Zoological Studies **43**(2): 454-463 (2004)

Zoological Studies

Temporal and Spatial Variations in the Species Composition, Distribution, and Abundance of Copepods in Kaohsiung Harbor, Taiwan

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(Accepted March 31, 2004)

Wen-been Chang and Lee-shing Fang (2004) Temporal and spatial variations in the species composition, distribution, and abundance of copepods in Kaohsiung Harbor, Taiwan. *Zoological Studies* **43**(2): 454-463. The composition, distribution, and abundance of copepods collected from surface waters of Kaohsiung Harbor were examined. Copepods were collected quarterly at 7 designated stations from Jan. 1999 to Oct. 2001. In the inner harbor, 58 species in 28 families of copepods were recorded; the average abundance was 1.45×10^5 individuals/1000 m^3. The 7 dominant species, which made up 66.6% of the overall collection, were *Temora turbinata* (18.5%), *Acartia erythraea* (16.4%), *Paracalanus parvus* (16.2%), *P. aculeatus* (6.4%), *Pseudodiaptomus marinus* (4.3%), *A. negligens* (2.7%), and *A. spinicauda* (2.1%). While *A. erythraea* and *P. parvus* were abundant at the inner harbor stations, *T. turbinata* was found mostly at one of the 2 outer harbor stations. Two-way ANOVA analysis of total abundance showed a significant seasonal effect ($F = 6.83$, $p < 0.01$), but not between stations ($F = 0.24$, $p > 0.05$). Multidimensional scaling (MDS) analysis of each cruise revealed an abundance difference with a low in July and a high in Apr. It also distinguished 1999 as a low abundance year. The range of the species diversity index (H') for each cruise was 1.21 to 3.79, with an average of 2.78 ± 0.59. The species diversity index was generally similar between stations, but was lower in Jan. and higher in Oct.. http://www.sinica.edu.tw/zool/zoolstud/43.2/454.pdf

Key words: Copepods, Species composition, Seasonal variation, Kaohsiung Harbor.

Kaohsiung Harbor, located on the southwestern coast of Taiwan, is the largest harbor on the island with a depth of less than 16 m. It is 12 km long in a north-south direction with an average east-west width of 1500 m. The total area is approximately 18 km^2. Due to industrial development and population growth in Kaohsiung City in the 3rd quarter of the 20th century (Yang 1995), a large quantity of waste water made its way into the harbor, polluting it to a level that endangered its aquatic organisms. In 1987, the city completed construction of a major wastewater treatment facility. Since then, high diversities of aquatic animals, such as shrimp, mollusks, mullet larvae and young fishes, have reappeared in the harbor (Hwang 1996). However, information on the copepod in the harbor is still unavailable.

In most marine ecosystems, copepods are the dominant zooplankton (Beers et al. 1980, Uye et al. 1996). They play a key role in the marine plankton food web by affecting primary productivity on the one hand and providing food for animals in higher trophic levels on the other. For instance, their nauplii are the dominant prey of *Boops boops* and supplementary prey of *Diplodus sargus*, both sparid fishes, in Monterey Bay, CA (Sanchez and Norbis 1997). Nauplii of cyclopoids (*Oithona* sp.) and calanoids (mainly of *Paracalanus*) are numerically the most important food items in the gut contents of the larvae of anchovy *Engraulis japonicus* found in Toyama Bay, Japan (Hirakawa et al. 1997). In the Sea of Japan, while young larvae of *Sebastes schlegeli* feed mainly on copepod nauplii, older ones prey on calanoid copepodites and the cladoceran, *Evadne nordmanni* (Nagasawa and Domon 1997). Also, the gut contents of the larvae of anchovy (*E. japonicus*) caught in the Yellow Sea were found to contain as high as 42%

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copepod eggs and 34% nauplii (Zhang et al. 2002). Copepods are known to consume large quantities of bacteria (Webber and Roff 1995), phytoplankton (Calbet et al. 2000), and organic detritus (Steinberg et al. 1998).

The purpose of this study was to determine the species composition and abundance of the copepod population in Kaohsiung Harbor, as well as spatial and temporal variations in species composition, distribution, and abundance of copepods within the harbor.

MATERIALS AND METHODS

Seven sampling stations were set up in Kaohsiung Harbor: 5 inner harbor stations (stns. 1~5) and 2 stations close to the harbor entrance (stns. 6, and 7) (Fig. 1). A series of 12 quarterly samples representing 4 seasons in 3 yr were collected from Jan. 1999 to Oct. 2001 at flood and ebb tides. Various environmental parameters were also measured at each station. Water samples were collected using metal-free Van-Dorn bottles. Immediately after collection, water samples were analyzed for temperature, salinity, pH, and dissolved oxygen. After that, the water samples were stored in a refrigerator at 4°C and then brought back to the laboratory for analysis of biological oxygen demand (BOD5), chemical oxygen demand (COD), nutrients (e.g., nitrite, nitrate and phosphate), and heavy metals (Cu, Pb, Zn, Fe, Hg, Cr, etc.) (Hung 1986, Pai and Yang 1990a b). The water sample used for the analysis of phytoplankton abundance was filtered through an MFS membrane filter with a 0.45 μm pore size. Zooplankton samples were collected by hauling a NORPAC net, (330 μm mesh size, 45 cm mouth diameter, and 180 cm length), with a flow meter (Hydro-Bio) suspended in the middle of the mouth of the net. Hauls were towed for 5 min at a speed of approximately 1 knot. Because most stations were located in shallow waters, zooplankton samples were collected by a horizontal tow, 1 m below the surface (Herman and Dapolito 1985). Plankton samples were immediately fixed in 5% formalin. Species identification and enumeration of preserved samples were carried out in the laboratory. The abundance of zooplankton was expressed in number of individuals per 1000 m^3 of water. After measuring the total and prosome lengths, specimens were quickly washed with ammonium formate and distilled water over a vacuum filter (Gooding 1957, Pearre 1980). They were then placed in pre-weighed aluminum foil pans, which were dried at 500°C and weighed on a METTLER UMTZ AE-240 microbalance to 0.1 μg, and dried at 60°C for 48 h (Harris and Paffenhöfer 1976). Samples were then cooled in a desiccator and allowed to equilibrate to a constant weight. They were burned in a muffle furnace at 500°C (Edmondson and Winberg 1971) and weighed to determine ash content.

Temporal and spatial variations in the abundance and distribution of copepods were analyzed using two-factor ANOVA without replication, with stations and seasons as major factors. Variations in copepods included species composition and total abundance. Differences between spatial and temporal variances were tested for statistical significance. Species contributing to dissimilarities between stations and between seasons were checked by percentage similarities (SIMPER, Clarke 1993). The similarity in copepod species composition among stations and seasons was

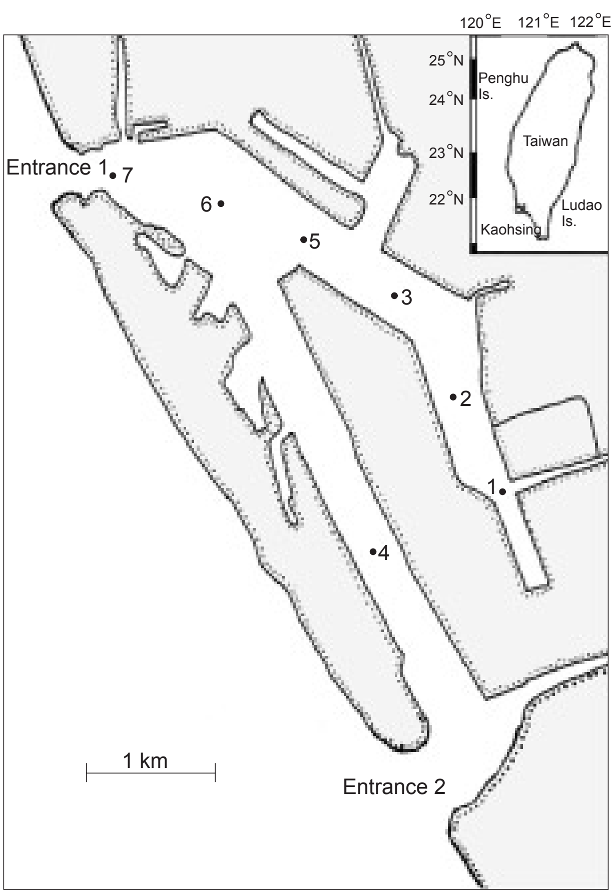

Fig. 1. Map of sampling locations in Kaohsiung Harbor, Ludao (Green Is.; 21°95'N, 120°98'E), and the Penghu (23°31'N, 119°39'E), Taiwan.

determined by non-metric cluster analysis and multidimensional scaling (MDS). The software package, PRIMER, developed by the Plymouth Marine Laboratory (Clarke and Warwick 1994) was used.

RESULTS

Hydrographic conditions

Surface temperature showed seasonal variations, being higher in the summer at 29.6 ± 0.7°C (28.6~31.1°C) and lower in the winter at 25.1 ± 0.9 °C (24.2 ~26.3°C). Temperatures also varied with phases of the tide, being higher at flood tides and lower at ebb tides. Lower salinities were recorded at stations in the inner harbor (stns. 1, and 2), and higher salinities at stations located closer to the harbor entrance (stns. 6, and 7). Salinities were higher for ebb than flood tides, and they were higher in winter (33.0‰ ± 1.8‰) than in fall (24.1‰ ± 6.9‰). pH values were lower at stations in the inner harbor (7.3 ± 0.8) compared to those closer to the harbor entrance (7.9 ± 0.3), and in general, were lower at ebb tide. They were higher in winter than in summer. Dissolved oxygen values were lower at stations in the inner harbor (< 0.1~4.0 mg/l) than those close to the entrance of the harbor (3.3~7.1 mg/l). They were lower at ebb than flood tides, and higher in winter than in summer. Surface chlorophyll-*a* values (μg chl. *a*/l) at stns. 3 and 5 (0.71 ± 0.46 μg chl. *a*/l) which are inner harbor stations were lower than those of stations closer to the entrance of the harbor (4.12 ± 2.46 μg chl. *a*/l). A bloom of *Skeletonema costatum* occurred in summer and autumn and was concentrated at stations in the inner harbor; and in winter, the dominant diatom, *Chaetoceros curvisetus*, was washed into the harbor from an offshore area with the flood tides and was concentrated at stations close to the harbor entrance.

Temporal and spatial variations in copepods

Copepod species composition and relative abundances of species in Kaohsiung Harbor are given in table 1. In the inner harbor, 58 species in 28 families were found; the numerical abundance of total copepods varied from 8.17 x 10^5 to 8.56 x 10^5 individuals/1000 m^3, with a mean of (1.45 ± 1.77) x10^5 individuals/1000 m^3. The lowest abundance was found in Jan. 1999 and the highest in Apr. 2000. In general, *Temora turbinata* (18.5% of

Table 1. Copepod species and their relative abundance in the Kaohsiung Harbor, during Jan. 1999 to Oct. 2001

Species	Relative abundance (%)
Temora turbinata	18.5
Acartia erythraea	16.4
Paracalanus parvus	16.2
Paracalanus aculeatus	6.4
Pseudodiaptomus marinus	4.3
Acartia negligens	2.7
Acartia spinicauda	2.1

< 2%

Acartia pacifica	*Centropages furcatus*	*Euchaeta indica*	*Oithona* sp.
Acartia sp.	*Canthocalanus pauper*	*Euchaeta* sp.	*Oncaea* sp.
Acrocalanus gibber	*Centropages tenuiremis*	*Euterpina acutifrons*	*Oncaea venusta*
Acrocalanus gracilis	*Centropages* sp.	*Labidocera euchaeta*	*Pontellopsis yamadae*
Acrocalanus longicornis	*Clausocalanus furcatus*	*Labidocera minuta*	*Pseudodiaptomus marinus*
Acrocalanus monachus	*Corycaeus catus*	*Labidocera* sp.	*Rhincalanus rostrifrons*
Acrocalanus sp.	*Corycaeus flaccus*	*Lucicutia flavicornis*	*Sapphirina* sp.
Calanopia sp.	*Corycaeus speciosus*	*Macrosetella gracilis*	*Scolecithricella* sp.
Calanus sp.	*Corycaeus* sp.	*Mecynocera clausi*	*Scolecithrix* sp.
Calocalanus pavo	*Diacyclops* sp.	*Microsetella* spp.	*Temora discaudata*
Calocalanus pavoninus	*Subeucalanus pileatus*	*Oithona nana*	*Temora stylifera*
Candacia sp.	*Subeucalanus subcrassus*	*Oithona plumifera*	*Tortanus forcipatus*
Centropages calaninus	*Subeucalanus* sp.	*Oithona similis*	

the total copepod abundance), *Acartia erythraea* (16.4%), and *Paracalanus parvus* (16.2%) were the dominant species, followed by *P*. *aculeatus* (6.4%), *Pseudodiaptomus marinus* (4.3%), *A*. *negligens* (2.7%), and *A*. *spinicauda* (2.1%); all had a mean abundance of greater than 2% of the total copepod abundance. These 7 species constituted 66.6% of the total copepod abundance of this study. The prosome length was greatest in *A*. *erythraea*, followed by *T*. *turbinata* and *P*. *parvus*; the weight was greatest in *T*. *turbinata*, followed by *A*. *erythraea* and *P*. *parvus* (Table 2). Analyses of temporal and spatial variations revealed a higher abundance for *A*. *erythraea* and *P*. *parvus* at stations in the inner harbor and for *T*. *turbinata* in the outer harbor at stn. 4 (Fig. 2). Two way ANOVA showed that season had a significant effect (F = 6.83, $p < 0.01$) on abundance (Table 3), but not on stations (F = 0.24, $p > 0.05$). Multidimensional scaling (MDS) analysis for each cruise revealed that lower abundances occurred in July and higher

Table 2. Mean body length and body weight of dominant copepod in the Kaohsiung Harbor

Species \ Lenght and weights	Prosome length (mm)	Dry weight (μg)	Ash free dry weight (μg)
Temora turbinata	0.77 ± 0.06	13.9 ± 1.9	7.0 ± 0.9
Acartia erythraea	0.96 ± 0.06	5.6 ± 0.8	2.3 ± 0.1
Paracalanus parvus	0.60 ± 0.03	4.3 ± 0.5	1.9 ± 0.6

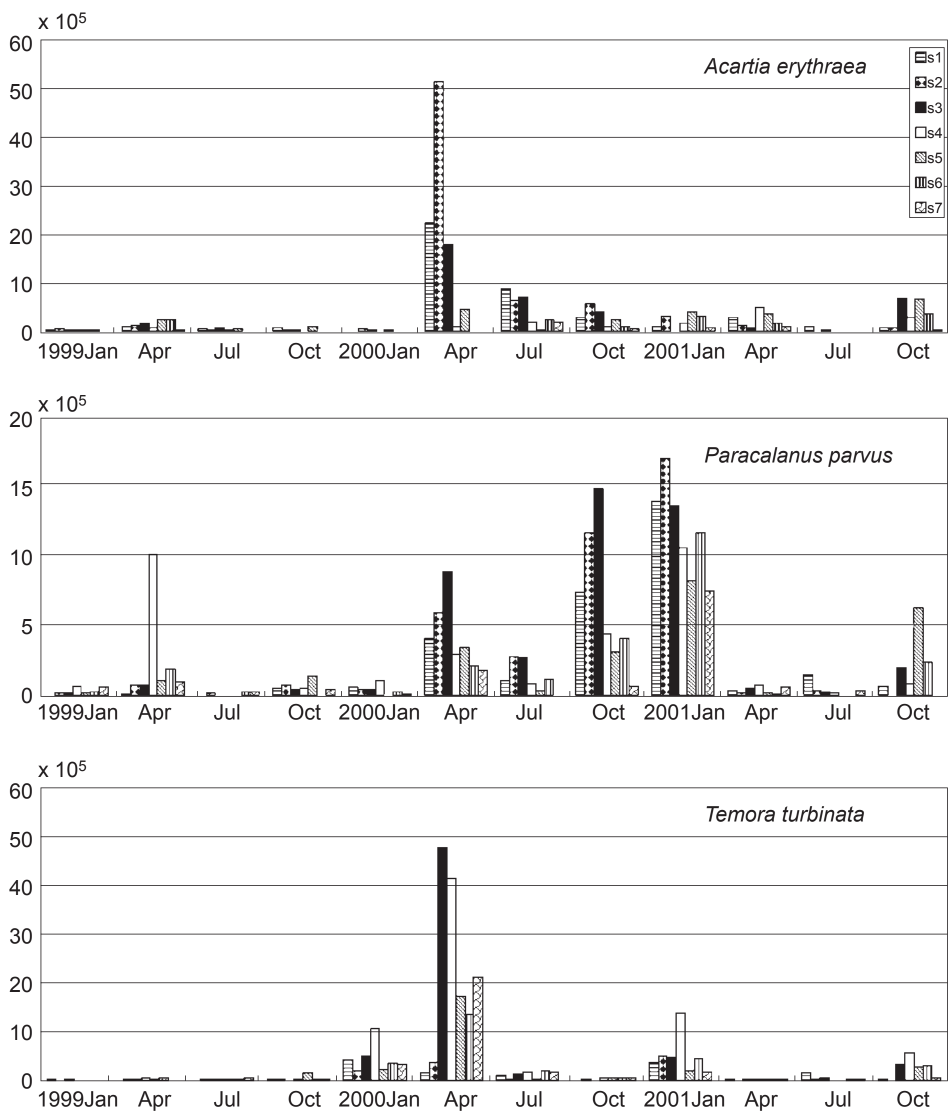

Fig. 2. Temporal and spatial variations in abundances (individuals/1000 m^3) of the 3 dominant copepods in Kaohsiung Harbor, Taiwan.

ones in Apr. It also separated the lower-abundance year (1999) from the higher abundance year (2000). The species diversity index (H') for each cruise ranged from 1.21 to 3.79, with a mean of 2.78 ± 0.59. The species diversity index was generally similar between stations, but it was lower during Jan. and higher during Oct. Cluster analysis (Fig. 3) of copepod composition showed a high affinity between stations, and varied with different seasons. Correlation coefficients were calculated with an attempt to identify any possible correlation between dominant copepods and phytoplankton, and parameters of water quality in Kaohsiung Harbor (Table 4). However, no significant correlations between them were found.

Length-weight relationship of the dominating copepod species

Length-weight relationships for copepodites

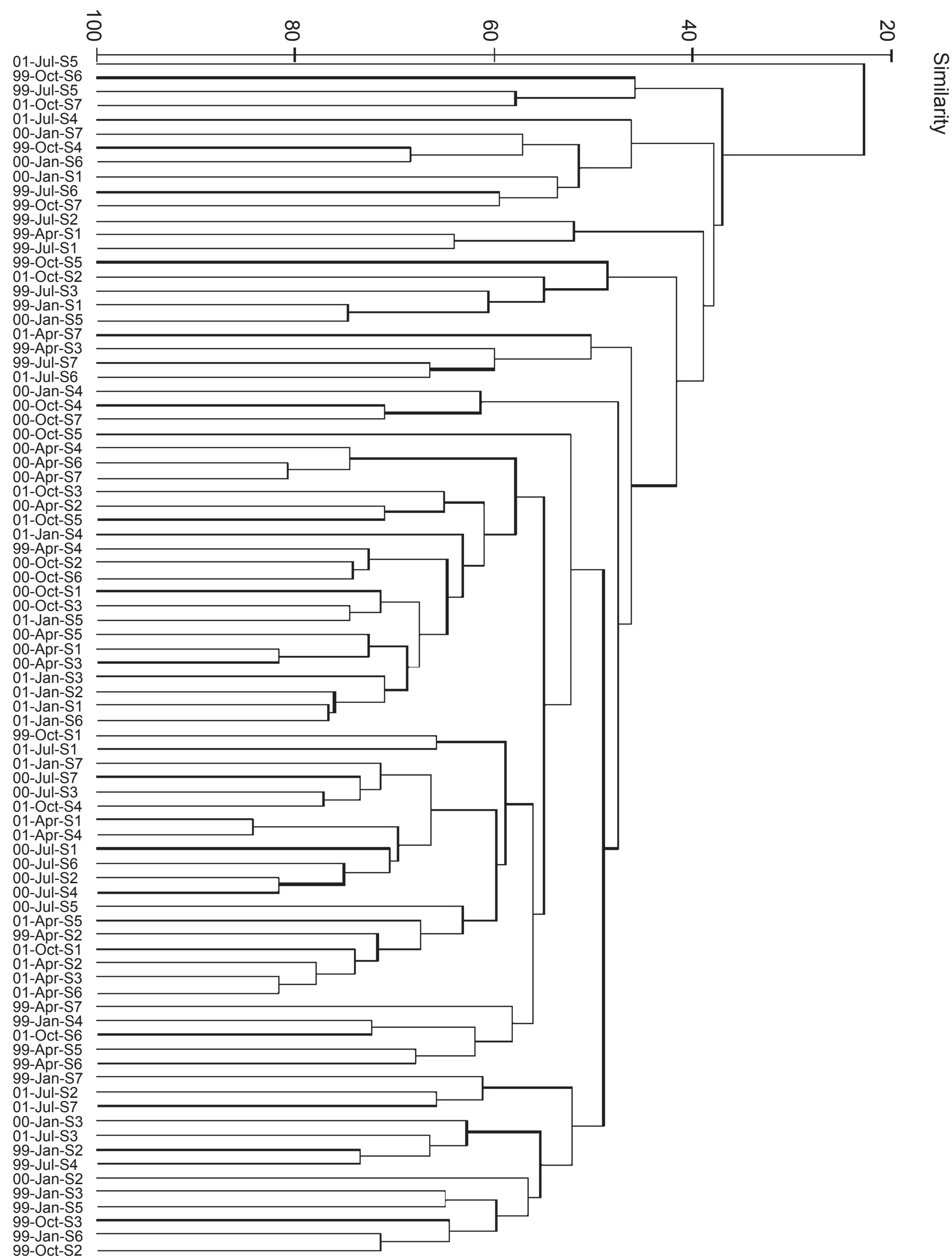

Fig. 3. Cluster analysis of the temporal and spatial variances of copepod species in Kaohsiung Harbor.

and adults of *Acartia erythraea*, *Paracalanus parvus*, and *Temora turbinata* are shown in table 2. Linear regression equations for prosome length (PL) vs. dry weight (DW) (Fig. 4), and vs. ash-free dry weight (AFDW) were calculated from 50 samples as follows:

A. erythraea: y (DW) = 8.2491 x (PL) - 2.3671 R^2 = 0. 6932;
y (AFDW) = 1.5782 x (PL) + 0.82 R^2 = 0.5097;
P. parvus: y (DW) = 15.096 x (PL) - 4.8095 R^2 = 0.7922;
y (AFDW) = 14.41 x (PL) - 6.7998 R^2 = 0.5863;
T. turbinate: y (DW) = 25.687 x (PL) - 5.8568 R^2 = 0.7424; and
y (AFDW) = 10.128 x (PL)- 0.8065 R^2 = 0.537.

DISCUSSION

During the past several decades, industrialization and urbanization have accelerated in Taiwan. They have been accompanied by an increase in heavy metal pollution augmented with organic pollution in and around coastal environments (Hung 1989, Lee and Fang 1997, Han et al. 1998, Lee et al. 2000, Hung et al. 2001). Heavy metals can affect the life processes (e.g., feeding, metabolism, growth, and reproduction) of zooplankton (Steele and Frost 1977, Reeve et al. 1977). *Acartia clausi* showed decreased feeding capacity and increased respiratory rates when Cr concentrations were increased, and the change was more pronounced in the summer generation than in the winter or autumn generation (Moraitou-Apostolopoulou and Verriopoulos 1982). Copper is known to cause prolongation of maturation time and reduction in offspring production in *Tisbe holothuriae*. These effects positively increased in proportion to the Cu concentration, but were not statistically significant (Moraitou-Apostolopoulou et

Table 3. Species diversity of different stations at different seasons in the Kaohsiung Harbor, and result of two-way ANOVA analysis of temporal and spatial variation of species diversity

Season \ Station	S1	S2	S3	S4	S5	S6	S7
1999 Jan	2.42	2.49	2.33	3.30	3.13	2.84	2.57
Apr	2.08	3.30	2.60	3.05	3.34	3.55	2.98
July	2.16	2.75	2.41	2.85	3.39	2.92	3.24
Oct	3.41	3.12	3.24	1.99	2.84	3.22	3.13
2000 Jan	1.69	2.83	2.04	1.90	1.61	1.38	1.47
Apr	2.43	1.92	2.03	1.21	2.56	2.36	2.11
July	2.68	2.37	2.86	3.30	3.20	2.84	2.99
Oct	2.90	2.81	2.94	3.75	3.79	3.33	3.38
2001 Jan	3.17	3.42	3.12	3.49	3.74	3.25	2.77
Apr	2.88	2.58	2.99	2.87	2.53	2.80	3.37
July	3.39	2.52	3.04	2.73	1.25	2.14	2.40
Oct	3.52	2.93	3.15	2.89	3.52	2.99	2.79

Source	DF	SS	MS	*F* value	Probability
Season	11	15.02	1.365829	6.83**	$p < 0.01$
Station	6	0.28	0.047193	0.24	
Error	66	13.19	0.19987		
Total	83	28.50	0.343358		

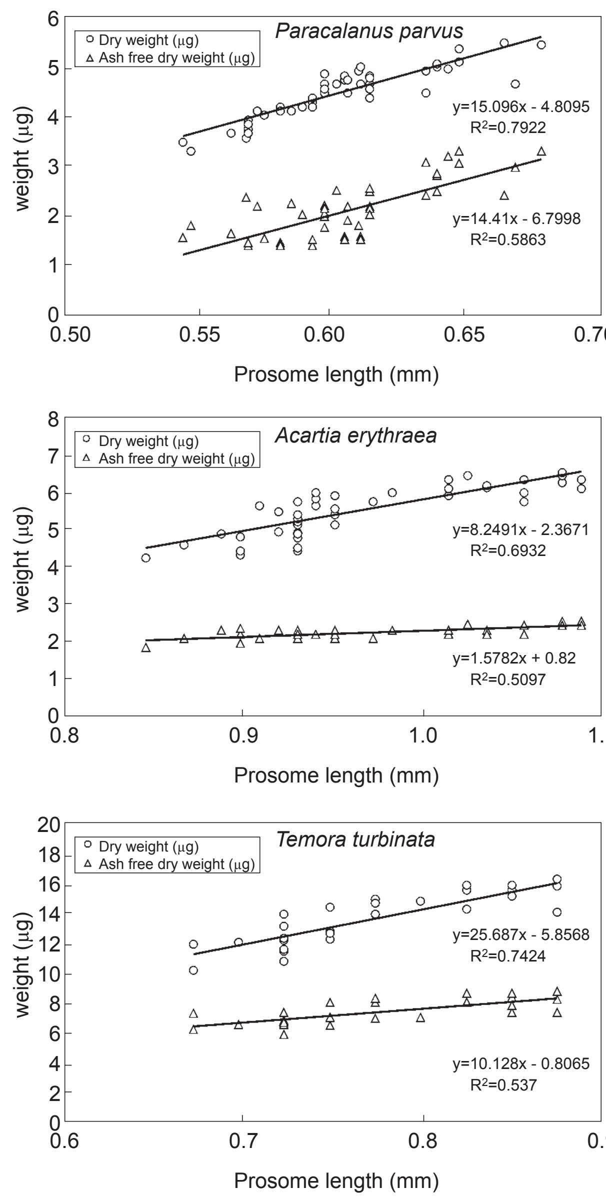

Fig. 4. Length-weight relationships of *Acartia erythraea*, *Paracalanus parvus*, and *Temora turbinata*: prosome length vs. dry weight (open circles); prosome length vs. ash free dry weight (open triangles).

al. 1983). Ingestion rates of *A. spinicauda* and *Paracalanus aculeatus* were not affected by Zn concentration in food particles (Wang et al. 2001). As a result of our investigation, we found that correlation coefficients between the abundance of the 3 dominant copepod species and heavy metal concentrations were not significant (Table 4).

According to website data of the Kaohsiung Harbor Bureau (available at http:// www.khb.gov.tw), the maximum speed of the current in the Harbor is 80 cm/s , calculated by tachometer and buoy measurer. During flood tides, the current turns northwestward from southeastward. The current speed in ebb tides is faster than that in flood tides. During Aug. 1999, six stations from the 1st to the 2nd entrance were selected to observe off port tides after the 2nd entrance to the harbor was opened. The outward current speed of the harbor was 80 cm/s, and the inward current speed was approximately 50 cm/s, while the speed exceeded 80 cm/s at the harbor entrance. During typhoons or a strong north west winds, tidal currents move more randomly and cause coastal turbulence. For individual organisms, it is important to be able to avoid advection in the water column. Wroblewski (1980) pointed out that *Acartia clausi* may remain in subsurface waters (nearly 10 m in depth) by utilizing current shear, and hence is able to cope with surface advection. In Kaohsiung Harbor, the spring tidal range is 0.85 m, and the neap range is 0.55 m. The average variation in water levels between flood and ebb tides is only 1.1 m. Generally, waves along the coast to the 2nd entrance move in a direction parallel to the wind, whereas to the west and south of the 2nd entrance, they are mostly perpendicular to the coastline. However, based on our investigation of variations in species composition, distribution, and abundance in copepods of Kaohsiung Harbor, we propose that copepods in the harbor are recruited primarily from the coastal waters outside the harbor with occasional replenishment coming through the harbor entrance.

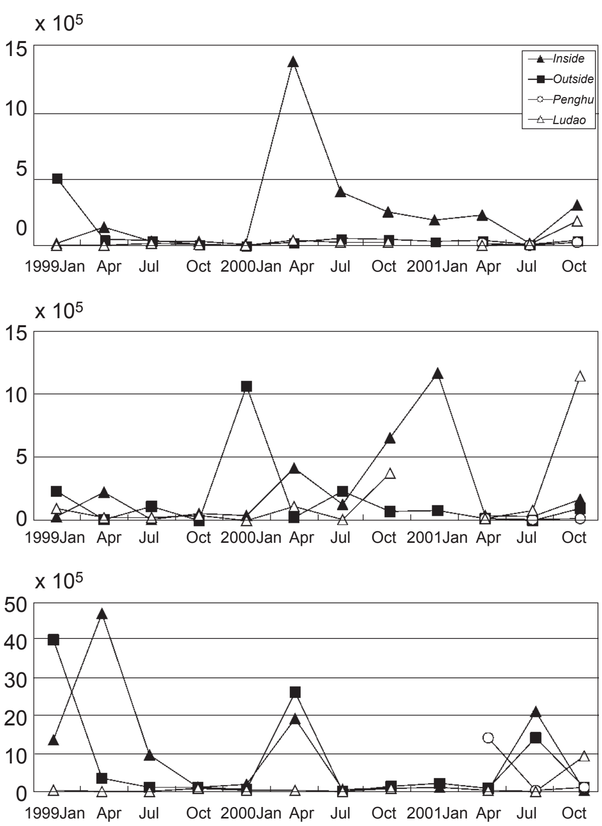

Fig. 5. Comparison of abundances (individuals/1000 m^3) of *Acartia erythraea*, *Paracalanus parvus*, and *Temora turbinata* inside and outside of Kaohsiung Harbor, the Penghu area, and the Ludao (Green Is.) area.

In this investigation, we also found that the abundance of these dominant copepods was significantly affected by season (Fig. 2). Environmental factors such as temperature (Landry 1983, Sande 1987), salinity (Sander 1987, Corvetto et al. 1999), dissolved oxygen (Roman et al. 1983, Escribano and Hidalgo 2000), food (Tang et al. 1994, Escribano and Hidalgo 2000), water circulation, tides (Wroblewski 1980, Sander 1987), and predation (Sander 1987) are known to affect the distribution, species composition, and abundance of copepods. It is also known that the vertical distribution of copepod may be limited by low oxygen (Roman et al. 1983). However, we found no significant relationship between oxygen and abundance of the 3 dominant copepod species in Kaohsiung Harbor (Table 4), which may have been due to the well-mixed water at various stations in the harbor. Differences in mean population abundance at various stations may have been a result of tidal influences. In this study, the abundance and diversity of copepod species were correlated with salinity. Salinity however varied with tidal phase, and it is likely that the total number of organisms collected in the present investigation reflects the lower abundance on ebb or low tides. This has been shown by other studies in which plankton in estuaries is more abundant on flood or high tides than on ebb or low tides (as reviewed in Meredith 1982). Population size of some copepods, e.g., *Oithona davisae* (Uye and Sano 1998), *Paracalanus* sp. (Liang and Uye 1996b), and *Acartia omorii* (Liang and Uye 1996a) in Fukuyama Harbor, the Inland Sea of Japan, and *Labidocera euchaeta* (Lin and

Li 1991) in Xiamen Harbor, Fujian, China, increased with increasing temperature. Nevertheless, in this study we found no significant relationship between temperature and the abundance of the 3 dominant copepod species (Table 4).

Paffenhöfer and Knowles (1978) observed that juvenile *Temora turbinata* younger than CII mainly ingested the diatom, *Skeletonema costatum*. As body weight increased at its advanced stages, the ingestion rate by this copepod of *S. costatum* remained constant, but the feeding rate on the diatoms, *Leptocylindrus danicus* and *Rhizosolenia alata* f. *indica*, increased. The diatoms, *Chaetoceros curvisetus* and *S. costatum*, were the dominant phytoplankton species in Kaohsiung Harbor; they provide abundant food supply to copepods. No correlations being found between the abundance of copepods and the 2 species of phytoplankton suggests that phytoplankton constitute only a portion of the food consumed by copepods. Another possible reason for the absence of significant correlations is perhaps a result of the patchy distribution patterns of plankton, so that copepod and phytoplankton distributions do not match. Valentin et al. (1986) observed a phytoplankton bloom (*Rhizosolenia fragilissima* and *Leptocylindrus danicus*) in conjunction with a large quantity of herbivorous zooplankton (*Paracalanus parvus*). The correlation coefficient of abundance between *T. turbinata* and *S. costatum* was not significant, but it was significant between the former and *L. danicus* in Kaohsiung Harbor (Table 4). The peak of copepod abundance in temperate estuaries mostly appears in spring and early fall, with sporadic changes in abundance in winter. In this study, peaks occurred in early spring, possibly due to the differential seasonal temperature distribution. In general, the water temperature is primarily a result of interactions among seasonal changes, hydrographic factors, sudden changes in weather, floods, or rainfall, and other geographical features. In dynamic and heterogeneous habitats, consumers and resources are usually not present in fixed ratios, and consequently, correlation analyses may lead to non-significant results (Pinckney and Sandulli 1990). This suggests that the abundance of total copepods or individual species is independent of phytoplankton abundance hydrographic conditions in the harbor. It seems that a simple correlation analysis cannot explain the complicated relationships between grazers and prey in a natural environment.

Another cause may have been that the spatial scale of sampling in this study was inadequate to identify spatial patterns of species abundances. The mechanisms affecting the observed distribution patterns of copepods range from abiotic factors such as aquatic parameters to biotic factors such as predation, reproduction, disturbance, and competition. The calanoid genus *Acartia* comprises over 70 species and is distributed throughout the world's oceans (Mauchline 1998). Most of them are neritic and abundant in coastal waters (Yoo et al. 1991). Copepods of *A. erythraea* in subtropical waters generally live on, or slightly above, the bottom in near-shore waters during the day and maintain their position against weak water currents (Ueda et al. 1983). They are highly concentrated in the surface layer in the afternoon (Checkley et al. 1992). Both *A. erythraea* and *P. parvus* are common in the productive coastal water of southern China (Chen and Zhang 1965,

Table 4. The correlation coefficients of the three dominant copepods to the dominant phytoplankton and various parameters of water quality in the Kaohsiung Harbor

	Acartia erythraea	*Paracalanus parvus*	*Temora turbinata*
Asterionella japonica	-0.073	0.497	0.068
Bacillaria paradoxa	-0.093	-0.133	-0.077
Chaetoceros curvisetus	0.092	-0.062	-0.054
Chaetoceros lorenzianum	-0.076	0.245	-0.078
Chaetoceros messanense	-0.062	0.333	0.022
Chaetoceros van heurckii	0.027	-0.074	-0.051
Lauderia borealis	-0.033	0.486	0.124
Leptocylindrus danicus	0.221	0.091	0.705
Melosira granulata	-0.119	-0.104	0.061
Rhizosolenia delicatula	-0.036	-0.109	-0.059
Skeletonema costatum	-0.104	-0.136	-0.103
Thalassiosira decipiens	-0.010	0.136	-0.055
Thalassiosira hyalina	-0.156	0.044	-0.095
Thalassiosira subtilis	0.162	-0.000	0.238
pH	0.179	0.105	0.216
Temperature (°C)	0.104	-0.256	-0.125
DO (mg/L)	0.041	0.188	0.155
BOD5 (mg/L)	-0.161	-0.250	-0.192
COD (mg/L)	-0.121	-0.296	-0.329
PO_4-P (mg/L)	-0.042	-0.158	-0.112
NO_3-N (mg/L)	-0.084	-0.030	-0.026
NO_2-N (mg/L)	-0.099	0.057	-0.036
Cu (μg/L)	-0.137	-0.207	-0.152
Pb (μg/L)	-0.125	-0.216	-0.122
Zn (μg/L)	-0.011	-0.086	0.082
Fe (μg/L)	-0.012	-0.167	0.141
Hg (μg/L)	0.079	-0.014	-0.011
Cr (μg/L)	0.033	0.405	0.121

Chen 1992), and south of Java (Tranter 1977). *Acartia* and *Oithona* species are dominant in estuaries, coastal areas, and inlet waters of the Sandy-Hook Bay area of New Jersey (Sage and Herman 1972, Herman and Dapolito 1985), and Maizuru Bay, Japan (Ueda 1987). Our study showed that *Acartia* species are abundant at stations close to the inner harbor. *Temora turbinata* is a dominant species in waters north of New Zealand (Dessier 1988), and is also common in warm coastal waters and harbor regions (Fulton 1984, Hopcroft et al. 1998). In Kaohsiung Harbor, *T*. *turbinata*, *A*. *erythraea*, and *P*. *parvus* are numerically the most dominant copepods throughout the year (Fig. 5). Significantly higher abundances of these dominant copepods were found in this harbor than in the oligotrophic offshore waters in adjacent waters of Taiwan, e.g., the Penghu and Ludao (Green Is.) (unpubl. data).

Acknowledgments: This work was supported in part by a grant from the Taiwan Power Company. Sincere thanks are due to anonymous reviewers for their invaluable and constructive comments.

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