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A Comparison of the Zooplankton Community in the Bay of Bengal and South China Sea During April−May, 2010

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Abstract This study compares the structure of the zooplankton community in the Bay of Bengal (BoB) and South China Sea (SCS) during the period of spring inter-monsoon, 2010. A total of 215 species of zooplankton were identified, of which 187 species were present in the BoB and 119 in the SCS. Of the taxonomic groups recorded, Copepoda was the most diverse group in all samples followed by pelagic Tunicata, Siphonophorae and Chaetognatha. *Flaccisagitta enflata*, *Cosmocalanus darwinii*, Euchaeta larva, Macrura larva and *Candacia truncata* were predominant both in the BoB and SCS. Moreover, the distribution of some dominant species differed regionally, such as *Cypridina dentata*, *Pleuromamma robusta* and *Mesosagitta decipiens* only in the BoB, and *Pleuromamma gracilis*, *Neocalanus gracilis* and *Eudoxoides spiralis* in the SCS. The average zooplankton abundance was 33.37 ± 7.19 ind. m^{-3} in the BoB and 35.08 ± 2.07 ind. m^{-3} in the SCS. Copepoda was one of the most abundant groups in the BoB and SCS. Based on multivariate analysis, it was possible to distinguish the zooplankton in the BoB and SCS communities at the similarity level of approximately 55%, and the dissimilarity was mainly due to *C. dentata*, *P. robusta*, *M. decipiens*, *C. darwinii*, *N. gracilis* and *P. gracilis*. The relationships between zooplankton and temperature, salinity and chlorophyll *a* were not statistically significant. Zooplankton community structure in the BoB and SCS was observed to be generally similar in terms of species composition and abundance, but the differences observed may be the result of species-specific geographical distribution and local hydrographic conditions.

Key words zooplankton; community; inter-monsoon; Bay of Bengal; South China Sea

1 Introduction

The Bay of Bengal (BoB) is a semi-enclosed bay and its proximity to the equator results in monsoon winds and voluminous riverine inflow (Babu *et al*., 2003). The South China Sea (SCS) and BoB, with a similar latitudenal range, are both within the scope of Indian-Pacific fauna (Madhupratap and Haridas, 1986; Miyamota *et al*., 2014). Understanding the zooplankton community is essential in pelagic ecosystems as it plays a pivotal role in the trophic link between primary production and predators such as fish and marine mammals. With regard to the patterns of zooplankton in the BoB, it has recently been demonstrated that the oceanic central BoB supports higher zooplankton diversity than the coastal western bay, and the zooplankton community structure can be affected by primary production and local hydrographic conditions (Rakhesh *et al*., 2006; Fernandes and Ramaiah, 2009; Jitlang, 2009).

A comprehensive cruise was undertaken in the tropical northeastern Indian Ocean during April−May, 2010. The section at the 10˚ latitude of the BoB was only well-sampled due to rough sea conditions. Three stations were also sampled at 10˚N from the SCS on the return leg. Based on the zooplankton samples from the BoB and SCS, the following were determined: 1) a comparison of the zooplankton community in the BoB and the SCS during the spring inter-monsoon; 2) possible reasons for the longitudinal distribution of zooplankton at the 10˚N transect in the BoB and SCS.

2 Materials and Methods

2.1 Study Site

From April 12 to May 29, 2010, physical, chemical and biological field studies were carried out along the transect 10˚N (83˚ to 111˚E) in the BoB and SCS onboard R. V. Shiyan 1. A total of 12 sampling stations were selected at an interval of approximately one longitudinal degree (Fig.1). Table 1 shows the detailed information obtained at the sampling stations.

2.2 Sampling Procedures

The sampling protocols and results of temperature, salinity, chlorophyll *a* (Chl *a*) and primary production have

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been documented by Liu *et al.* (2011) and Li *et al.* (2012). Zooplankton were collected using a planktonic net (80 cm mouth diameter, 505 µm mesh opening) towed vertically from a depth of 200 m to the surface. The net mouth was equipped with a flowmeter (Hydro-Bios) to determine the volume of filtered water in each tow (unit: m^3). Trawl winch speed was approximately 0.5–1 $m\,s^{-1}$. The samples were preserved in a 5% formalin-seawater solution for subsequent analysis. All specimens were identified and counted based on the status of currently available taxonomic information (Chen and Zhang, 1965; 1974; Chen and Shen, 1974; Zheng *et al*., 1984; Zhang *et al*., 2010).

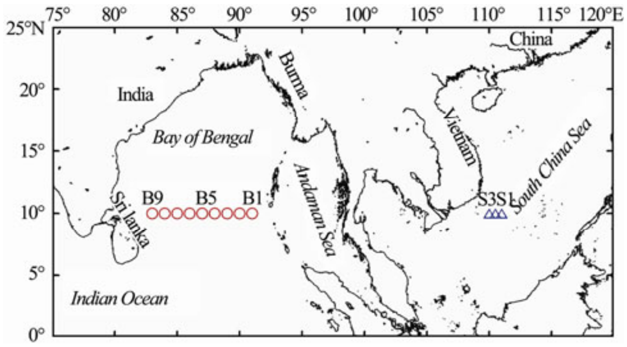

Fig.1 Sampling stations in the Bay of Bengal (B1–B9, ○) and South China Sea (S1–S3, Δ).

Table 1 Detailed information on the location of the stations, depth, sampling date and time during the cruise

Station	Longitude (˚E)	Latitude (˚N)	Depth (m)	Date (Month/Day)	Sampling time
B1	91	10	3441	04/25	04:39–05:42
B2	90	10	3303	04/25	21:00–22:08
B3	89	10	3374	04/26	21:40–22:36
B4	88	10	3422	04/27	16:25–17:25
B5	87	10	3475	04/28	03:20–04:16
B6	86	10	3515	04/28	15:15–16:15
B7	85	10	3458	04/29	03:15–04:04
B8	84	10	3589	04/29	13:45–14:38
B9	83	10	3630	04/30	01:06–01:56
S1	111	10	2510	05/23	19:45–20:35
S2	110.30	10	2500	05/24	08:12–09:00
S3	110	10	1644	05/24	14:15–15:15

2.3 Data Analysis

Species richness (S) was calculated as the number of taxa observed in a given sample. The Shannon-Wiener diversity index (H') and Pielou's index of evenness (J') were calculated as follows (Ma, 1994):

$$H' = -\sum_{i=1}^{s} P_i \ln P_i\ , \quad J = H' / \ln S\ ,$$

where P_i is the proportion of individuals from a sample unit belonging to species i. A species was defined as dominant when $Y > 0.02$, where Y is the dominance indicator (Xu and Chen, 1989). Y was calculated as follows:

$$Y = (n_i / N) \cdot f_i\ ,$$

where n_i was the ith species abundance, f_i was the frequency of i species occurrence, and N was the total abundance of all zooplankton species.

A similarity matrix was constructed using the Bray-Curtis index. Non-metric multidimensional scaling (nMDS) was also applied to the similarity matrices to determine the similarity of sites with respect to zooplankton composition. The similarity percentage (SIMPER) method was selected to show the percentage contribution of each taxon to the average dissimilarities within the BoB and SCS. All multivariate analyses were carried out using PRIMER 6.0 software (Clarke and Gorley, 2006). The Shapiro-Wilk test was used to examine the difference in the zooplankton community structure between the BoB and SCS, with a significance level of $P<0.05$. The Pearson correlation between zooplankton abundance (after log-transformed) and environmental parameters (surface sea temperature, salinity, and Chl *a*) was determined to identify which factor influenced their distribution. The distribution of species and stations in relation to physical and biological factors was also evaluated by canonical correspondence analysis (CCA) using CANOCO 4.5.

3 Results

3.1 Environmental Conditions

The results for temperature, salinity and Chl *a* concentration published by Liu *et al*. (2011) and Li *et al*. (2012) are briefly described here. The surface temperature and salinity ranged from 30.61 to 30.79℃ and from 33.48 to 33.65 in the SCS, respectively. However, higher temperature and lower salinity were present in the BoB and

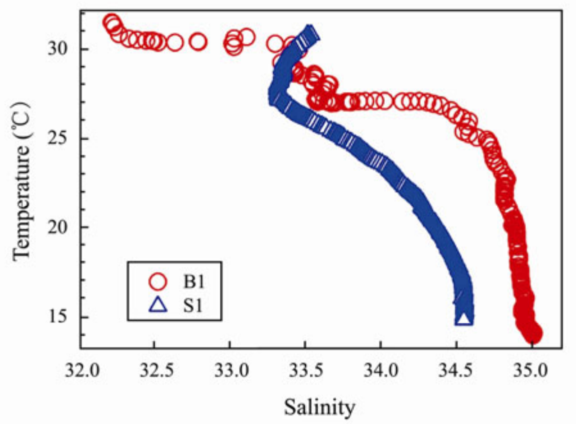

Fig. 2 T-S plot from 200 m to surface layer data at station B1 (located in the Bay of Bengal) and S1 (located in the South China Sea).

ranged from 31.16–32.09℃ and 31.72–33.43, respectively, reflecting the influence of freshwater influx from the land. The surface Chl *a* concentration was 0.065 ± 0.009 mg m^{-3}, 80% of which was contributed by picophytoplankton cells (<3 μm) (Li *et al.*, 2012). The concentration of Chl *a* was approximately 0.05 mg m^{-3} in the SCS. The temperature-salinity (T-S) plot at stations S1 and B1 suggested the presence of low salinity and high temperature in the BoB was influenced by coastal waters (Fig.2).

3.2 Zooplankton Community

3.2.1 Species diversity

In total, 215 species were identified, of which 187 species were present in the BoB and 119 in the SCS (Table 2). Copepoda was the most diverse taxon with 81 species, consisting of 58 calanoid species, 22 cyclopoids and one harpacticoids. The other groups such as pelagic tunicates, siphonophores and chaetognaths were also important components of the zooplankton in both regions. The similarity ratio of siphonophores, calanoids, cyclopoids, chaetognaths and tunicates ranged from approximately 40% to 67%, and were present in both the BoB and SCS (Table 2). Zooplankton was diverse based on the species diversity indices (Table 3). There was no significant difference in species diversity between the BoB and SCS.

Table 2 The number of species of zooplankton in the Bay of Bengal (BoB) and South China Sea (SCS) and their similarity (%) during April–May 2010

Group	BoB	SCS	Total	Similarity (%)
Hydromedusae	8	4	8	50.00
Siphonophorae	22	19	25	64.00
Scyphomedusae	1	0	1	0.00
Ctenophora	1	0	1	0.00
Polychaeta	2	3	4	25.00
Mollusca	14	4	16	12.50
Ostracoda	9	4	10	30.00
Calanoida	50	32	58	43.10
Cyclopoida	18	14	22	45.45
Harpacticoida	0	1	1	0.00
Amphipoda	9	2	10	10.00
Euphausiacea	6	1	6	16.67
Decapoda	2	1	2	50.00
Chaetognatha	17	13	18	66.67
Tunicata	23	17	27	48.15
Larvae	5	4	6	50.00
Total	187	119	215	42.79

Table 3 Species richness, diversity index, and evenness index of zooplankton in the Bay of Bengal (BoB) and South China Sea (SCS). *P* values from the Shapiro-Wilk test

Index	BoB		SCS		*P*
	Range	Mean ± SD	Range	Mean ± SD	
Richness	59–84	72 ± 8	74–83	77 ± 5	0.276
H'	4.04–5.16	4.75 ± 0.33	4.94–5.12	5.05 ± 0.10	0.157
J'	0.69–0.81	0.77 ± 0.04	0.79–0.82	0.81 ± 0.02	0.172

3.2.2 Dominant species

There were 13 and 11 dominant species in the BoB and SCS, respectively, determined by the dominance indicator

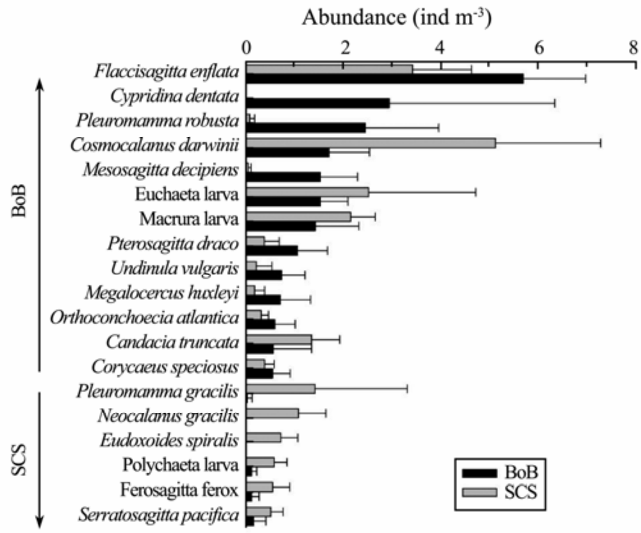

Fig.3 Dominant species and their abundance (mean ± SD, ind m^{-3}) in the Bay of Bengal (BoB) and South China Sea (SCS) during April–May 2010. Species dominant in both the BoB and SCS are shown in bold.

Y > 0.02 (Fig.3). *Flaccisagitta enflata*, *Cosmocalanus darwinii*, Euchaeta larva, Macrura larva and *Candacia truncata* were predominant in both the BoB and SCS, but abundance differed significantly for *F. enflata* (P=0.023) and *C. darwinii* (P=0.026) in the two regions, and no significant differences for the other 3 dominant species were observed. Moreover, some species dominated in the BoB and others in the SCS. For example, *Cypridina dentata*, *Pleuromamma robusta* and *Mesosagitta decipiens* were dominant only in the BoB, and *Pleuromamma gracilis*, *Neocalanus gracilis* and *Eudoxoides spiralis* were dominant in the SCS.

3.2.3 Abundance

The average zooplankton abundance (mean ± SD) was 33.37 ± 7.19 ind m^{-3} and 35.08 ± 2.07 ind m^{-3} in the BoB and SCS, respectively. Marked variation was found at the BoB stations, with relatively higher abundance at B1 (Fig.4a). The percentage of different groups to total abundance varied among the sampling stations (Fig.4b). Copepods, together with chaetognaths, siphonophores and tunicates contributed approximately 80% to the total abundance in the BoB and SCS, with the exception of B3 and B8. The difference in zooplankton abundance between the BoB and SCS was not significant (P=0.704).

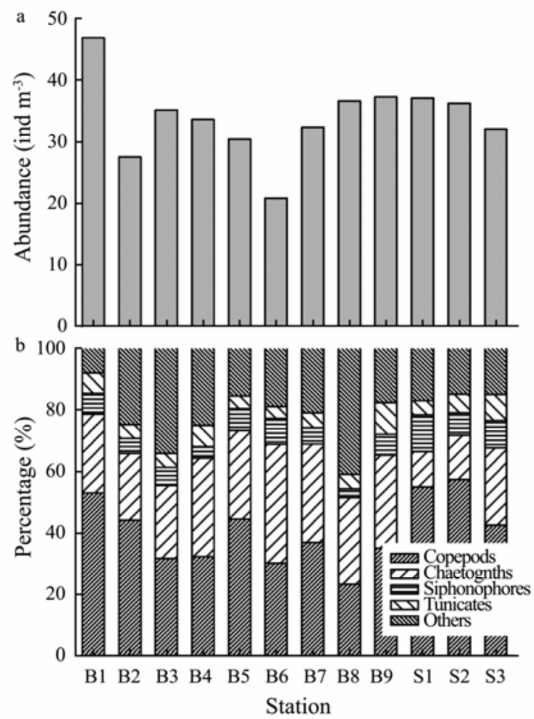

Fig.4 Abundance distribution (a) and percentage (b) of different groups of zooplankton in the Bay of Bengal (B1–B9) and South China Sea (S1–S3).

Table 4 Variations in abundance and percentage of different zooplankton groups in the Bay of Bengal (BoB) and South China Sea (SCS)

Groups	BoB		SCS	
	Abundance (ind m^{-3})	Percentage (%)	Abundance (ind m^{-3})	Percentage (%)
Hydromedusae	0.65 ± 0.15	1.95	0.36 ± 0.15	1.02
Siphonophorae	1.89 ± 0.68	5.66	3.31 ± 0.98	9.43
Scyphomedusae	<0.01	<0.01	<0.01	<0.01
Ctenophora	<0.01	<0.01	<0.01	<0.01
Polychaeta	0.26 ± 0.10	0.77	0.14 ± 0.06	0.39
Mollusca	0.38 ± 0.29	1.14	0.17 ± 0.06	0.49
Ostracoda	3.62 ± 3.57	10.83	0.73 ± 0.15	2.09
Calanoida	10.91 ± 5.18	32.70	16.30 ± 4.44	46.47
Cyclopoida	1.53 ± 0.55	4.60	1.90 ± 0.78	5.43
Harpacticoida	<0.01	<0.01	0.03 ± 0.06	0.10
Amphipoda	0.12 ± 0.19	0.35	0.10 ± 0.00	0.29
Euphausiacea	0.38 ± 0.70	1.13	0.10 ± 0.17	0.29
Decapoda	0.22 ± 0.16	0.67	0.73 ± 0.75	2.09
Chaetognatha	9.53 ± 1.90	28.56	5.83 ± 1.95	16.63
Tunicata	1.92 ± 0.97	5.77	2.20 ± 0.50	6.27
Larvae	1.96 ± 0.98	5.87	3.17 ± 0.81	9.03

Copepods were the most abundant group (Table 4), and calanoids dominated with 32.70% and 46.47% in the BoB and SCS, respectively. Chaetognaths were the second most abundant group. A high number of ostracods were observed in the BoB, but not in the SCS. The abundance of siphonophores was relatively high in the SCS, and low in the BoB. Tunicates and planktonic larvae were also important groups. Significant differences in the abundance of siphonophores (P=0.017), calanoid copepods (P=0.043), and chaetognaths (P=0.009) were observed between the BoB and SCS.

3.2.4 Multivariate analysis

The results of hierarchical cluster analyses revealed the presence of two main groups at the similarity level of approximately 55%: S1–S3 in the SCS, B1 and B2–B9 in the BoB (Fig.5a). The zooplankton community in the SCS differed significantly from that at B1 and the other eight sampling stations in the BoB (2D stress = 0.09) (Fig.5b). In addition, the species at station B1 were also significantly different from those at the other eight sampling stations in the BoB. The results of the SIMPER analysis showed that the average rate of dissimilarity was 48.23% for the BoB and SCS, with 31 species contributing to the difference at the 90% cut-off level for cumulative dissimilarity. The species contributing to the BoB and SCS dissimilarly were represented mainly by *Cypridina dentata*, *Pleuromamma robusta*, *Mesosagitta decipiens*, *Cosmocalanus darwinii*, *Neocalanus gracilis* and *Pleuromamma gracilis*.

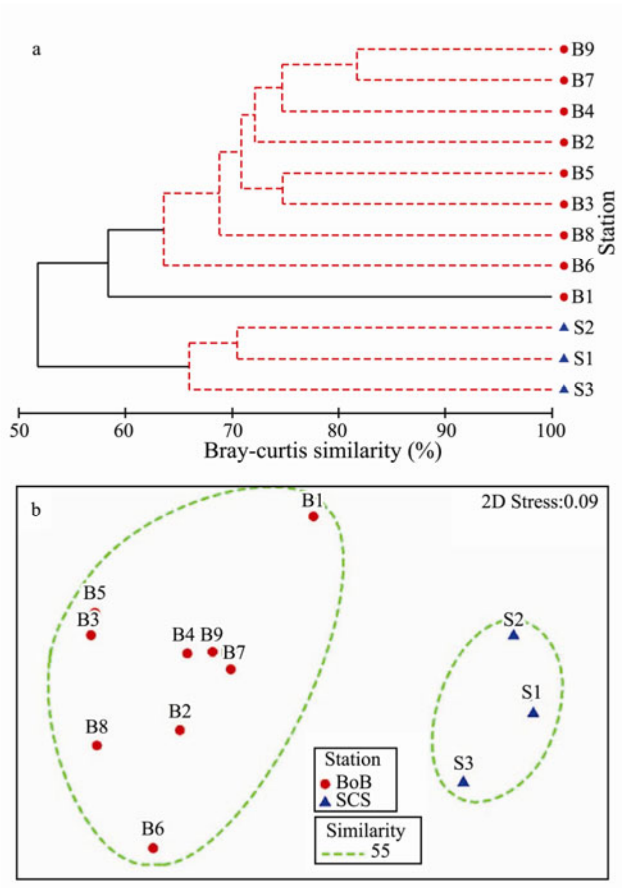

Fig.5 Results of the clustering (a) and multidimensional scaling analysis (b) of the zooplankton community at the sampling stations in the Bay of Bengal (BoB, B1–B9) and South China Sea (SCS, S1–S3). Black solid lines connect stations that are statistically distinct groups ($P<0.05$), and red dotted lines connect samples that are not statistically unique ($P>0.05$) in Fig.5a.

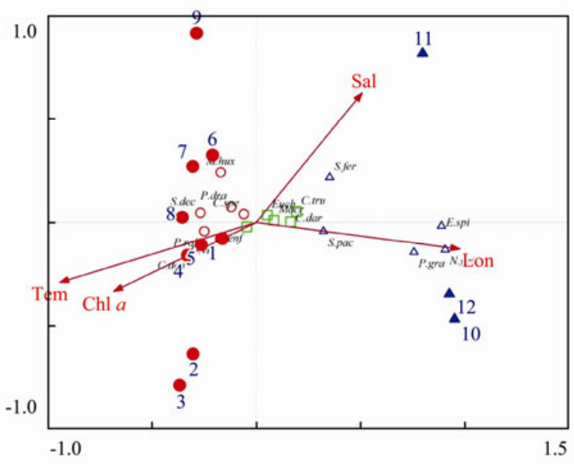

Fig.6 CCA triplots of dominant species abundance (□, dominant species in the BoB and SCS; △, dominant in the SCS; ○, dominant in the BoB) in relation to environmental parameters (Lon, longitude; Sal, salinity; Tem, temperature; Chl *a*, chlorophyll *a*) and sampling stations (●, the BoB stations 1–9 for B1–B9, ▲, the SCS stations 10–12 for S1–S3). The abbreviation for dominant species refers to the first letter of the genus and three letters of the species in Fig.3.

Results of the CCA analysis also suggested that the sampling stations could be classified into BoB and SCS groups (Fig.6). Salinity and longitude may have affected zooplankton distribution in the SCS, while zooplankton distribution was influenced mainly by temperature and Chl *a* in the BoB. However, no correlation coefficients were found between zooplankton abundance and temperature, salinity and Chl *a* concentration in the BoB and SCS (data not shown).

4 Discussion

This study aimed to compare the structure of the zooplankton community based on 12 sampling stations at 10˚N latitude in the BoB and SCS. A significant difference was found in the zooplankton community in these regions on the basis of multivariate analysis. However, the BoB and SCS also had a lot in common in terms of the occurrence and abundance of species.

The sampling sites were located within the biogeographic province of the Indian-Pacific region (Madhupratap and Haridas, 1986; Miyamoto *et al*., 2014), which is characterized by high biodiversity. A total of 215 species were identified from a depth of 200 m to the surface at 12 stations (Table 2). There may have been a few species in the study areas which were not recorded such as smaller or deeper species, due to the coarse mesh size used and limited hauling depth. Studies on zooplankton distribution in the BoB during and after the International Indian Ocean Expedition (1960–1965) are scarce, and most include the coastal waters. Furthermore, these data are mainly focused on the Copepoda and Chaetognatha (Madhupratap and Haridas, 1986; Fernandes and Ramaiah, 2009; Nair *et al*., 1981, 2015). Copepods and gelatinous zooplankton, including siphonophores and pelagic tunicates, were the main contributors to zooplankton composition and abundance in the study area (Table 2, Fig.4). Hence, the comparable data are very rare in the BoB.

The species richness differed little among the sampling stations with an average of 70 species of zooplankton per station (Table 3), which suggests that the spatial variation in zooplankton species richness was not distinct in the investigated waters of the BoB and SCS. This is inconsistent with recent results found in the Nansha Islands in the South China Sea (Yin *et al*., 2006) where most of the zooplankton species inhabited the tropical oceanic waters and were distributed more evenly. Copepoda was the most abundant group in terms of diversity and abundance, followed by Chaetognatha in the BoB and SCS (Fig.4, Table 4). Similarly, copepods also dominated numerically in the waters around Nansha Islands. Moreover, zooplankton in the Nansha Islands was predominated mainly by *Flaccisagitta enflata*, *Cypridina nami*, *Cosmocalanus darwinii*, *Pleuromamma gracilis* and Echinopluteus larva (Yin *et al*., 2006). Our results show that *F. enflata* was also abundant in the BoB and SCS during the study period (Fig.3). This species often dominated the BoB (Nair *et al*., 1981, 2015). Thus, *F. enflata* may determine the zooplankton abundance in both BoB and SCS waters.

It is notable that the number of species was lower in the SCS than in the BoB, probably because only 3 stations were sampled in the SCS, and sampling dates were 20 days apart. Overall, the zooplankton communities in the BoB and SCS were generally similar.

In marine ecological research, multivariate methods (through clustering and ordination) have proved very useful for detecting differences in the biotic structure between samples in space and time or changes over time (Clarke and Warwick, 1994; Rakhesh *et al*., 2006). The sampling stations could be separated into the BoB and SCS communities at the level of about 55% (Fig.5), which confirmed that there was a difference in the zooplankton structure as shown by the low 2D stress value. Although the similarity in species composition in the two regions was approximately 45%, the abundance and distribution of some species varied between the BoB and SCS. The abundance of groups (siphonophores, calanoids and chaetognaths), and dominant species (*F. enflata* and *Cosmocalanus darwinii*) differed significantly in the BoB and SCS. Although 5 dominant species were present both in the BoB and SCS, other species dominated only in one region (Fig.3). This species-specific distribution may be the result of geographical variation or local hydrographic conditions (Miyamota *et al*., 2014). The presence of low temperature and high salinity waters in the SCS and high temperature and low salinity waters in the BoB may be one reason for the dissimilarity in the zooplankton community. During the spring inter-monsoon period, the southern BoB is influenced by low-salinity coastal water (Xuan *et al*., 2012), which could enhance the Chl *a* concentration and provide a potential food source for zooplankton. Li *et al*. (2012) found that high Chl *a* concentration occurred from 89˚–91˚E, and micro-phytoplankton dominated. High primary production was also observed at stations located from 89˚–91˚E (Liu *et al*., 2011). The effect of coastal waters in the BoB may contribute to the difference in zooplankton between B1 and other stations in the BoB (Figs.2 and 6). Fernandes and Ramaiah (2009) reported that mesozooplankton biomass was increased when food availability was enhanced by eddies in the oceanic central BoB during the summer monsoon. It should be borne in mind that zooplankton in this study was collected from only 12 stations during the spring inter-monsoon period. Therefore, this study provides only preliminary information on the spatial connection or dislocation of the zooplankton community from the SCS to the BoB. The characteristics of the zooplankton community structure in the BoB and SCS require further study based on more observations.

In conclusion, the zooplankton community in the BoB and SCS was found to be significantly different based on multivariate analysis. The difference in species composition and abundance of zooplankton in the BoB and SCS may be due to species-specific associations related to geographical distribution and hydrographic conditions.

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