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Striking taxonomic differences in summer zooplankton in the northern South China Sea: implication of an extreme cold anomaly

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Abstract

An extreme persistent cold anomaly was prevailing in the South China Sea in February 2008. In order to understand the effect of the cold anomaly on zooplankton community, the zooplankton composition, abundance and biomass were analyzed in the northern South China Sea in August 2007 and August 2008. A total of 467 zooplankton species representing 16 groups were identified, with 275 species in August 2007 and 351 in August 2008. Copepods were the most dominant zooplankton group in the study area. Compared with 2007, a dramatic decline was observed in the abundance of four dominant copepod species: *Subeucalanus subcrassus*, *Temora discaudata*, *Nannocalanus minor* and *Temora turbinata* in 2008. Moreover, zooplankton abundance declined from 133.37 ind./m^3 in August 2007 to 75.49 ind./m^3 in August 2008. In contrast, the abundance of medusa, such as *Diphyes chamissonis*, and tunicate, such as *Doliolum denticulatum* and *Dolioletta gegenbauri*, increased during the same season. Cluster analysis showed that there was a difference in zooplankton community structure between the two years. These variations in zooplankton communities were indicative of an anomalous oceanographic condition along with the extreme cold event in 2008.

Key words: zooplankton, community, cold anomaly, northern South China Sea

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1 Introduction

Zooplankton plays an important role in the biological cycling of carbon and other elements in the ocean (Roemmich and McGowan, 1995), and is the main trophic link that connects phytoplankton and microzooplankton with larger vertebrate and invertebrate predators (Mackas and Beaugrand, 2010). Zooplankton serves also as excellent indicators of changes in ocean and climate conditions because of their short life cycles and free floating feature (Hays et al., 2005; Hooff and Peterson, 2006; Zhang and Wong, 2011). Interannual changes in zooplankton species assemblages often reflect an integrated response of the ecosystem to hydro-climatic forcing (Dippner et al., 2001; Beaugrand and Ibanez, 2004; Wiafe et al., 2008). For instance, dramatic changes in zooplankton community observed in eastern Pacific were attributed to the abnormal temperatures during El Niño/La Niña in 1997–1999 (Jiménez-Pérez and Lavaniegos, 2004; McKinnon et al., 2008). The utility of zooplankton as indicators of such changes in oceanographic conditions is based on a solid understanding of the ecology of dominant species (McKinnon et al., 2008).

The South China Sea (SCS) is the largest semi-enclosed sea in the western tropical Pacific Ocean (Su, 2004; Qiu, 2011). In the northern SCS (NSCS), the bottom topography is characterized by a steep continental slope between a shallow continental shelf (150–250 km in width) in the northwest, and a wide deep basin in the southeast (Zhang et al., 2009). The summer monsoon is typically southwesterly, which peaks in July and gradually decay in September. The SCS is a haven for oceanographers and climate researchers because it is a crossroads for currents that influence the climate of the entire globe (Qiu, 2011).

In February 2008, an extreme persistent cold anomaly is accompanied by a long-persisting northerly anomaly and a sequence of cold advection occurring in Southeast Asia. The extreme cold anomaly not only broke the lowest temperature record for the past 50 year but also caused numerous agriculture and fishery losses over Southeast Asia (Hong and Li, 2009). It was reported that nearly 90% of fishes around the coastline of Penghu, a small island west of Taiwan, died during this cold event (Xian et al., 2008). These geological and oceanographic features were expected to have greatly affected zooplankton communities in the NSCS.

Our present knowledge of zooplankton in the NSCS is mainly derived from previous studies (Li et al., 2004, 2006; Tan et al., 2004; Hwang et al., 2007, 2010; Tseng et al., 2008; Zhang et al., 2009; Chertoprud et al., 2011). However, these studies either focused on special groups, such as copepod communities, or con-

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ducted in the Zhujiang (Pearl River) Estuary. Moreover, research on the structure of zooplankton community in the NSCS and the impact of hydro-climatic events on zooplankton community is limited.

We have monitored and analyzed zooplankton composition, abundance and biomass in the NSCS in August 2007 and 2008. The results indicated a significant difference in zooplankton community between August 2008 and August 2007. What were the causes of such differences? We try to use the two years data to illustrate the structure of zooplankton community in the NSCS, demonstrate the difference in zooplankton community in August 2007 and August 2008, and present possible reasons for this difference.

2 Materials and methods

2.1 *Field sampling*

The investigations were conducted in the NSCS in 2007 and 2008, from August 10 to 30. Zooplankton samples were collected at 21 sites in 2007 and at 23 sites in 2008 (Table 1), and were obtained by a vertical tow net (505 μm mesh size, 0.8 m diameter at a pulling speed of 0.5 m/s) from 2 m above the bottom with depths less than 200 m, or from 200 m to the surface with depths more than 200 m. The samples were fixed immediately in 5% formaldehyde. Temperature and salinity were measured using a SBE-19 CTD. Sea water for chlorophyll *a* (Chl *a*) analysis was collected by 5-L Niskin bottles. A 500 mL subsample was gently filtered through a GF/F filter, which was then stored at –20°C for laboratory analysis. Size fractionated Chl *a* was measured by sequential filtrating the water samples onto 25 mm polycarbonate filters (20 μm, 3 μm, and 0.7 μm) by steps.

2.2 *Laboratory procedures*

Zooplankton samples were identified to the species level when possible and counted (Chen and Zhang, 1965, 1974a, b; Chen et al., 1974; Liu, 2008). Wet biomass was measured with an electronic balance after removing large detrital particles, jellyfishes and tunicates under a microscope, and eliminating excess interstitial water by vacuum extraction technique. Zooplankton abundance and wet biomass were expressed as ind./m^3 and mg/m^3, respectively. For the determination of total Chl *a* concentration, Chl *a* samples were extracted in 90% acetone and preserved in a refrigerator (dark, –20°C) for 24 h. Chl *a* concentration was then measured fluorometrically (Turner designs 10 AU fluorometer) before and after acidification.

2.3 *Data analysis*

2.3.1 *Sea surface temperature (SST)*

Monthly averaged satellite-derived SST images for August 2007 and 2008 were obtained from the advanced very high resolution radiometer (AVHRR) (http://data.nodc.noaa.gov/pathfinder/Version5.0). Interannual variations of the SST in the SCS (0°–25°N, 99°–130°E) were calculated from January 2006 to December 2008. The SST data were obtained from the TMI (http://www.remss.com/tmi/tmibrowse.html). Monthly climatology of the SST at each grid point was calculated by averaging the SSTs for the individual calendar months during the three years, and then monthly anomalies of the SSTs were calculated by subtracting the monthly climatology from the individual SSTs. In this study, positive (negative) SST anomaly means that ocean SST was higher (lower) than the average SST.

2.3.2 *Dominant species*

Y is the dominance indicator, and a species is considered as dominant when $Y \geqslant 0.02$ (Xu and Chen, 1989). *Y* index was calculated as

$$Y = \frac{N_i}{N} \cdot f_i,$$

where N_i is the abundance of the *i*th species, *N* is the total species abundance, and f_i is the occurring frequency of species *i*th at all sites.

2.3.3 *Cluster analysis*

Cluster analysis was performed using PRIMER v6 (PRIMER-E Ltd.) software. Similarity matrices were constructed using Bray-Curtis similarity because it does not derive similarity from conjoint absences (Clarke and Warwick, 1994). Species abundance data, which were square root transformed, were used for the analysis. Relationships between the sites were visualized using non-metric multidimensional scaling (nMDS) ordination, which was further supplemented by cluster analysis. Following a cluster analysis, the species that had a major contribution to the dissimilarities of site groups were determined using SIMPER dissimilarity percentage program (Clarke and Warwick, 1994).

3 Results

3.1 *Variation of environmental factors*

The monthly SST anomalies demonstrated that a long-per-

Table 1. Depths (m) at the collection stations in 2007 and 2008

Station	Depth	Station	Depth	Station	Depth	Station	Depth
07-A3	52	07-E205	105	08-E201	34	08-E426	158
07-E101	34	07-E107	250	08-E101	30	08-E205	105
07-E709	40	07-E426	98	08-E103	77	08-E412	3 924
07-E201	40	07-E705	117	08-E709	40	08-E424	2 020
07-E202	40	07-E412	4 036	08-E203	49	08-E422	2 472
07-E302	29	07-E420	2 113	08-S702	38	08-E418	3 567
07-E304	35	07-E308	1 466	08-S402	40	08-E420	2 096
07-T001	41	07-E401	3 017	08-S706	37	08-E416	3 790
07-E105	115	07-E407	3 130	08-S704	41	08-E414	3 934
07-E103	77			08-S708	30	08-E401	3 017
07-E306	69			08-S710	107	08-E407	1 914
07-E203	49			08-E705	117		

Note: Samples collected at the stations were coded according to the sampling year: 07 means August 2007 and 08 August 2008.

sisting cold anomaly prevailed in the SCS in early 2008 (Fig. 1) (Hong and Li, 2009). The SST in the NSCS was higher in August 2007 than that in August 2008 (Fig. 2), while the average sea surface salinity in 2007 (33.13) was very similar to that in 2008 (33.08), and increased from onshore to offshore (Fig. 3).

The average sea surface Chl *a* was 0.64 mg/m^3 in August 2007 with values ranging from 0.05 to 3.73 mg/m^3. However, the average sea surface Chl *a* decreased to 0.33 mg/m^3 in August 2008 with values ranging from 0.04 to 2.32 mg/m^3 (Fig. 4). We also found that the largest size fraction of phytoplankton (>20 μm) took a bigger percentage of total sea surface Chl *a* in August 2007 than that in August 2008 (Fig. 5).

Fig. 1. Time series of the monthly average SSTs anomalies (°C) which is spatially averaged over the whole SCS.

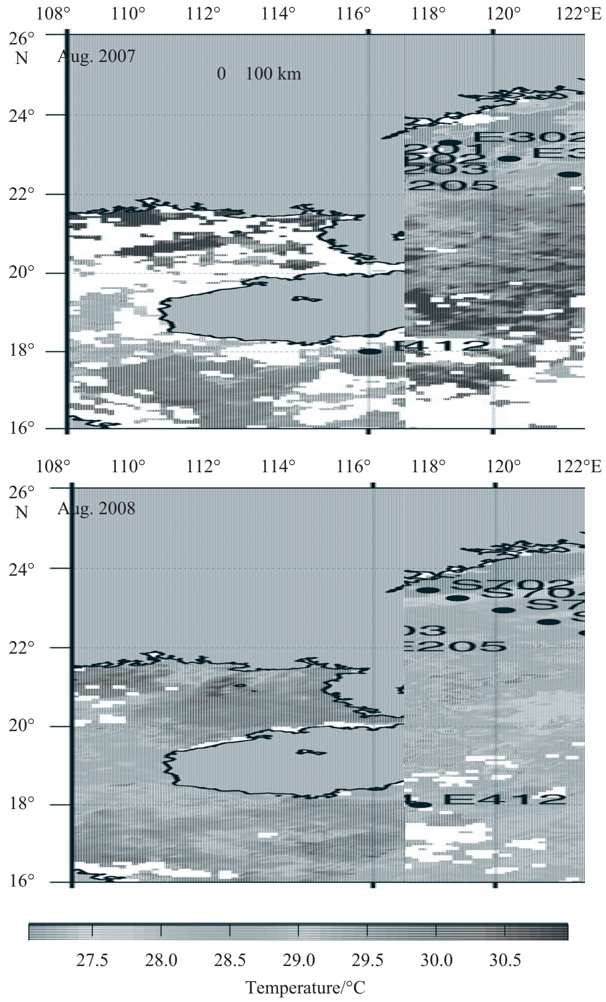

Fig. 2. Sampling stations and remote-sensed AVHRR SST images in August 2007 and August 2008 in NSCS.

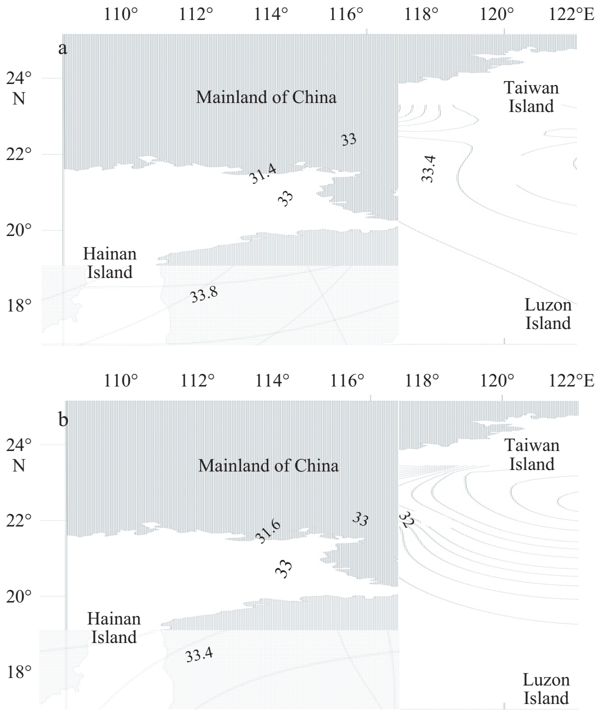

Fig. 3. Distribution of sea surface salinity in August 2007 (a) and August 2008 (b) in NSCS.

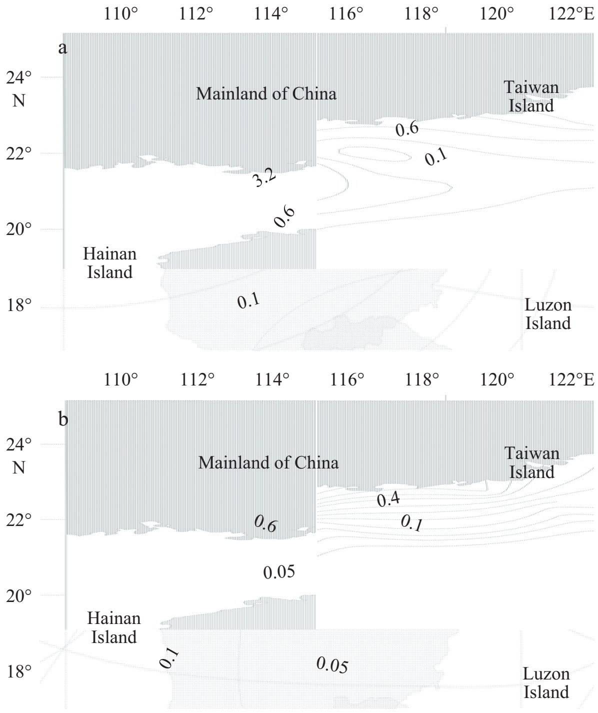

Fig. 4. Distribution of sea surface Chl *a* (mg/m^3) in August 2007 (a) and August 2008 (b) in NSCS.

3.2 *Changes in zooplankton biomass and abundance*

The average zooplankton biomass in the NSCS was 207.68 mg/m^3 in 2007, and sharply decreased to 52.98 mg/m^3 in 2008

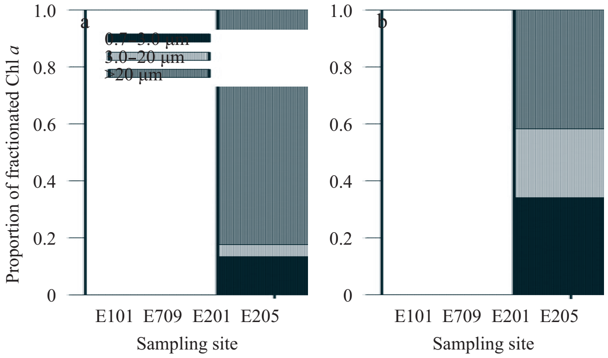

Fig. 5. Proportion of size fractionated Chl *a* in August 2007 (a) and August 2008 (b) in NSCS.

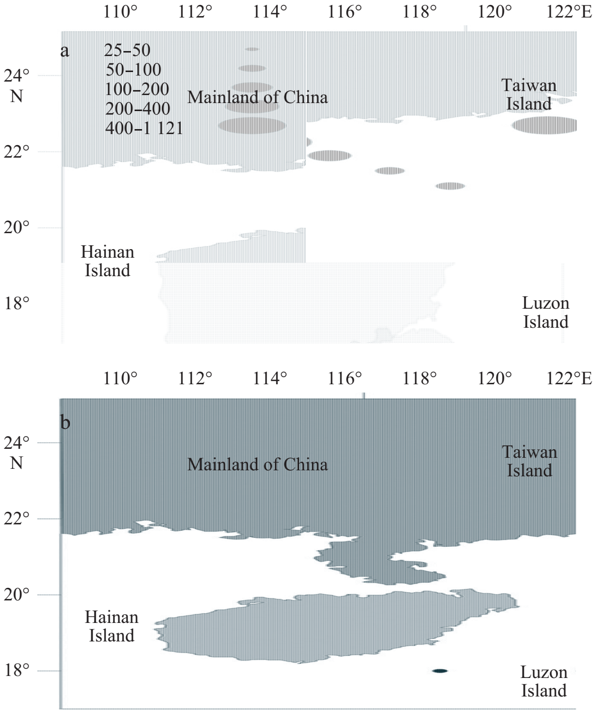

Fig. 6. Distribution of zooplankton biomass (mg/m^3) in August 2007 (a) and August 2008 (b) in NSCS.

(Fig. 6). In addition, a remarkable change in zooplankton abundance was also recorded (Table 2). The average zooplankton abundance was 133.37 ind./m^3 in 2007, with copepods being the most abundant group (69.40 ind./m^3), which accounted for 52.04% of the total zooplankton abundance. Other abundant groups included planktonic larvae (including copepod nauplii, polychaete larvae, echinopluteus larvae, etc.) and chaetognatha, with mean abundance of 21.00 ind./m^3 and 12.99 ind./m^3, respectively, in 2007.

The average zooplankton abundance decreased to 75.49 ind./m^3 in 2008, exhibiting a sharp decrease in the abundance of copepods and larva decreased sharply. Copepods abundance was 30.35 ind./m^3 in 2008, less than half of that in 2007. The abundance of larvae decreased from 21.00 ind./m^3 in 2007 to 3.74 ind./m^3 in 2008.

The abundance of medusae and tunicates also showed great fluctuations between 2007 and 2008. The average abundance of medusae was 8.63 ind./m^3 in 2007 with values ranging from 0 to 32.91 ind./m^3, but increased to 13.99 ind./m^3 in 2008 with values ranging from 1.36 to 72.86 ind./m^3 (Fig. 7). Medusae became the second most abundance group in 2008, but not in 2007. The same trend was also observed in tunicates (Fig. 8). The average abundance of tunicates was higher in 2008 (10.27 ind./m^3) than in 2007 (4.97 ind./m^3).

Multiple regression analysis between zooplankton and environmental variables showed that zooplankton abundance and biomass increased with increasing Chl *a* concentration in 2007. However, there was no correlation between zooplankton abundance and Chl *a* concentration in 2008 (Table 3).

3.3 *Succession in taxonomic composition*

Sixteen groups representing 275 species, including 118 species of copepods and 157 other zooplankton species, were identified in 2007 (Table 2), copepods were the most important group

Table 2. Variations of abundance (ind./m^3) and species richness in different groups in August 2007 and August 2008

Group	August 2007		August 2008	
	Abundance	Species richness	Abundance	Species richness
Protozoa	1.05	7	0.00	0
Medusa	8.63	43	13.99	88
Polychaeta	0.08	4	0.70	17
Mollusca	2.95	14	2.65	15
Cladocera	0.04	1	1.31	2
Ostracoda	2.81	13	0.89	21
Copepoda	69.40	118	30.35	121
Amphipoda	5.03	18	2.29	21
Mysidacea	0.01	2	0.01	2
Euphausiacea	0.93	6	0.24	3
Decapoda	3.34	1	1.61	2
Chaetognatha	12.99	18	7.40	21
Tunicata	4.97	10	10.27	16
Cumacea	0.08	1	0.03	2
Isopoda	0.16	2	0.00	0
Larvae	21.00	17	3.74	20
Total	133.37	275	75.49	351
Total species richness	467			

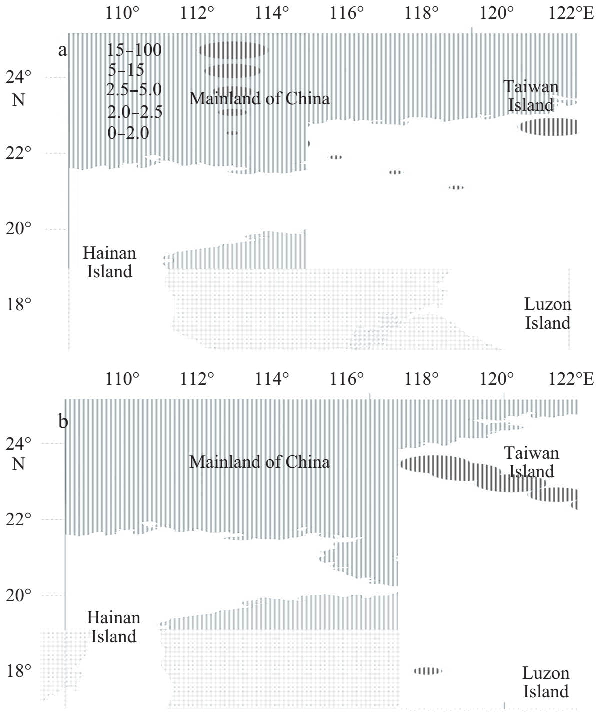

Fig. 7. Distribution of Medusa abundance (ind./m^3) in August 2007 (a) and August 2008 (b) in NSCS.

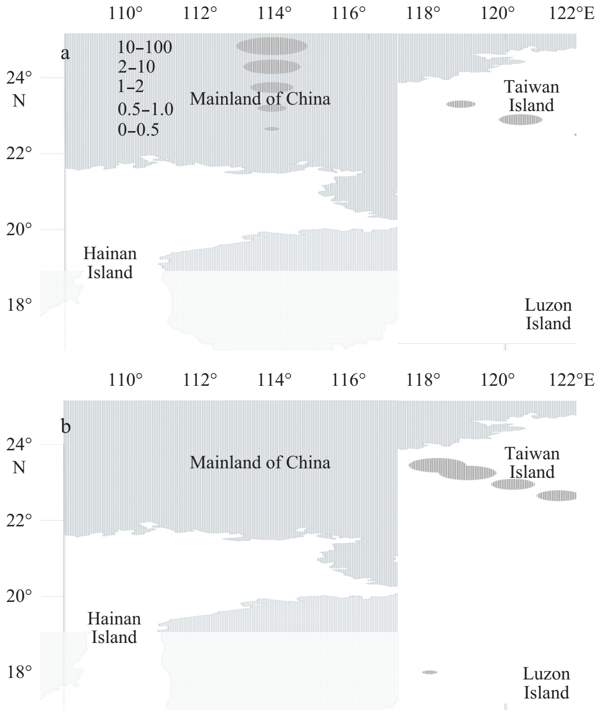

Fig. 8. Distribution of Tunicata abundance (ind./m^3) in August 2007 (a) and August 2008 (b) in NSCS.

followed by medusae (43), chaetognatha (18), amphipoda (18), and zooplankton larvae (17).

In 2008, 351 species were recorded, including 121 species of copepods and 230 species of other zooplanktons that represented 14 groups. Copepods were also the most dominant zooplankton group. Major copepod species in both years are listed in Appendix (Table A1). Besides copepods, medusae were the second important group in 2008. The species richness of medusae increased from 43 species in 2007 to 88 species in 2008 (Table 2).

Table 3. Correlation coefficients between zooplankton and environmental factors (salinity, temperature and Chl *a*)

Variables	Abundance		Biomass	
	Year 2007	Year 2008	Year 2007	Year 2008
Surface temperature	–0.837*	–0.372	–0.628*	–0.475
Surface salinity	–0.603*	0.830*	–0.598*	–0.688*
Surface Chl *a*	0.739*	0.345	0.765*	0.794*

Note: Level of significant: * P<0.05.

There are also remarkable changes in dominant species. *Subeucalanus subcrassus* was the most dominant copepod in the NSCS in August 2007, followed by *Temora discaudata*, *Nannocalanus minor* and *T. turbinata*. Other dominant species were Echinoplutes larvae, Macruran larvae, *Flaccisagitta enflata*, *Lestrigonus schizogeneios*, and *Lucifer typus*. However, in August 2008, the dominant species changed into *Doliolum denticulatum*, *F. enflata*, *Diphyes chamissonis*, *S. subcrassus*, *T. turbinata*, *Euchaeta concinna* and *Dolioletta gegenbauri*. Among these, *D. denticulatum* and *F. enflata* contributed substantially to the total zooplankton abundance.

The decline in abundance of the dominant copepod species *Subeucalanus subcrassus*, *Temora discaudata*, *Nannocalanus minor*, and *T. turbinate* in 2008 indicated a major change in zooplankton composition. For instance, the mean abundance of *S. subcrassus* decreased from 6.04 ind./m^3 in August 2007 to 2.29 ind./m^3 in August 2008. The other two dominant species, *T. discaudata* and *N. minor* in 2007, were replaced by *Euchaeta concinna*, which usually dominated in winter (Zhang et al., 2009) (Fig. 9a).

In addition to the change in dominant copepod species, other tropical water copepod species, such as *Subeucalanus pileatus*, *Undinula vulgaris*, *Cosmocalanus darwinii*, *S. subtenuis*, *Paraeuchaeta russelli*, *Euchaeta rimana*, *E. plana*, *Labidocera acuta* and *Scolecithrix danae* recorded in 2007 also showed a relatively lower abundance or absence in August 2008 (Fig. 9b), which coincided with the occurrence of the low temperature period. In contrast, *Clausocalanus arcuicornis* and *C. furcatus*, usually dominant in winter (Zhang et al., 2009), were recorded only in August 2008.

3.4 *Variation of zooplankton community structure by cluster classification and nMDS ordination*

Zooplankton communities from the collection stations were classified into four groups (I–IV) according to the cluster analysis (Fig. 10). The dissimilarities between these stations were also visualized by non-metric multidimensional scaling (nMDS) ordination (Fig. 11). The relative distance between these stations reflected their relative dissimilarity in species composition and abundance. For example, samples collected from the onshore sites in 2007 clustered together, indicating that samples from those sites were similar in zooplankton composition. A similar phenomenon was observed in the offshore sites in 2007. However, they were far apart from the samples in 2008 (Fig. 11). SIMPER analysis demonstrated that Echinoplutes larvae, Macruran larvae, *Subeucalanus subcrassus*, *Flaccisagitta enflata*, *Temora discaudata*, *Doliolum denticulatum*, *T. turbinata* and *Diphyes chamissonis*, etc. contributed much to the difference between zooplankton in 2007 and 2008 (Table 4).

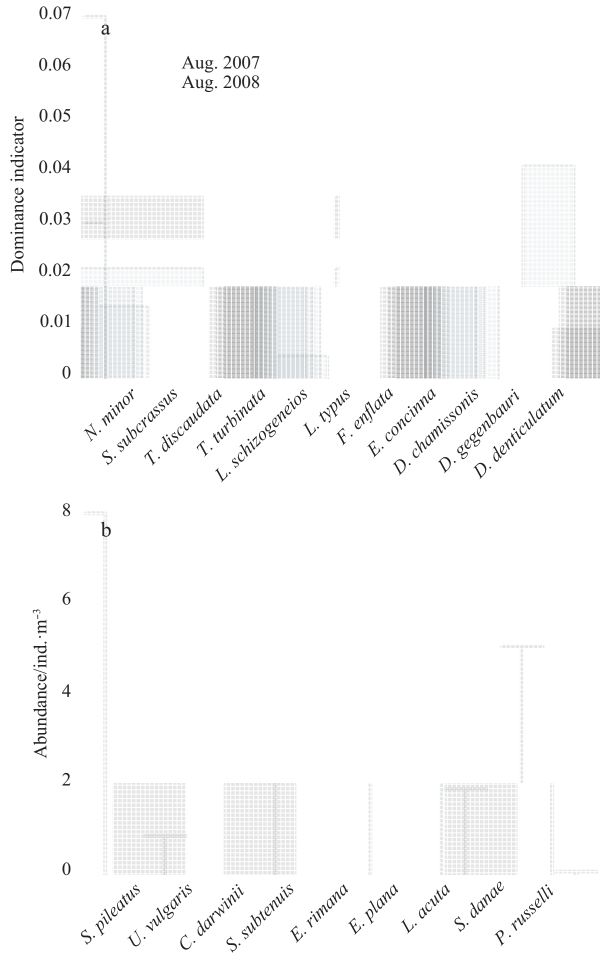

Fig. 9. Dominance indicator of dominant species (a) and abundance (ind./m^3) of other tropical species (b) in August 2007 and August 2008 in NSCS. The full names of dominant species are shown in turn: *Nannocalanus minor*, *Subeucalanus subcrassus*, *Temora discaudata*, *Temora turbinate*, *Lestrigonus schizogeneios*, *Lucifer typus*, *Flaccisagetta enflata*, *Euchaeta concinna*, *Diphyes chamissonis*, *Dolioletta gegenbauri*, *Doliolum denticulatum*. The full names of tropical species are shown in turn: *Subeucalanus pileatus*, *Undinula vulgaris*, *Cosmocalanus darwinii*, *Subeucalanus subtenuis*, *Euchaeta rimana*, *Euchaeta plana*, *Labidocera acuta*, *Scolecithrix danae* and *Paraeuchaeta russelli*.

4 Discussion

The composition of copepod dominant species in the northern South China Sea in summer 2007 was similar to that observed in previous years, such as, in the summer of 2004 (Zhang et al., 2009). Moreover, copepod abundance in the summer of 2007 (69.40 ind./m^3) was very similar to that in the summer of 2004 (70.27 ind./m^3), whereas the copepod community structure between summer 2007 and summer 2008 was strikingly different. The decrease in total zooplankton biomass, abundance, abundance of dominant copepod species and abundance of tropical copepod species correlated with the influence of cold water in early 2008. It is also coincided with the increase in warm temperature species, which are usually dominant in winter.

The anomaly in ocean and climate conditions was also demonstrated by Wheeler (2008), Perlwitz et al. (2009), Trenberth and Fasullo (2010), and Kaufmann et al. (2011), who illustrated a strong La Niña event that dominated the tropical Pacific and nearby in 2008. Affected by La Niña, the long-persisting cold anomaly was prevailed in the SCS in early 2008 (Fig. 1) (Hong and Li, 2009; Wang and Guo, 2009), causing interannual variations of many oceanographic features. For example, the integrated primary productivity in the euphotic zone in NSCS was 745 mg/(m^2·d) in August 2007 (Liu et al., 2009), and sharply decreased to 225.39 mg/(m^2·d) in August 2008 (Song et al., 2010).

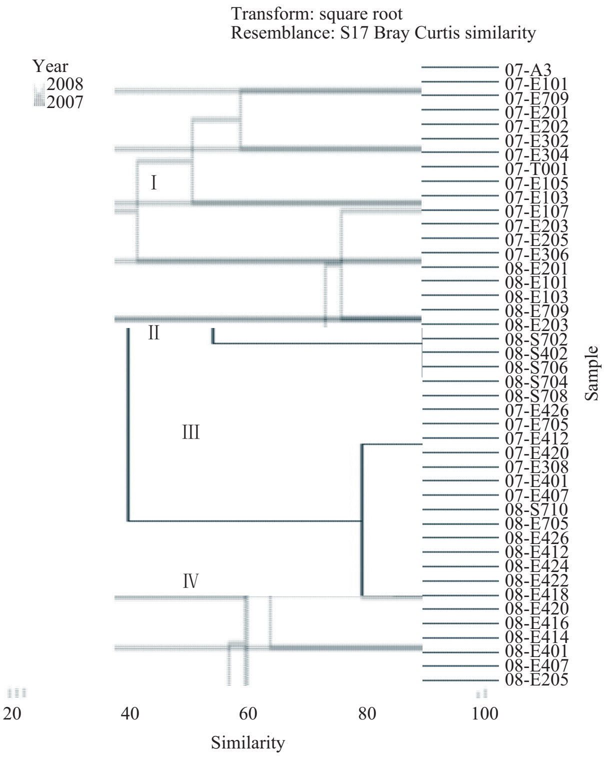

Fig. 10. Cluster analysis using the hierarchical agglomerative method employing group average linking of Bray-Curtis similarities. Samples from stations were coded according to sampling years: 07 means August 2007 and 08 August 2008.

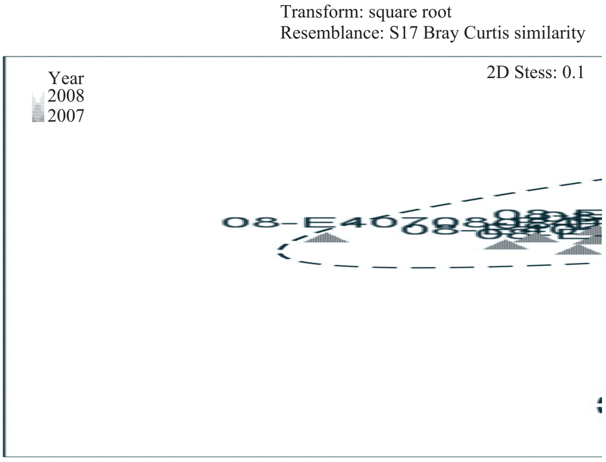

Fig. 11. Non-metric multidimensional scaling ordination (nMDS) showing the relative position of samples based on the Bray-Curtis similarity index using transformed species abundance data. Samples from stations were coded according to sampling years: 07 means August 2007 and 08 August 2008.

Table 4. List of dominant species identified by SIMPER as responsible for dissimilarity in the structure of the clusters shown in Fig. 10

Species	Mean abundance/ind.·m^{-3}		*P*/%
	2007	2008	
Echinoplutes larvae	11.62	0	2.13
Macruran larvae	4.28	0.19	1.39
Subeucalanus subcrassus	6.04	2.29	1.32
Flaccisagitta enflata	6.59	4.85	1.28
Candacia sp.	2.66	0	1.26
Temora discaudata	5.15	1.21	1.22
Doliolum denticulatum	0.72	6.12	1.12
Temora turbinata	3.34	1.77	1.12
Diphyes chamissonis	2.46	2.87	1.12
Lestrigonus schizogeneios	4.38	0.88	1.07
Dolioletta gegenbauri	1.88	2.05	1.04
Lucifer typus	3.34	1.46	1.01
Nannocalanus minor	3.95	1.03	0.99
Total	56.38	24.73	16.07

Note: The mean abundance (ind./m^3) of each species in each assemblage (2007, 2008) is also shown, as their proportional contribution to dissimilarity (only species of top thirty for dissimilarity are reported here). *P* means the proportion of contribution to dissimilarity.

The decline of copepod abundance in August 2008 could also be attributed to the decrease in number of larger phytoplankton preferred by copepods (Fig. 5). Copepods have a preference for larger particles (>20 μm) such as microphytoplankton and ciliates (Kleppel, 1993; Sommer et al., 2000; Stibor et al., 2004; Vargas and González, 2004). The decline of large size phytoplankton in August 2008 could have affected the zooplankton community structure (Lavaniegos et al., 2002), which was further corroborated by the lack of correlation between Chl *a* and zooplankton abundance in August 2008.

In contrast, the increase in tunicate abundance during the same period may be due to their ability to remove particles at high filtration rates and their preference for small particles (<20 μm) (Alldredge and Madin, 1982; Flood et al., 1992; Sommer et al., 2000). Furthermore, their life histories permit rapid, exponential population increases to take immediate advantage of increased food supply and to exist without reproduction during periods of low food supply (Alldredge and Madin, 1982). Although the numerical increase in tunicates contribution was lower in comparison to the decrease in copepod abundance, differences in typical body sizes of both groups would mean a much larger change in ecosystem functioning (González et al., 2000; Lavaniegos et al., 2002).

Medusa was usually used as indicator of environmental changes, such as temperature change (Purcell et al., 2007). The increase in medusa was probably due to the extremely cold anomaly event in early 2008. The medusa distribution and abundance patterns have also been correlated with climate change, such as the southern-oscillation and the North Pacific Decadal Oscillation (Hays, 2006). On the other hand, many fish compete for the same prey as medusa (Purcell and Arai, 2001). Many fish stocks are in decline in some regions, and there is strong evidence for coincident rises in jellyfish abundance (Graham et al., 2001; Lynam et al., 2006). Xian et al. (2008) investigated the catch rate and diversity in waters near the Penghu Island from March 2008 to May 2008, and found that both the catch rate and diversity decreased significantly, and nearly 90% of fishes died during the cold event. Their findings support our results that the death of fish caused by extremely low temperatures and climatic changes may have led to the increase of medusa.

5 Conclusions

A total of 467 zooplankton species, representing 16 groups, were identified in the two cruises in the NSCS, with 275 species being identified in August 2007 and 351 in August 2008. Compared with the summer of 2007, the zooplankton abundance and biomass decreased in the summer of 2008. There are also remarkable changes in dominant species and tropical species in 2008. For example, a dramatic decline was revealed in the abundance of four dominant copepod species: *Subeucalanus subcrassus*, *Temora discaudata*, *Nannocalanus minor* and *Temora turbinata* in 2008. A decrease in total zooplankton abundance and abundance of dominant species, especially abundance of tropical species were correlated with the influence of cold water in the early of 2008, and coincided with the increase in warm temperature species that are usually dominant in winter. Zooplankton species composition showed a change from tropical and subtropical species to warm temperate species. The decline of copepod abundance in 2008 could also be attributed to a decrease in larger phytoplankton (>20 μm), which is preferred by copepods. In contrast, the increase of tunicate abundance may be attributed to an increase in small particles (<20 μm) preferred by tunicates. The variation in zooplankton communities during the two years indicated an anomaly in oceanographic conditions along with the occurrence of a strong La Niña event.

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Appendix:

Table A1. Major copepod species present (+) during August 2007 and 2008 in the NSCS

Species	Cruises	
	2007	2008
Order Calanoida Sars 1903		
Family Acartiidae Sars 1903		
Acartia negligens Dana 1849		+
Family Augaptilidae Sars 1905		
Haloptilus longicornis (Claus 1863)		+
Family Calanidae Dana 1849		
Neocalanus gracilis (Dana 1849)		+
Neocalanus tenuicornis Dana 1849	+	+
Canthocalanus pauper (Giesbrecht 1888)	+	+
Nannocalanus minor (Claus 1863)	+	+
Undinula valgaris (Dana 1849)	+	+
Undinula darwini (Lubbock 1860)	+	+
Family Candaciidae Giesbrecht 1892		
Candacia bipinnata (Boeck 1864)		+
Candacia catula (Giesbrecht 1889)		+
Candacia pathydactyla (Dana 1849)		+
Family Centropagidae Giesbrecht 1892		
Centropages calaninus (Dana 1849)	+	+
Centropages gracilis (Dana 1849)	+	+
Centropages longicornis (Mori 1932)		+
Centropages orsinii Giesbrecht 1889	+	+
Family Eucalanidae Giesbrecht 1892		
Eucalanus elongatus (Dana 1849)		+
Pareucalanus attenuatus (Dana 1849)	+	+
Subeucalanus crassus (Giesbrecht 1888)	+	+
Subeucalanus mucronatus (Giesbrecht 1888)	+	+
Subeucalanus subtenuis (Giesbrecht 1888)	+	+
Subeucalanus subcrassus (Giesbrecht 1888)	+	+
Family Euchaetidae Giesbrecht 1892		
Euchaeta concinna Dana 1849	+	+
Euchaeta plana Mori 1937	+	+
Euchaeta marine Bradford 1974	+	+
Family Heterohabdidae Sars 1902		
Heterorhabdus papilliger (Claus 1863)	+	+
Family Lucicutiidae Sars 1902		
Lucicutia flavicornis (Claus 1863)		+
Family Metridiidae Sars 1902		
Pleuromamma abdominalis (Lubbock 1856)	+	+
Pleuromamma gracilis (Claus 1863)	+	+
Pleuromamma xiphias (Giesbrecht 1889)		+
Family Paracalanidae Giesbrecht 1892		
Paracalanus parvus (Claus 1863)	+	+
Pavocalanus crassirostris F.Dahl 1893	+	+
Paracalanus gracilis Chen and Zhang 1965	+	+
Acrocalanus gibber Giesbrecht 1888	+	
Family Pontellidae Dana 1853		
Calanopia elliptica (Dana 1849)	+	
Calanopia minor A.Scott 1902	+	
Labidocera cauta (Dana 1849)	+	+
Pontellina plumata (Dana 1849)		+
Family Rhincalanidae Geletin 1976		
Rhincalanus cornutus (Dana 1849)	+	+
Family Scolecithricidae Giesbrecht 1892		

to be continued

Continued from Table A1

Species	Cruises	
	2007	2008
Scolecithrix danae Lubbock 1856	+	+
Family Temoridae Giesbrecht 1892		
Temora discaudata Giesbrecht 1889	+	+
Temora turbinata (Dana 1849)	+	+
Order Cyclopoida Burmeister 1834		
Family Oithonidae Dana 1853		
Oithona plumifera Baird 1843		+
Oithona setigera Dana 1849		+
Order Poecilostomatoida Thorell 1859		
Family Oncaeidae Giesbrecht 1892		
Oncaea venusta Philippi 1843	+	+
Oncaea mediterranea (Claus 1863)	+	
Pachyos punctatum (Claus 1863)		+
Family Sapphirinidae Thorell 1859		
Sapphirina nigromaculata Claus 1863	+	+
Sapphirina opalina Dana 1849		+
Copilia mirabilis Dana 1849	+	+
Family Corycaeidae Dana 1852		
Corycaeus affinis Mcmurrichi 1916		+
Farranula concinna Dana 1847		+
Corycaeus longistylis Dana 1849	+	+
Corycaeua speciosus Dana 1849	+	+

Note: The major copepod species which were collected in 50% or more samples during each cruise.