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ORIGINAL ARTICLE

Mesozooplankton and copepod community structures in the southern East China Sea: the status during the monsoonal transition period in September

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Abstract A field sampling was conducted before the onset of the northeasterly monsoon to investigate the copepod community composition during the monsoon transition period at the northern coast of Taiwan (East China Sea). In total, 22 major mesozooplankton taxa were found, with the Calanoida (relative abundance: 66.36%) and Chaetognatha (9.44%) being the most abundant. Mesozooplankton densities ranged between 226.91 and 2162.84 individuals m^{-3} (mean ± SD: 744.01 ± 631.5 individuals m^{-3}). A total of 49 copepod species were identified, belonging to 4 orders, 19 families, and 30 genera. The most abundant species were: *Temora turbinata* (23.50%), *Undinula vulgaris* (17.92%), and *Acrocalanus gibber* (14.73%). The chaetognath *Flaccisagitta enflata* occurred at all 8 sampling stations, providing a 95% portion of the overall chaetognath contribution. Amphipoda were abundant at stations 4 and 5, with *Hyperioides sibaginis* and *Lestigonus bengalensis* being dominant, and comprising about 50% of all amphipods. Chaetognath abundance showed a significantly negative correlation with salinity ($r = 0.77$, $p = 0.027$), whereas mesozooplankton group numbers had a significantly positive correlation with salinity ($r = 0.71$, $p = 0.048$). Densities of four copepod species (*Calanus sinicus*, *Calocalanus pavo*, *Calanopia elliptica* and *Labidocera acuta*) showed a significantly negative correlation with seawater temperature. Communities of mesozooplankton and copepods of northern Taiwan varied spatially with the distance to land. The results of this study provide evidence for the presence of *C. sinicus* in the coastal area of northern Taiwan during the early northeast monsoon transition period in September.

Keywords Mesozooplankton · Copepod · East China Sea · Monsoon transition period

Introduction

The marine biota in the waters around the island of Taiwan is highly diverse. It has been estimated that around 10% of the world's marine species can be found in waters around Taiwan (Shao 1998). Several authors explained this high biodiversity as being caused by the convergence of several large water masses (Jan et al. 2002; Hwang et al. 2010a; Tseng et al. 2011a). Copepod communities in Taiwan waters are highly influenced by water masses from ocean currents (Hwang et al. 2004, 2006, 2010b; Dur et al. 2007; Tseng et al. 2008b, d, e; Lan et al. 2009). Temperate species are transferred from the north and tropical species from the south via the Taiwan Strait, affecting the mesozooplankton communities on the west coast of Taiwan (Hwang et al. 2004, 2006, 2009; Dur et al. 2007; Tseng et al. 2008a, e).

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The Kuroshio Current flows from the equator via the east coast of the Philippines and brings warm water masses all along the east coast of Taiwan year round. In this manner, many warm water species from the south reach the western and northern coastal areas of Taiwan (Hsiao et al. 2004; Hwang et al. 2007; Tseng et al. 2008a, b, e). In the Taiwan Strait and at the southern edge of the East China Sea (ECS), water circulation is strongly influenced by the prevailing monsoonal winds and their seasonal changes (Lee and Chao 2003; Tseng et al. 2008b). During the northeast (NE) monsoon period in winter and spring (September to March), the China Coastal Current (CCC) brings cold water masses from the Bohai Sea, the Yellow Sea and the ECS to the Taiwan Strait (Wong et al. 2000; Liang et al. 2003; Lo et al. 2004a; Zuo et al. 2006; Tseng et al. 2008b). The southwest (SW) monsoon brings species from the South China Sea during summer and autumn (April to August) to the south of Taiwan (Lo et al. 2001; Liao et al. 2006; Tseng et al. 2008b; Lan et al. 2004, 2009).

Such complex water exchange affects the composition and abundance of oceanic biota around the island of Taiwan. This also holds for microzooplankton (Vandromme et al. 2010; Chang et al. 2011) and the mesozooplankton dominated by copepods (Liao et al. 1999; Tseng et al. 2008e). Pelagic copepods are important food sources for fish (Dahms and Hwang 2007; Mahjoub et al. 2011) and likely play a pivotal role in the transfer of matter and energy in the southern Taiwan Strait (Tseng et al. 2008c) and in the northern South China Sea (Tseng et al. 2009).

Zooplankton communities have long been applied as indicators of water movements (Hwang and Wong 2005; Dahms and Hwang 2010). In northern Taiwan, long-term studies of copepod successions showed that *Calanus sinicus* is an important indicator species for cold water masses from the Bohai Sea and the Yellow Sea (Hwang et al. 2004, 2006; Dur et al. 2007). Hwang et al. (2004) described *C. sinicus* as rare in samples from July to September, but the species appeared again in October, dramatically increasing in density and occurrence ratio. As yet, however, it is not known when exactly *C. sinicus* reaches the coastal areas of northern Taiwan from the north. The present study aimed to characterize the mesozooplankton community and copepod assemblages during the southwest (SW)–northeast (NE) monsoon transition period in northern Taiwan waters because this appears to be an important period for community alterations.

Materials and methods

Field sampling

For the present study, we selected the coastal waters of the southern ECS in the vicinity of Taipei County of northern Taiwan. The sampling stations included one station near Bi-Sar Harbor (northern Taiwan) and seven stations located on the transect between northern Taiwan and Pengjiayu Island in the southern ECS, between 25°09.809′–25°51.256′N and 121°40.355′–122°16.918′E (Table 1, Fig. 1).

Table 1 Locations and dates/day times of sampling on cruise ORII-CR488 (2–3/September/1998)

Station	Latitude (N)	Longitude (E)	Date (September/day time)
1	25°09.809′	121°46.520′	02/18:04
2	25°14.957′	121°40.355′	02/19:17
3	25°21.717′	121°47.054′	02/20:59
4	25°27.666′	121°52.105′	02/22:32
5	25°33.546′	121°58.469′	03/00:25
6	25°39.874′	122°04.830′	03/02:00
7	25°45.529′	122°10.716′	03/03:48
8	25°51.256′	122°16.918′	03/06:00

A research cruise was conducted in September 1998, i.e. before the onset of the northeasterly monsoon. Zooplankton samples were collected at the 8 selected stations by surface tows (0–5 m) with a standard North Pacific zooplankton net (mouth diameter 45 cm, mesh size 333 μm) provided with a flow meter in the center of the net opening (Hydrobios; Kiel, Germany). Samples were preserved immediately in 5% buffered formaldehyde in seawater. Prior to plankton collection, salinity and temperature were measured on board. In the laboratory, samples were split by a Folsom splitter until the subsample contained less than 500 specimens. Copepods and mesozooplankton were sorted and identified at the species level using the identification aids of Chen and Zhang (1965), Chen et al. (1974) and Chihara and Murano (1997). Additional original papers were used for species identification if required.

Statistical analyses

Species density matrices were analyzed using multivariate analyses for copepod species. Non-metric cluster analysis was performed together with the Bray–Curtis similarity index after logarithmic transformations of species abundance data. Significance levels of copepod assemblages between stations were calculated using a similarity program provided by the Plymouth Routine in Multivariate Ecological Research (PRIMER), version IV software package (Clarke and Warwick 1994). The abundance of copepod species of whole samples were used for the calculation of similarities before clustering. The functional test of Box and Cox (1964) for the transformation of data was applied before the similarity analysis. The value (λ) of the power transformation was set as 0.95, and the log $(x + 1)$ was applied to treat the individual densities of all samples.

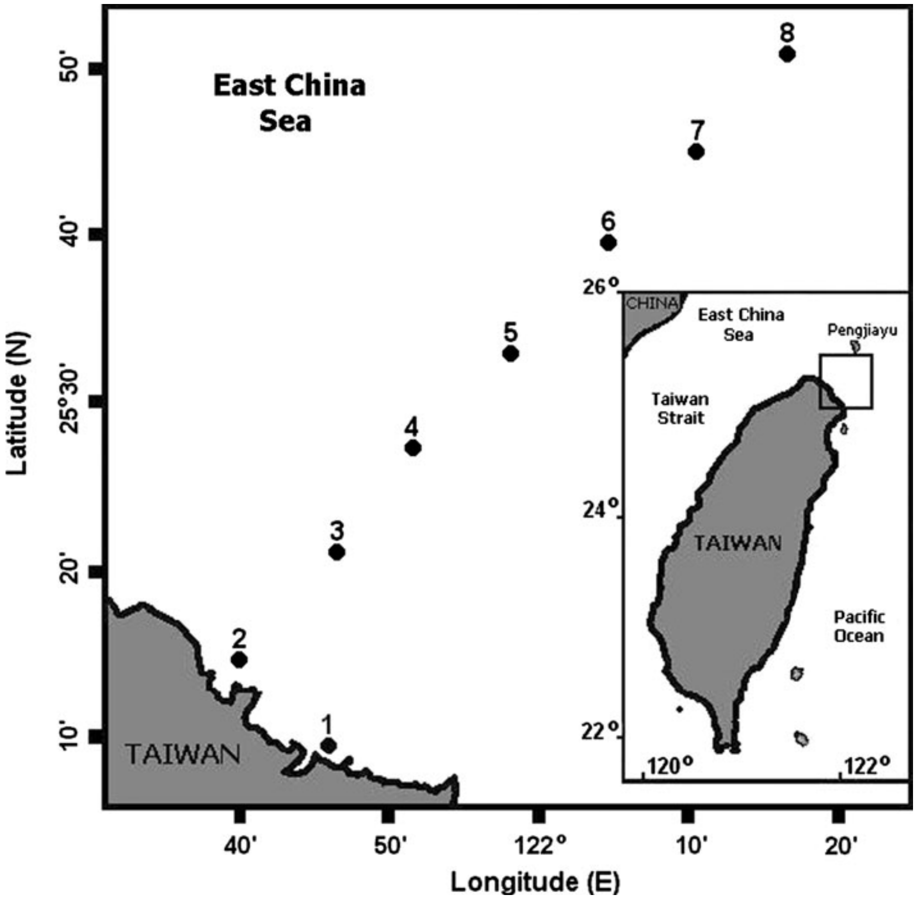

Fig. 1 Map of the sampling stations on cruise ORII-CR488 during 2–3/September/1998

The copepod species characterizing each cluster were further identified using the Indicator Value Index (IndVal) proposed by Dufrêne and Legendre (1997). This index is obtained by multiplying the product of two independently computed values by 100:

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

where (*SPj, s*) is the specificity, and (*FIj, s*) is the fidelity of a species (*s*) towards a group of samples (*j*), and these are calculated by:

$$SP(j,s) = \frac{NI(j,s)}{\Sigma NI(s)}; \quad FI(j,s) = \frac{NS(j,s)}{\Sigma NS(s)}$$

where *NI*(*j*, *s*) is the mean abundance of species *s* across samples pertaining to *j*, Σ*NI*(*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 Σ*NS*(*s*) is the total number of samples in that group. The specificity of a species for a group is greatest if a species is present 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. Here, we only considered values of *SP*(*j, s*) above 5% of each cluster grouping for the calculation of the IndVal indices. To evaluate copepod assemblages for the present sampling period, an analysis of indicator species was applied to each sampling cruise separately.

The Shannon-Wiener diversity index was used to evaluate species diversity, and Pielou's evenness was used to measure the relative abundance of species at each station. The relationship between copepod abundance and temperature and salinity was studied with Pearson's product moment correlation.

Results

Hydrographic and weather conditions

In September 1998, the monthly-averaged sea surface temperature (SST; satellite images from NOAA) in the area north of Taiwan showed values higher than 28°C (Fig. 2). In northeastern Taiwan (southern ECS), where water masses are derived from the Kuroshio Current flowing along the eastern Philippines, the surface waters in September 1998 had temperatures even higher than 30°C. In the area of the northern Taiwan Strait, the CCC brings colder waters from the ECS into the Taiwan Strait, and the

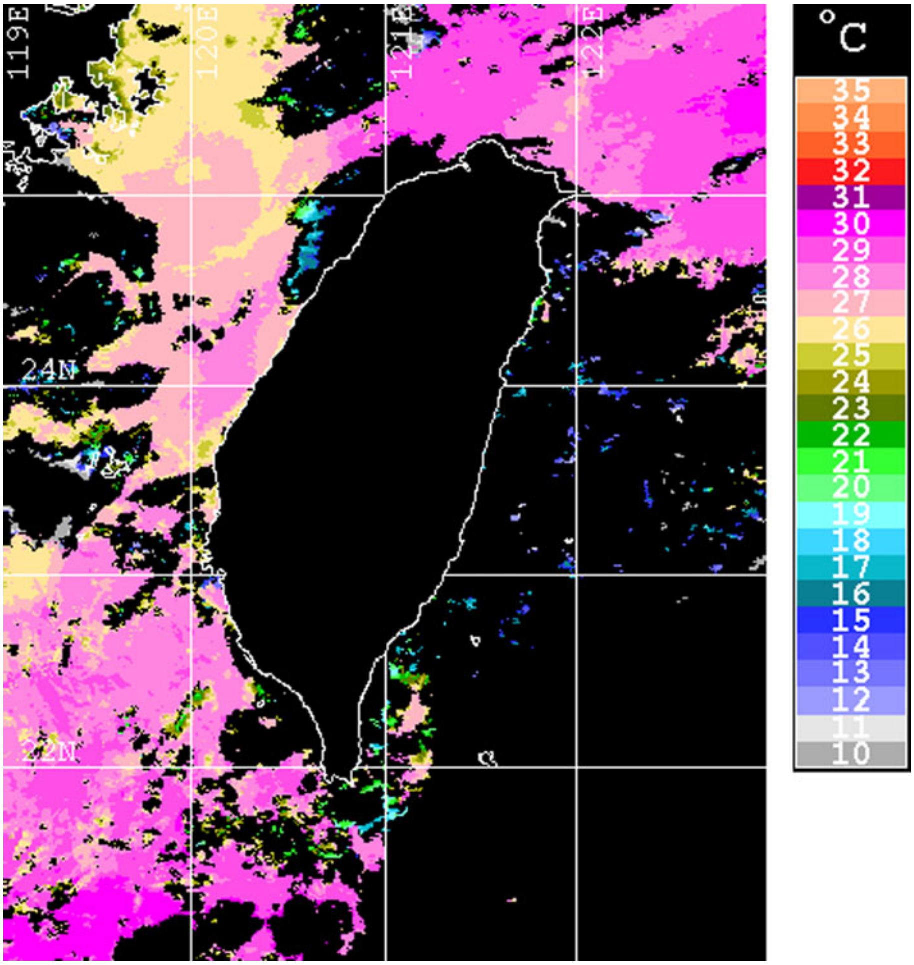

Fig. 2 Satellite image showing the monthly-averaged surface seawater temperature in September 1998

water temperatures were about 26–27°C. The slight variations in salinity and water temperature among stations are shown in Fig. 3a. The water temperature at a depth of 5 m ranged from 26.75°C (station 5) to 28.56°C (station 1); the average temperature of all sampling stations was 27.85 ± 0.59°C. The salinity at a depth of 5 m ranged between 33.49 (station 2) and 34.19 (station 7) (Fig. 3b). The average salinity of all sampling stations was 33.77 ± 0.28. The salinities were lowest at stations 1 and 2 of the coastal area and showed an increase with distance to the coastline of Taiwan (particularly at stations 3 to 8). The salinity variation among stations was affected by freshwater from the island mixed with waters of the Kuroshio Current (Fig. 2). A temperature-salinity diagram characterizes the water masses at each sampling station (Fig. 3b). The similarities in the temperature/salinity profiles indicate that waters at all sampling stations belonged to the same water mass.

Figure 4 shows the daily averages (recorded every hour) of air temperature, wind direction, and wind speed from 1/July/1998 to the 1/January/1999. Data were retrieved from the automatic monitoring instrument of the Central Weather Bureau at Keelung City, Ministry of Transportation and Communications, Taiwan. Keelung City is located in northeastern Taiwan adjacent to the sampling area. During the recording period, the daily average temperature varied from 17.2°C (11/December) to 32.6°C (20/July). The air temperature in summer (July and August) was higher than 29.0°C (Fig. 4a). The temperature showed a decreasing trend from July to the end of 1998. The wind direction followed the monsoonal changes (0 and 360 degree means wind coming from the north, 90 degree means wind from the east, etc.) (Fig. 4b). The SW monsoon prevails in summer (July to mid-September) and the NE monsoon from mid-September to the end of December. During the SW monsoon period air temperatures were higher than during the NE monsoon period. A transition period occurred during September. Most records of wind direction before September belonged to the SW monsoon and this changed during the NE monsoon after September. The daily average wind speed varied from 1.1 to 7.5 ms^{-1}. Both lowest (October 21 and December 21) and highest (October 16) wind speeds were recorded, when the NE monsoon prevailed (Fig. 4c). Wind speeds during the SW monsoon period were lower than 6 ms^{-1} before

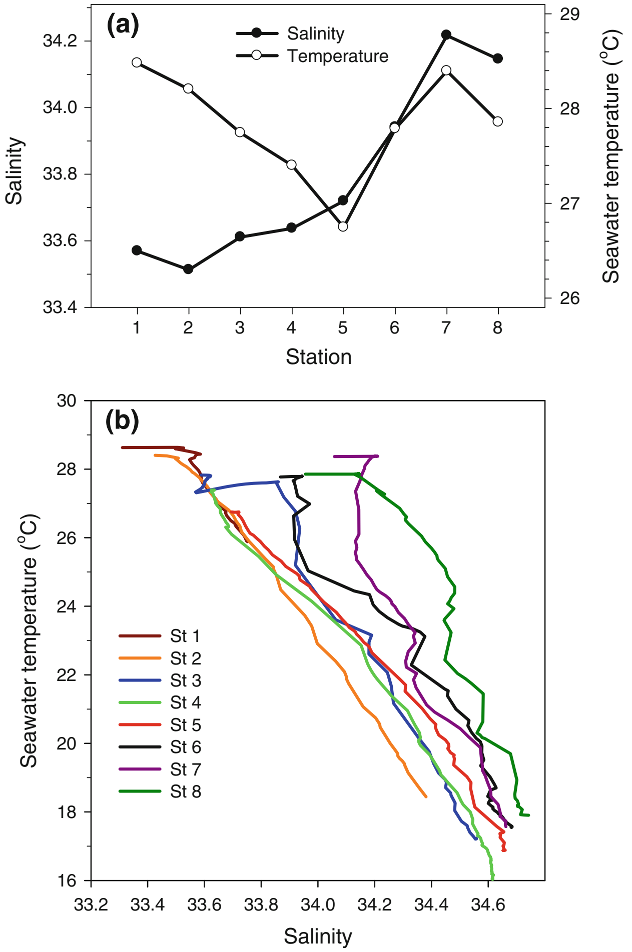

Fig. 3 Temperature and salinity at 10 m depth at the sampling stations 1–8

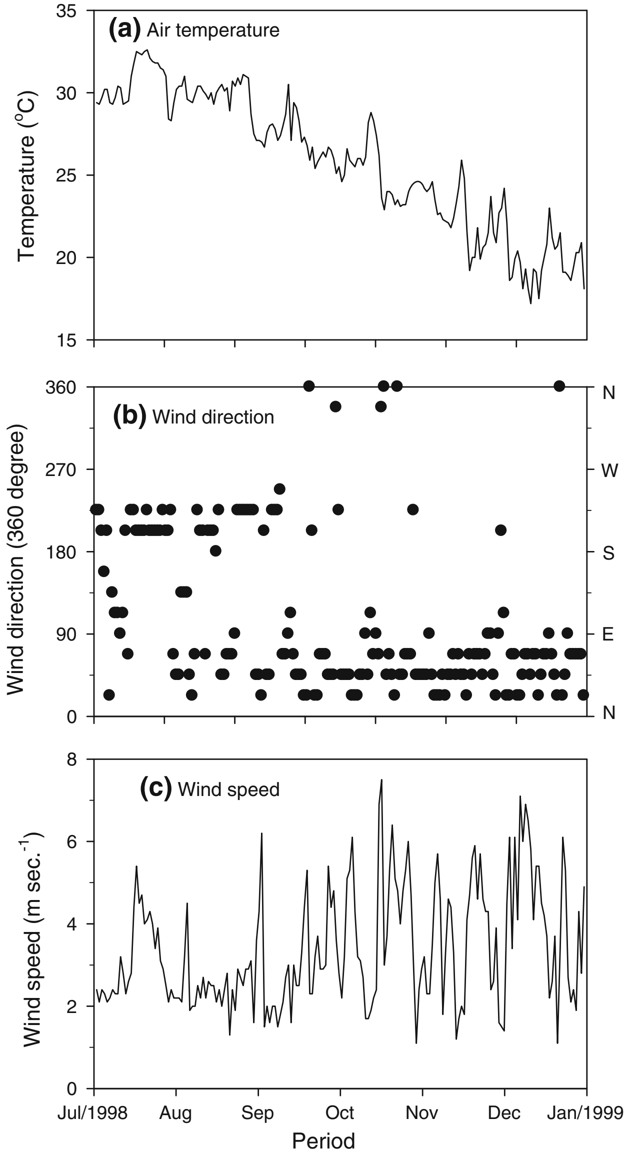

Fig. 4 Air temperature (**a**), wind direction (**b**) and wind speed (**c**) during the period from 1/July/1998 to the 1/January/1999 (information from the automatic monitoring instrument of the Central Weather Bureau at Keelung City, Ministry of Transportation and Communications, Taiwan)

September. The daily variations in wind speed records were higher during the period of the NE monsoon (Fig. 4c) from September onwards.

Mesozooplankton composition and abundance

Among the samples from the 8 stations, we identified 22 mesozooplankton groups (Table 2). The numerically dominant groups were calanoid copepods (relative abundance 66.36%) and chaetognaths (9.44%), which together comprised 75.80% of the overall mesozooplankton counts (Table 2). Figure 5 shows, for each sampling station, total abundance and number of groups (Fig. 5a) as well as the proportions of the six top dominant groups (Fig. 5b). Both total abundance values and numbers of groups varied clearly among stations. The mesozooplankton densities ranged between 226.9 (station 6) and 2162.8 (station 5) individuals m^{-3}, and the average was 744.0 ± 631.5 individuals m^{-3}. Station 5 showed the highest density values of mesozooplankton, which correlated with the lowest temperature of all stations. The numbers of mesozooplankton group ranged between 7 (station 3) and 18 (station 6) station^{-1}, averaging 13.25 ± 3.92 station^{-1}. Thus, station 6 showed the lowest mesozooplankton density, but the highest group number in this sampling cruise. There was no correlation between density and number of groups ($r = -0.410$, $p = 0.313$, Pearson's correlation). Five mesozooplankton groups were dominant in the present study: Calanoida, Chaetognatha, other Decapoda (i.e. decapods except of *Lucifer* larvae, Table 2), Poecilostomatoida and Amphipoda (Fig. 5b). At all sampling stations, calanoid copepods were the most dominant group,

Table 2 Abundance (mean ± SD), relative abundance (RA) and occurrence ratio (OR) of each mesozooplankton group recorded on cruise ORII-CR488 (2–3/September/1998)

Group	Abundance (individuals m^{-3})	RA (%)	OR (%)
Medusae	3.2 ± 5.85	0.43	62.5
Polychaeta	1.45 ± 2.97	0.19	50.0
Sagitta spp.	70.23 ± 49.6	9.44	100.0
Cladocera	0.64 ± 1.49	0.09	25.0
Ostracoda	0.61 ± 1.48	0.08	37.5
Copepod nauplii	0.03 ± 0.08	0.00	12.5
Calanoida	493.74 ± 450.54	66.36	100.0
Cyclopoida	0.56 ± 1.49	0.07	25.0
Harpacticoida	0.03 ± 0.08	0.00	12.5
Poecilostomatoida	23.61 ± 27.49	3.17	100.0
Amphipoda	22.32 ± 55.57	3.00	50.0
Lucifer larvae	12.71 ± 12.74	1.71	87.5
Euphausiacea	0.82 ± 1.22	0.11	37.5
Mysidacea	1.99 ± 3.01	0.27	50.0
Other Decapoda	49.45 ± 77.32	6.65	75.0
Pteropoda	21.47 ± 15.43	2.89	100.0
Echinoderm larvae	0.75 ± 1.3	0.10	37.5
Appendicularia	8.34 ± 13.23	1.12	75.0
Thaliacea	11.24 ± 8.4	1.51	100.0
Fish eggs	1.17 ± 1.62	0.16	50.0
Fish larvae	1.29 ± 1.6	0.17	50.0
Other larvae	18.38 ± 28.31	2.47	87.5

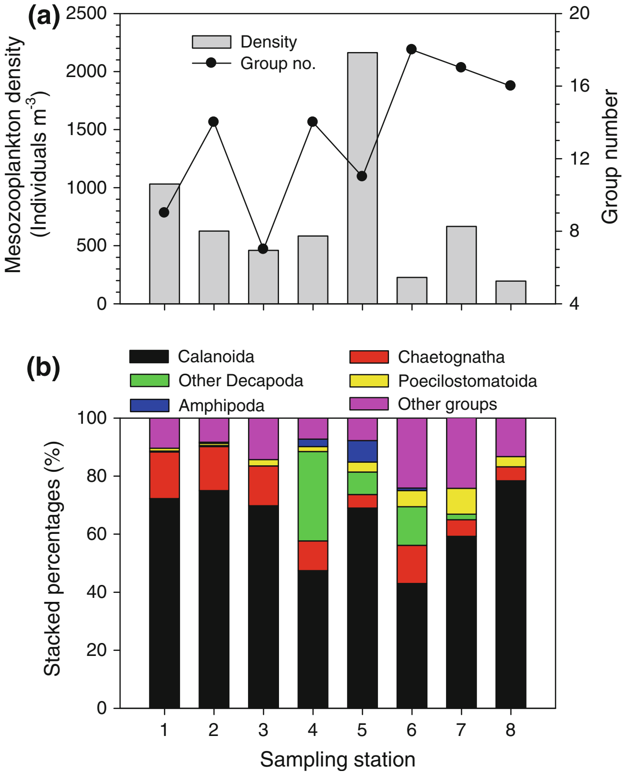

Fig. 5 Mesozooplankton recorded at stations 1–8; **a** mesozooplankton density and numbers of mesozooplankton groups; **b** relative abundance (proportion) of the 6 most dominant groups

with a contribution ranging from 42.99% (station 6) to 78.39% (station 8). Decapods showed higher abundance values at stations 4, 5 and 6, with contributions of 30.77%, 7.75% and 13.18%, respectively (Fig. 5b). Chaetognaths were identified at all eight sampling stations. The dominant species was *Flaccisagitta enflata* (Grassi 1881), amounting to 95% of all chaetognath samples. The second most abundant species was *Serratosagitta pacifica* (Tokioka 1940) (2–3%), and other species were *Ferosagitta ferox* (Doncaster 1902), *F. robusta* (Doncaster 1902), *Mesosagitta minima* (Grassi 1881), *Decipisagitta decipiens* (Fowler 1905), *Aidanosagitta delicate* (Tokioka 1939), *A. neglecta* (Aida 1897), and *A. regularis* (Aida 1897), with a relative abundance of around 2–3% of the chaetognath samples (Fig. 5b). Amphipoda were abundant at stations 4 and 5. The two most abundant amphipod species were represented by *Hyperioides sibaginis* (Stebbing 1888) and *Lestigonus bengalensis* Giles 1887; they had a relative abundance of around 50% of the amphipod samples, followed by *Lestrigonus schizogeneios* (Stebbing 1888) with 21%. Other amphipods belonging to the genera *Lestrigonus, Hyperioides* and *Hyperietta* showed a contribution of around 20% to the amphipod samples (Fig. 5b). The densities of calanoid copepods were positively correlated with total mesozooplankton abundance ($r = 0.999$, $p < 0.001$, Pearson's correlation), indicating that calanoid copepods were the dominant group of mesozooplankton in the southern ECS during the monsoon transition period.

Copepod diversity and abundance

From the 8 stations, we identified 49 copepod species. They belonged to 4 orders, 19 families, and 30 genera (Table 3). Figure 6 shows the variation in copepod abundance and species number (Fig. 6a), as well as in species richness, diversity index and evenness index (Fig. 6b) among sampling stations. Total copepod densities ranged between 110.24 (station 6) and 1567.64 (station 5) individuals m^{-3}, with a mean of 517.94 ± 470.02 individuals m^{-3}. It showed a similar variation over the sampling stations as total mesozooplankton abundance, with highest values at station 5, where surface temperature was lowest. The copepod species numbers ranged between 16 (stations 1 and 2) and 34 (station 8), with a mean of 21.38 ± 6.37 species station^{-1} (Fig. 6a). Copepod densities showed no clear trend over the sampling stations ($r = -0.225$, $p = 0.592$, Pearson's correlation), but the species number increased significantly with the distance from the coastline of Taiwan ($r = 0.875$, $p = 0.004$, Pearson's correlation).

Table 3 Abundance (mean ± SD), relative abundance (RA) and occurrence ratio (OR) of each copepod species recorded on cruise ORII-CR488 (2–3/September/1998)

Species	Abundance (individuals m^{-3})	RA (%)	OR (%)
Calanoida			
Acartiidae			
Acartia(*Odontacartia*) *erythraea* Giesbrecht 1889	0.11 ± 0.30	0.02	12.50
Acartia(*Plantacartia*) *negligens* Dana 1849	0.87 ± 2.29	0.17	25.00
Calanidae			
Calanus sinicus Brodsky 1965	3.37 ± 5.72	0.65	50.00
Canthocalanus pauper (Giesbrecht) 1888	59.52 ± 49.02	11.49	100.00
Cosmocalanus darwini (Lubbock) 1860	2.02 ± 2.99	0.39	50.00
Nannocalanus minor (Claus) 1863	3.95 ± 8.92	0.76	37.50
Undinula vulgaris (Dana) 1849	92.8 ± 85.44	17.92	100.00
Calocalanidae			
Calocalanus pavo (Dana) 1849	2.9 ± 3.42	0.56	62.50
Calocalanus plumulosus (Claus) 1863	0.03 ± 0.08	0.01	12.50
Candaciidae			
Candacia bradyi A. Scott 1902	0.95 ± 1.83	0.18	25.00
Candacia catula (Giesbrecht) 1889	0.27 ± 0.76	0.05	12.50
Candacia ethiopica (Dana) 1849	0.05 ± 0.15	0.01	12.50
Paracandacia truncata (Dana) 1849	0.56 ± 1.49	0.11	25.00
Centropagidae			
Centropages furcatus (Dana) 1849	10.55 ± 17.24	2.04	87.50
Centropages orsini Giesbrecht 1889	0.56 ± 1.00	0.11	37.50
Clausocalanidae			
Clausocalanus arcuicornis (Dana) 1849	9.81 ± 15.4	1.89	50.00
Clausocalanus furcatus (Brady) 1883	0.51 ± 1.15	0.10	25.00
Clausocalanus mastigophorus (Claus) 1863	0.26 ± 0.52	0.05	25.00
Eucalanidae			
Pareucalanus attenuatus (Dana) 1849	0.56 ± 1.49	0.11	25.00
Rhincalanus rostrifrons (Dana) 1852	0.03 ± 0.08	0.01	12.50
Subeucalanus crassus (Giesbrecht) 1888	0.03 ± 0.08	0.01	12.50
Subeucalanus subcrassus (Giesbrecht) 1888	21.61 ± 20.43	4.17	100.00
Euchaetidae			
Euchaeta indica Wolfenden 1905	0.35 ± 0.98	0.07	12.50
Euchaeta plana Mori 1937	2.25 ± 3.52	0.43	37.50
Euchaeta rimana Bradford 1973	0.18 ± 0.51	0.03	12.50
Lucicutiidae			
Lucicutia flavicornis (Claus) 1863	0.15 ± 0.42	0.03	12.50
Metridinidae			
Pleuromamma gracilis (Claus) 1863	0.2 ± 0.56	0.04	12.50
Paracalanidae			
Acrocalanus gibber Giesbrecht 1888	76.29 ± 130.81	14.73	87.50
Acrocalanus gracilis Giesbrecht 1888	38.35 ± 32.48	7.40	100.00
Acrocalanus monachus Giesbrecht 1888	0.97 ± 1.49	0.19	50.00
Paracalanus parvus (Claus) 1863	3.52 ± 4.20	0.68	87.50
Pontellidae			
Calanopia elliptica (Dana) 1849	7.09 ± 11.05	1.37	75.00
Calanopia minor A. Scott 1902	10.32 ± 13.02	1.99	87.50
Labidocera acuta (Dana) 1849	8.46 ± 17.45	1.63	50.00
Labidocera minuta Giesbrecht 1889	0.41 ± 1.15	0.08	12.50
Pontellina plumata (Dana) 1849	1.05 ± 2.96	0.20	12.50

Table 3 continued

Species	Abundance (individuals m^{-3})	RA (%)	OR (%)
Scolecithricidae			
Scolecithrix danae (Lubbock) 1856	0.58 ± 1.49	0.11	25.00
Temoridae			
Temora discaudata (Giesbrecht) 1889	10.54 ± 23.46	2.03	62.50
Temora turbinata (Dana) 1849	121.71 ± 148.08	23.50	100.00
Cyclopoida			
Oithonidae			
Oithona setigera (Dana) 1849	0.56 ± 1.49	0.11	25.00
Harpacticoida			
Miraciidae			
Macrosetella gracilis (Dana) 1847	0.03 ± 0.08	0.01	12.50
Poecilostomatoida			
Corycaeidae			
Corycaeus(*Corycaeus*) *speciosus* Dana 1849	1.04 ± 1.70	0.20	50.00
Corycaeus(*Ditrichocorycaeus*) *asiaticus* F. Dahl 1894	0.15 ± 0.42	0.03	12.50
Corycaeus(*Ditrichocorycaeus*) *dahli* Tanaka 1957	1.01 ± 1.59	0.20	37.50
Corycaeus(*Farranula*) *gibbula* Giesbrecht 1891	2.34 ± 3.00	0.45	50.00
Corycaeus(*Onychocorycaeus*) *pumilus* M. Dahl 1912	1.17 ± 1.69	0.23	50.00
Oncaeidae			
Oncaea venusta Philippi 1843	16.22 ± 23.22	3.13	87.50
Sapphirinidae			
Copilia mirabilis Dana 1849	1.66 ± 2.89	0.32	62.50
Sapphirina nigromaculata Claus 1863	0.03 ± 0.08	0.01	12.50

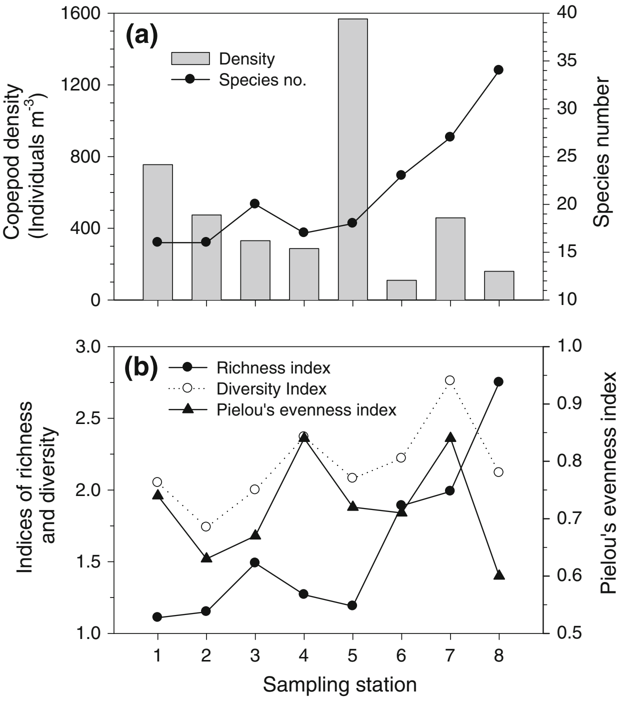

Fig. 6 Copepods recorded at stations 1–8; **a** copepod density and species number; **b** richness, evenness and Shannon-Wiener diversity index

The copepod species richness, Shannon-Wiener diversity and evenness indices differed among sampling stations (Fig. 6b). The richness index ranged from 1.11 (station 1) to 2.75 (station 8), and the average value was 1.61 ± 0.57. The evenness index ranged between 0.6 (station 8) and 0.84 (station 4 and 7), with a mean of 0.72 ± 0.09. The Shannon-Wiener diversity index ranged from 1.74 (station 2) to 2.76 (station 7), with a mean value of 2.71 ± 0.30. Richness index and species number showed a similar trend, increasing with the distance from the coast. The richness index showed a significant positive correlation ($r = 0.98$, $p < 0.001$, Pearson's correlation) with species number. The evenness and Shannon-Wiener diversity indices did not show a clear trend, but were positively correlated with each other ($r = 0.785$, $p = 0.021$, Pearson's correlation).

The most common copepod species in the present study were: *Acrocalanus gracilis*, *Canthocalanus pauper*, *Subeucalanus subcrassus*, *Temora turbinata* and *Undinula vulgaris*—all having a 100% occurrence rate (OR). Fifteen copepod species were exclusively identified from a single sample (OR = 12.5%). Of all the samples, the top five abundant species were: *Temora turbinata* (relative abundance of 23.50%), *Undinula vulgaris* (17.92%), *Acrocalanus gibber* (14.73%), *Canthocalanus pauper* (11.49%) and *Acrocalanus gracilis* (7.40%). The total numbers of the

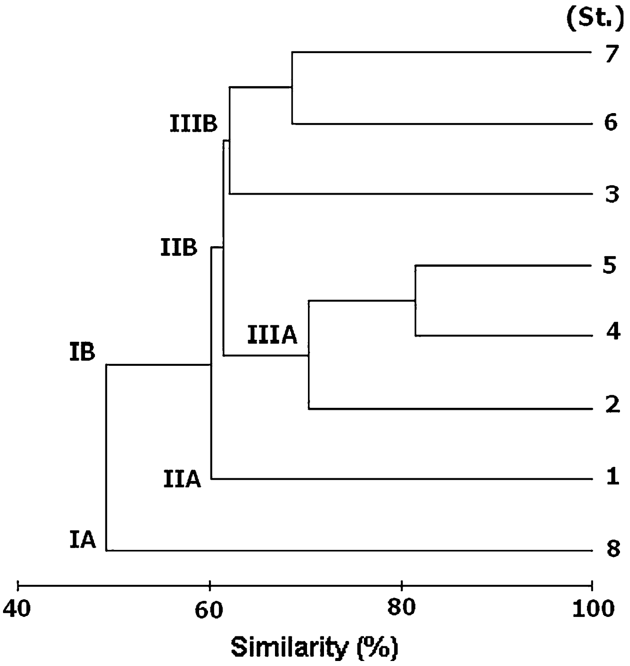

Fig. 7 Dendrogram indicating similarities between stations based on Bray–Curtis indexes for plankton composition

top five most abundant species contributed 75.04% to the total adundance of all samples (Table 3). Among all samples, the relative abundance of the indicator species *Calanus sinicus* was 0.65%, with an occurrence rate of 50.0%, and an average density for the 8 sampling stations of 3.37 ± 5.72 individuals m^{-3} (Table 3).

Cluster analysis

The dendrogram (Fig. 7) shows the results of a clustering analysis based on Bray-Curtis similarities to characterize the copepod communities at the 8 sampling stations during the monsoon transition period. The values of IndVal were calculated for copepods with relative abundances above 5% (Table 4).

Station 8 is separated from the others and allocated to group IA. The top three dominant copepod species of group IA were: *Canthocalanus pauper* (31.93%), *Acrocalanus gracilis* (26.99%) and *Temora turbinata* (11.09%). At the next grouping level, station 1 was separated as group IIA, which showed the lowest richness index (Fig. 6b) and a specific composition of copepod species. The top three dominant species of group IIA were: *Temora turbinata* (32.76%), *Canthocalanus pauper* (19.83%), and *Acrocalanus gibber* (10.34%). In group IIA, two copepods, *Temora turbinata* (32.76%) and *Centropages furcatus* (6.90%) showed a higher proportion than in other cluster groups, and 7 species with relative abundances higher than 5%. The third level (III) separated the remaining stations into two groups. Group IIIA (stations 2, 4 and 5) were closer to land than the stations of group IIIB (stations 3, 6 and 7). The three most dominant species of group IIIA were: *Temora turbinata* (25.05%), *Undinula vulgaris* (22.61%) and *Acrocalanus gibber* (20.47%). The most dominant species of group IIIB were: *Undinula vulgaris* (17.89%), *Temora turbinata* (13.92%) and *Canthocalanus pauper* (13.02%). The copepods *Subeucalanus subcrassus* (10.85%) and *Oncaea venusta* (5.35%) showed a higher abundance in group IIIB than in other groups. The results suggest that during the monsoon transition period copepod communities in the surface waters of northern Taiwan vary horizontally and with distance to land.

Correlations with environmental factors

Among all mesozooplankton taxa, the abundance of chaetognaths was negatively correlated with salinity ($r = 0.77$, $p = 0.027$, Pearson's correlation, Fig. 8a). In contrast, the group number of the mesozooplankton showed a positive correlation with salinity ($r = 0.71$, $p = 0.048$, Pearson's correlation, Fig. 8b). The abundance of *Acrocalanus monachus* ($r = 0.75$, $p = 0.03$, Pearson's correlation, Fig. 8c) and copepod species number ($r = 0.91$, $p = 0.002$, Pearson's correlation, Fig. 8d) were also positively correlated with salinity. Species numbers increased

Table 4 Indicator value indexes of copepod species with more than 50% OR (indicator species)

No.	Indicator species (index value %)			
	I A	II A	III A	III B
1	*Canthocalanus pauper* (31.93)	*Temora turbinata* (32.76)	*Temora turbinata* (25.05)	*Undinula vulgaris* (17.89)
2	*Acrocalanus gracilis* (26.99)	*Canthocalanus pauper* (19.83)	*Undinula vulgaris* (22.61)	*Temora turbinata* (13.92)
3	*Temora turbinata* (11.09)	*Acrocalanus gibber* (10.34)	*Acrocalanus gibber* (20.47)	*Canthocalanus pauper* (13.02)
4	*Undinula vulgaris* (9.95)	*Temora discaudata* (9.05)	*Canthocalanus pauper* (6.79)	*Subeucalanus subcrassus* (10.85)
5		*Centropages furcatus* (6.90)	*Acrocalanus gracilis* (6.24)	*Acrocalanus gracilis* (10.62)
6		*Undinula vulgaris* (5.17)		*Acrocalanus gibber* (6.17)
7		*Calanopia minor* (5.17)		*Oncaea venusta* (5.35)

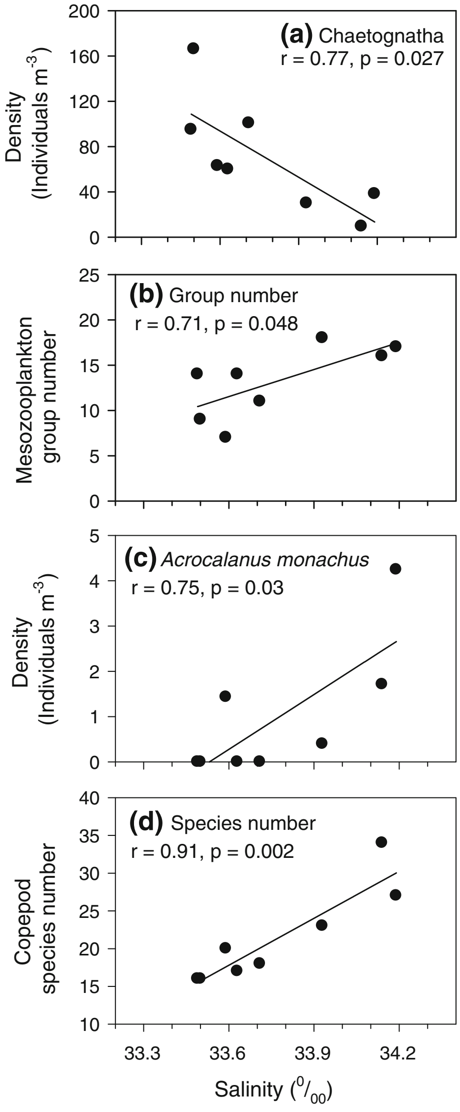

Fig. 8 Correlation between salinity and chaetognath density (**a**), number of mesozooplankton groups (**b**), densitiy of the copepod *Acrocalanus monachus* (**c**), and number of copepod species (**d**), showing significant correlations (Pearson's correlation analysis)

with increasing distance of the sampling stations from the coast.

Only a few mesozooplankton taxa showed changes in density which were significantly correlated with seawater temperature. The abundances of mesozooplanktonic amphipods ($r = -0.79$, $p = 0.019$, Pearson's correlation, Fig. 9a) and decapods ($r = -0.81$, $p = 0.014$, Pearson's correlation, Fig. 9b) were negatively correlated with seawater temperature, and this also applied to the following four copepod species: *Calanus sinicus* ($r = -0.85$, $p = 0.008$, Pearson's correlation, Fig. 9c), *Calocalanus pavo* ($r = -0.74$, $p = 0.035$, Pearson's correlation, Fig. 9d), *Calanopia elliptica* ($r = -0.72$, $p = 0.044$, Pearson's correlation, Fig. 9e) and *Labidocera acuta* ($r = -0.82$, $p = 0.013$, Pearson's correlation, Fig. 9f).

Discussion

Zooplankton communities in the ocean are influenced by several factors including river discharge (Tan et al. 2004), monsoons (Yoshida et al. 2006), urban runoffs and change of water masses (Tseng et al. 2008a). Tan et al. (2004) and Yoshida et al. (2006) reported copepods as the main fraction of mesozooplankton in the Pearl River estuary and the Malacca Strait, respectively. In the present study the dominant taxa of mesozooplankton were calanoid copepods (66.36%), followed by chaetognaths (9.44%). Huang (1983) studied the zooplankton communities in the upwelling waters off the southeastern coast of Taiwan, and reported calanoid copepods to be highly abundant (44.0–59.7%) in all samples. Tseng et al. (2008a) found calanoid copepods to dominate (37.07%) the mesozooplankton communities in an outfall area in the northeastern South China Sea. The results confirm calanoid copepods to be the dominant mesozooplankton taxon.

Another dominant species in the present study was the chaetognath *Flaccisagitta enflata*. This species is widely distributed in the coastal waters of mainland China (Chen 1992). Chen (1992) reported the the species to be abundant during summer and autumn in the waters of the boundary zone of the Yellow Sea and the ECS. According to Pierrot-Bults and Nair (1991), the species is circum-globally distributed and commonly found between 40°N and 40°S. Tse et al. (2008) found *F. enflata* to be a dominant species in the waters of Hong Kong. Tseng et al. (2011) reported the species to be abundant in the waters of the western and southern ECS during a summer cruise. The present study confirmed *F. enflata* to be abundant in the southern ECS during the SW-NE monsoon transition period. The amphipods *Hyperioides sibaginis* and *Lestigonus bengalensis* were common in the samples of the present study. *H. sibaginis* is distributed in the waters of eastern mainland China and has been reported in the South China Sea (Chen 1983; Lowry 2000), the Taiwan Strait (Lin and Chen 1988), and the ECS (Xu and Jiang 2006; Xu 2009). Our study shows that this species can occur in the southern ECS during the monsoon transition period.

Copepod communities change dynamically with water masses during northeast and southwest monsoons (Hsieh et al. 2004, 2005; Hwang et al. 2004, 2006, 2009; Dur et al. 2007; Tseng et al. 2008b). The dominant copepod species in the present study were: *Temora turbinata*, *Undinula vulgaris*, *Acrocalanus gibber*, *Canthocalanus pauper* and *Acrocalanus gracilis*. These species are warm-water species that are commonly found around Taiwan (Shih and

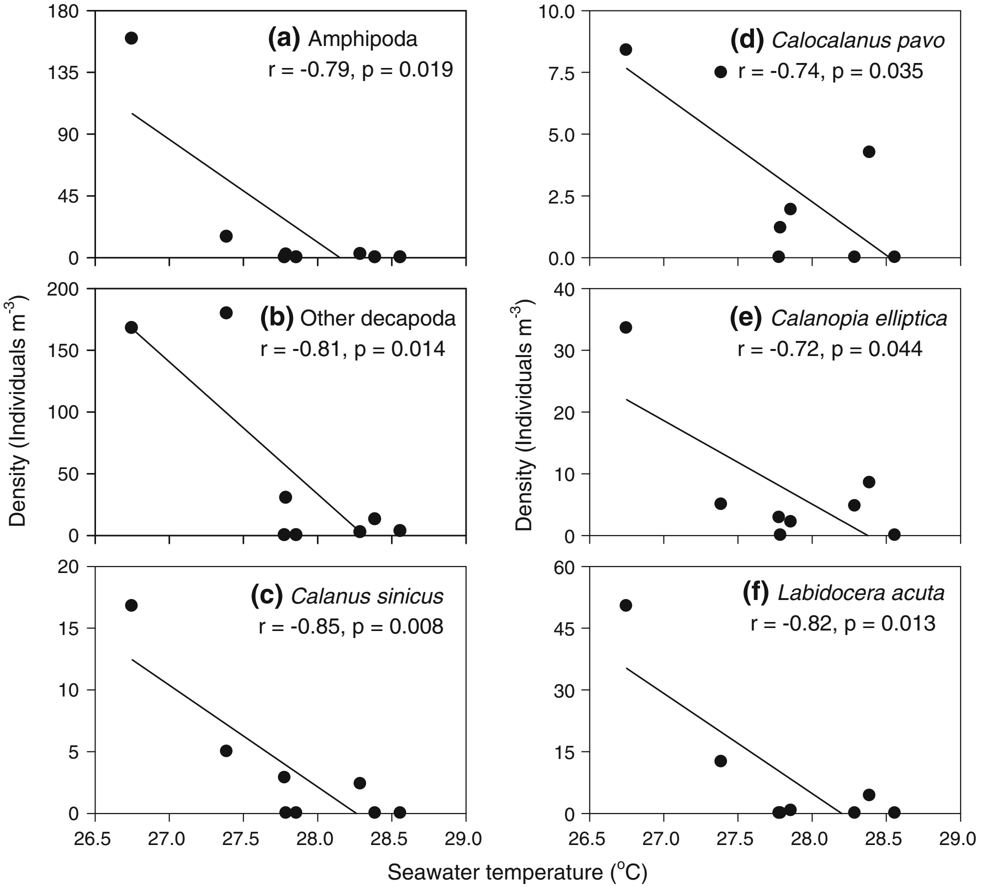

Fig. 9 Correlation between seawater temperature and the densities of amphipods (**a**), decapods (**b**), and the copepods *Calanus sinicus* (**c**), *Calocalanus pavo* (**d**), *Calanopia elliptica* (**e**) and *Labidocera acuta* (**f**), showing significant correlations (Pearson's correlation analysis)

Young 1995; Hwang et al. 2004; Dur et al. 2007; Tseng et al. 2008d, 2011b). *Temora turbinata* is an indicator species of warm water masses (Dur et al. 2007; Tseng et al. 2008b) which can also tolerate polluted environments (Fang et al. 2006; Tseng et al. 2008e; Wu et al. 2010).

A limited number of studies reported a seasonal succession of copepods in the waters north of Taiwan (Hwang et al. 2004, 2006; Hwang and Wong 2005; Dur et al. 2007; Tseng et al. 2008b). These studies included different types of coastal areas, including areas such as those close to nuclear power plants (Hwang et al. 2004), the estuary of the Danshuei River (Dur et al. 2007; Hwang et al. 2006, 2009), and the northeastern Taiwan Strait (Tseng et al. 2008b). Previous reports indicated that the calanoid copepod *C. sinicus* belongs to the cold-water masses of the CCC that derive from the Yellow Sea during the northeast monsoon. Previous reports never found *C. sinicus* in summer samples from the coastal areas. However, this species was frequently recorded with high rates of occurrence and relative abundance from October to April. Previous reports did not provide information about copepod composition in the waters north of Taiwan in September. This may be due to a lack of data collection in September. To date, there is no information on when *C. sinicus* first arrives in the waters of northern Taiwan from its probable origin in the Bohai Sea. Our results show that *C. sinicus* was present in the sampling area in September 1998, before the CCC affected the coastal areas of northern Taiwan. This is clearly shown by the contemporaneous satellite images of the sea surface temperature (Fig. 2), indicating that the colder waters of the CCC were still separated from the study area. Contrary to previous studies (Hwang et al. 2004, 2006; Hwang and Wong 2005; Dur et al. 2007; Tseng et al. 2008b) that suggest *C. sinicus* to be exclusively transported by the cold CCC water, we demonstrate that *C. sinicus* is present in the southern ECS even during the northeast monsoon transit period. However, it cannot be excluded that *C. sinicus* survives in the deeper layers of the ECS when surface waters seasonally warm up, sinking to deeper water during summer and returning to surface waters via cold upwelling or vertical migration.

Previous field studies reported *C. sinicus* in the south ECS close to the present area of study. Hsieh et al. (2004) still reported *C. sinicus* north of the Taiwan Strait when the northeast monsoon was prevailing. Liao et al. (2006) found *C. sinicus* occurred in August at the upwelling area of the

Table 5 Number of copepod species identified in different parts and during different periods in the East China Sea (ECS)

Area of ECS	Number of identified species	Study period	References
Southwestern (Tanshui)	83	June/1970	Tseng (1975)
Southwestern (Tanshui River estuary)	62	August/1996–January/1997	Hsieh and Chiu (1997)
Southern (Coastal water)	25[a]	May/1996	Hwang et al. (1998)
Southern (Nuclear power plants)	37[a]	August/1996	Wong et al. (1998)
Southern (North of Taiwan)	113	April/1995	Shih and Chiu (1998)
Southern (North of Taiwan)	183	March/1995	Shih et al. (2000)
Southeastern (Upwelling water)	178	March/1995	Lo et al. (2004b)
Southern (Nuclear power plants)	116	November/2000–December/2003	Hwang et al. (2004)
Southwestern (Boundary coastal waters)	110	October/1998–September/2003	Hwang et al. (2006)
Southeastern (Upwelling water)	95	August/1998	Liao et al. (2006)
Southwestern (Estuary of Danshuei River)	79[a]	October/1998–July/2004	Dur et al. (2007)
Southwestern area	77	July/2001	Tseng et al. (2008d)
Southwestern (Estuary of Danshuei River)	120	October/1998–July/2004	Hwang et al. (2009)
Southern area	49	September/1998	Present study

[a] Only calanoid copepods recorded

southeastern ECS. Their study indicated that *C. sinicus* occasionally occurred at low abundances. They suggested that *C. sinicus* was coming from the north of the Taiwan Strait with the Taiwan Strait warm current. Chen (1992) reported that the temperature range of *C. sinicus* was 5–23°C. Therefore, Liao et al. (2006) inferred that *C. sinicus* in fact comes from the waters of the northern Taiwan Strait and later appears at the surface due to upwelling. In the present study we found three more species related to cold-water masses: *Calocalanus pavo*, *Calanopia elliptica* and *Labidocera acuta,* which are temperate species originating from the ECS (Chen 1992).

The copepod species numbers found in the southern ECS varied in different studies according to sampling location and study period (Table 5). The two studied areas with high species numbers were located in the upwelling zone (Shih et al. 2000; Lo et al. 2004b; Liao et al. 2006) and in the southwest ECS in the estuary of Danshuei River (Hwang et al. 2009). Upwelling areas with higher primary productivity commonly support a higher biodiversity of secondary producers (Nybakken 1993). Liao et al. (2006) reported 95 species in the upwelling waters of the southeast ECS with higher species richness than previously reported from coastal areas (Hwang et al. 1998; Wong et al. 1998). Station 5 of the present study was located close to the upwelling area and showed the highest density of mesozooplankton of the 8 sampling stations. Shih et al. (2000) and Lo et al. (2004b) found 178 and 183 species, respectively, in the upper 250 m water layer. Similarly, Shih and Chiu (1998) recorded 113 species in the upper 200 m. To date, most ecological studies of copepod communities were performed in the southwestern ECS and the estuary of the Danshuei River (Tseng 1975; Hwang et al. 2006, 2009; Dur et al. 2007). This includes a longer study period of 6 years (Hwang et al. 2009). Hwang et al. (2004) identified 116 copepod species during a 3-year study close to the nuclear power plants I and II in the northeastern coastal area of Taiwan, and 120 species were reported off the Danshui Estuary during a 6-year study (Hwang et al. 2009). The previous studies showed that the number of identified copepod species increased with the temporal and spatial scale of the investigations.

The present study was carried out during the monsoonal transition period before the onset of the northeast monsoon in late summer. The SST image did not provide any evidence that the coastal areas of northern Taiwan were affected by the CCC during the study period. Nevertheless, we identified *C. sinicus* in northern Taiwan waters. Future studies should focus on the deeper water layers of the ECS to see whether *C. sinicus* uses the cold water stratum as a refuge during the seasons with warm surface waters.

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