lalli and Parsons 2000). Similar trends were found by Meng et al. (1996), Yang et al. (1999a), and Xu et al. (2003). On the other hand, general fluctuations in the number of species at the various stations indicated an increasing trend seaward (Fig. 6, ranging 29-62), and thus conformed the results (ranging 21-64) of Shih and Chiu (1998).

In marine planktonic copepod communities, different numbers of species and abundances occur in different environments. Diversity, mostly shown as the univariate Shannon-Wiener index based on the relative values of numbers of species and abundances, generally decreases from neritic coastal waters to inner regions such as enclosed bays and estuaries while the corresponding biomass tends to increase (Sautour and Castel 1993). However, copepod diversity in the present study also exhibited an increasing trend from coastal waters to the open sea, and conformed to the results of Kang and Hong (1995), Shih and Chiu (1998), and Yang et al. (1999b). The relatively low value of the Shannon-Wiener index at station KS in spring was clearly due to the presence of a large amount of *Cal. sinicus* and *Paracalanus aculeatus* (24.8% and 24.3% in numerical abundances, respectively). A similar phenomenon was observed by Yang et al. (1999b) at their station S1-4 in spring and their stations S2-4 and S2-5 in autumn, caused by the most dominant species, *Temora turbinata* (e.g., 35% in numerical abundance at S1-4). Stable seasonal variations of high copepod diversity expressed by the Shannon-Wiener index (which varied from 4.51 to 4.91) were observed at station C. This was possibly due to the relatively homogeneous hydrographic conditions throughout the year (Fig. 2).

Of the species composition, 80.3% (53 of 66) of the calanoid species collected from Kuroshio waters (stations C and/or D) were common to species in the 200-0 m samples collected with the same net from Kuroshio waters off eastern Taiwan

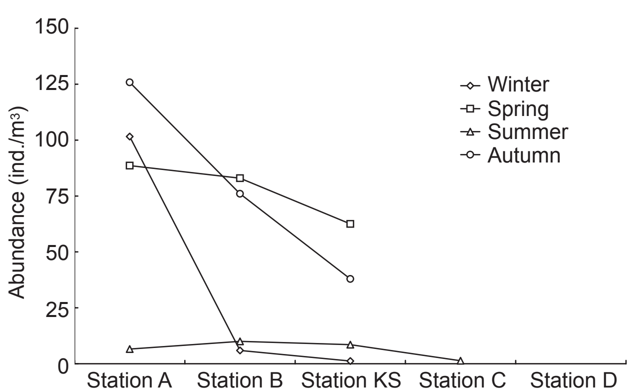

Fig. 5. Seasonal fluctuations in the abundances of *Calanus sinicus* at the various stations in 2005.

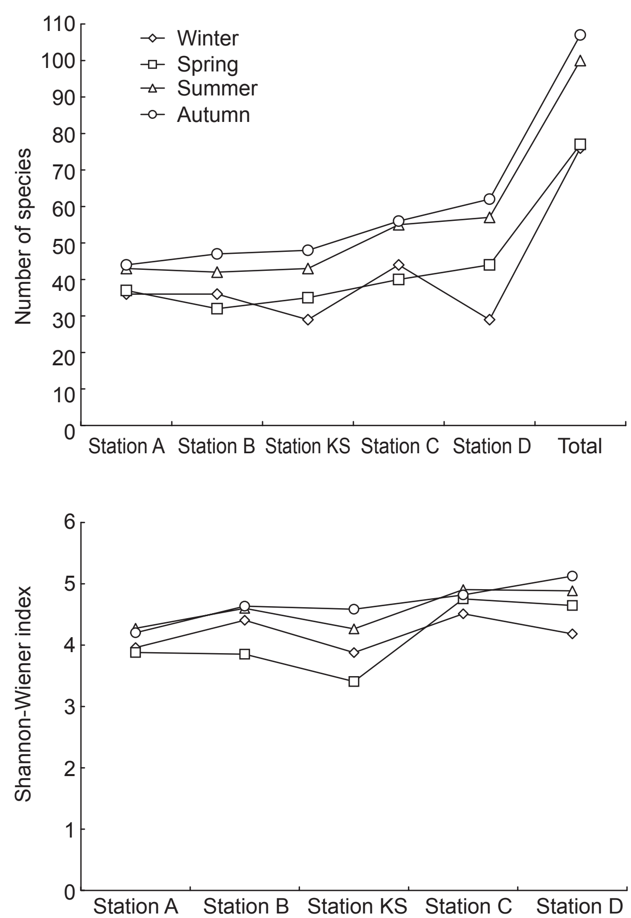

Fig. 6. Number of species and Shannon-Wiener index of planktonic copepods collected at the various stations in the 4 seasons of 2005.

(the upstream section of this study) by Hsiao et al. (2004), implying a small annual variation in the calanoid species composition in these waters. Moreover, the 100 species found in our sample in summer was higher than the 90 species collected in surface waters in the southeastern Taiwan Strait in June (at 34 stations bounded roughly by 22°15'N-24°00'N and 118°50'E-120°20'E) by Lo et al. (2004). This could reflect a stronger influence of the Kuroshio Current on northeastern waters off Taiwan where more species were usually found. The result in the present study of there being more species in winter was also obtained by Lo et al. (2001). Nine species only occurred at stations C and D, three of these, i.e., *Calocalanus pavo*, *Copilia lata*, and *Cop. mirabilis*, are Kuroshio warm-water species according to Chihara and Murano (1997); another species, *Pleuromamma xiphias*, was classified as an indicator species of the Kuroshio by Huang et al. (2000); and the remaining 5 species, *Oithona robusta*, *Corycaeus* (*Corycaeus*) *clausi*, *Corycaeus* (*Urocorycaeus*) l*ongistylis*, *Lubbockia squillimana*, and *Oncaea media*, are also warm-water species distributed in the epi- and mesopelagic zones of oceans around the world (Chihara and Murano 1997).

The replacement rates in this study ranged 25.0%-61.9%, were lower than the 66.7%-88.9% rates in Xu et al. (2004), and were closer to the range of 36.4%-75.0% in Yang et al. (1999b). However, 5 species, *Cal. sinicus*, *Undinula vulgaris*, *Acrocalanus gibber*, *Temora discaudata*, and *T. turbinata*, were common in the waters investigated by these 3 studies. The dominant species composition in this study obviously differed from that in the open sea of the subtropical circulation zone east of Taiwan reported by Lin (2007). There was only 1 common species, i.e., *Undinula vulgaris*, that was dominant in both studies.

Kang and Hong (1995) reported 4 major clusters of oceanic warm-water calanoid copepods from Korean waters, which were grouped on the basis of Jaccard's similarity index. The seasonal distribution variation of each cluster was closely related to the strength of the Tsushima Current. They, therefore, suggested that the regime of the Tsushima Current can be traced by examining the biological characteristics of the copepods in those waters. Similarly, 2 major faunal areas recognized by cluster analysis in the present study also illustrate a geographical distribution of the copepod community influenced by the Kuroshio Current. Station KS was shown to have a closer association with shelf fauna during spring, summer, and autumn, but with the Kuroshio fauna during winter (Fig. 7). This result coincides with those of hydrographic surveys by Chern and Wang (1994) and Lee and Hu (1998), who indicated that the Kuroshio axis moves toward the shelf during winter

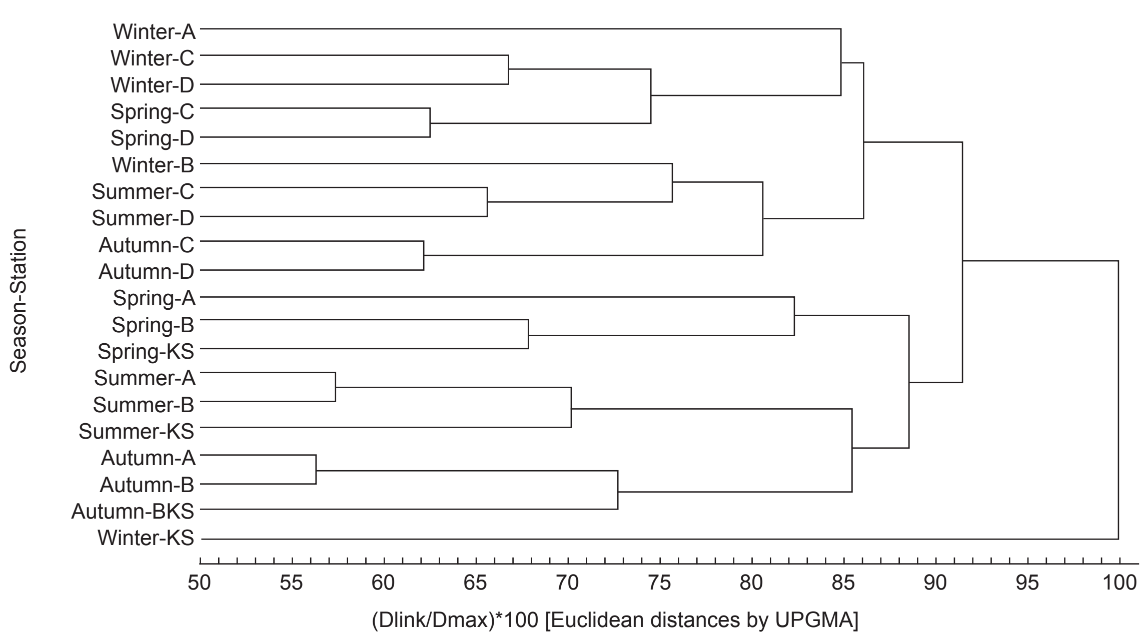

Fig. 7. Dendrogram of season-station associations based on the Jaccard coefficient using UPGMA, and showing the degree of relative dissimilarity in copepod faunas among seasons and stations in 2005.

and shifts further offshore during summer.

Calanus sinicus is one of the key species in the Yellow Sea and East China Sea, comprising about 85% of the total zooplankton biomass in the Yellow Sea in spring (Liu et al. 2003). All stages of *Cal. sinicus* can be found throughout the year, and the peak of abundance usually occurs in spring in response to the rising water temperatures and a richer food supply (Chang and Sun 2001, Wang et al. 2002, Xu et al. 2004). A recent systematic investigation of seasonal fluctuations in the horizontal distribution of this widely distributed species in the East China Sea by Xu et al. (2004) showed that there was a certain area of high abundance in the southern region during winter. There was a sharp increase in abundance during spring which reached a peak during summer, but was mainly concentrated in the northern region where the water temperature was relatively lower, and the abundance decreased to a low level throughout the southern region during autumn. The seasonal fluctuation pattern of *Cal. sinicus* abundance in the present study closely matched that in the southern region of the East China Sea according to Xu et al. (2004), especially the great abundances at stations A and B during spring and autumn, where only a few individuals were found during summer. The fairly steady countercurrent on the inshore side of the Kuroshio off northeastern Taiwan observed by Chuang et al. (1993) is supposedly a transporting current for this non-indigenous population into Ilan Bay. That is, *Cal. sinicus* could be an indicator species of the countercurrent of the Kuroshio, a continuation of remote origin which rubs the slope, spills over the shelf edge, and then feeds back to the ocean in the northeastern waters of Taiwan (Chuang et al. 1993). Furthermore, the upper thermal range for reproduction by *Cal. sinicus* is about 23°C, indicating that the population cannot be maintained in the warm Kuroshio Current, except at great depths (Uye 2000). This is why this species prospers in the shelf region where the water temperatures are ideal in winter, spring, and autumn (Fig. 2), but are lethally high in the upper water column during summer. A previous study by Shih and Chiu (1998) indicated that the small numbers of *Cal. sinicus* were expatriates at the Kuroshio stations (just downstream of our study, where the numerical percentage was < 4.5%), while at other stations in the southern East China Sea, it was dominant (with numerical percentage ranging 6.7%-52.3%). Three individuals found at station C in summer were probably also expatriates (with a numerical percentage of 0.8%) which inhabited deeper water, where the temperature was still suitable for *Cal. sinicus*.

Acknowledgments: This study was supported by a research grant (94AS-9.2.1-AI-A2) from the Council of Agriculture, Executive Yuan, Taiwan. We thank Captain Wang and the crew of the research vessel *Hai-Chien*, who helped us collect the samples and hydrographic data. Mr. Y.M. Chen of the Marine Fisheries Division, Fisheries Research Institute, is thanked for handling the pre-processing modules of the CTD data.

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