Vol. 20: 209–217, 2014
doi: 10.3354/ab00556

AQUATIC BIOLOGY
Aquat Biol

Published online April 24

Hyperiid amphipod communities and the seasonal distribution of water masses in eastern Beibu Gulf, South China Sea

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ABSTRACT: The species composition and abundance of the planktonic Hyperiidea and their relationship with environmental factors (depth, temperature, salinity, dissolved oxygen, turbidity and chlorophyll *a* concentration) were analyzed based on 4 seasonal investigations in the Beibu Gulf between 2006 and 2007. Hyperiids were represented by 82 species, 5 of which had not previously been recorded in the South China Sea. The hyperiid communities were dominated by *Lestrigonus bengalensis* year-round, *Hyperioides sibaginis* was dominant in spring, summer and autumn, and *Tullbergella cuspidata* became dominant in spring. Both species richness and the Shannon-Wiener diversity index increased from north to south, and from nearshore to offshore. Biodiversity was higher in some regions where the water mass was strongly influenced by the open sea or the lower salinity water off the northern sea shelf. Results of partial correlation analysis showed that species richness was positively related to depth at all times, and negatively related to temperature only in summer and winter. TWINSPAN classification indicated that the Hyperiidea community was divided into 2 groups in spring and winter (a widely distributed group and a pelagic warm-water group), and 3 groups in summer and autumn. A clear distinction between euryhaline and pelagic species can be discerned, based on different geographical distributions of water masses.

KEY WORDS: Hyperiidea · Beibu Gulf · Species composition · Community Structure · DCCA

INTRODUCTION

The Suborder Hyperiidea is comprised exclusively of pelagic amphipods that are typically less than 10 mm in length. Hyperiid amphipods are a significant component of epi- and mesopelagic communities in the tropical ocean, where they are represented mainly by the Physocephalata group (Vinogradov 1991). Most hyperiid species have a wide distribution or are cosmopolitan, although true cosmopolitanism has been questioned by Shih (1986). Hyperiid amphipods play an important role in material circulation and energy flow of the marine ecosystem, are major contributors to secondary productivity, and are the main food of many economically important fishes. Their species composition and distribution are closely linked to fisheries resources development. The distribution and seasonal change of the hyperiid community can be used as a clue for location of shoals of fish (and thus aid fishery exploration), because the fish often chase and follow the amphipods. From the abundance of hyperiids, the size and species of fish in the area can be determined, which can provide guidance to capture fisheries. In addition, the different ecological groups of amphipods are indicative of water quality and ocean currents,

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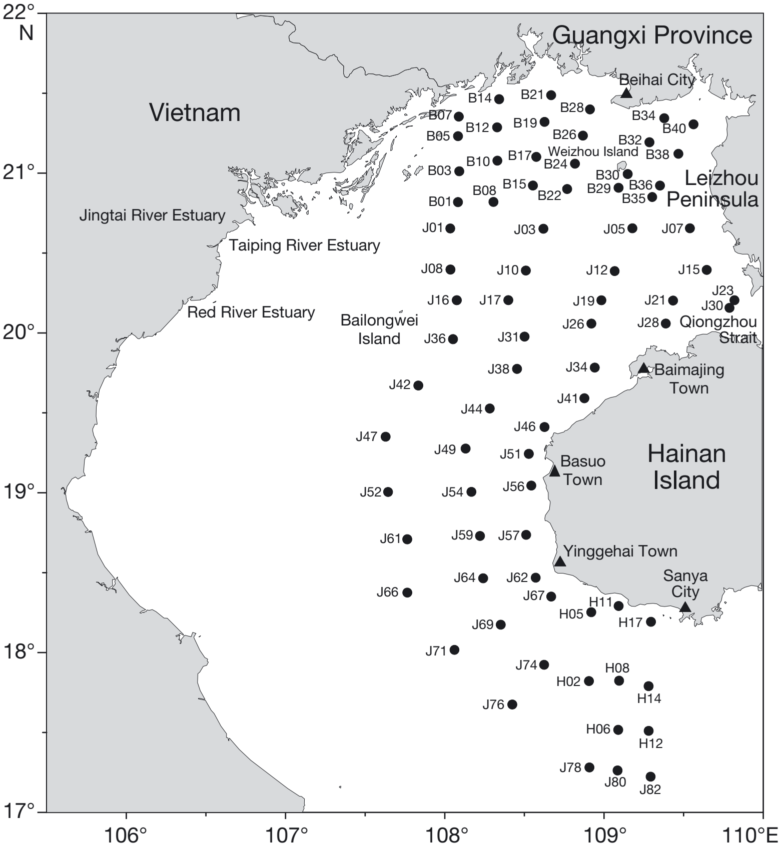

Fig. 1. Sampling stations for Hyperiidea in the Beibu Gulf, South China Sea

and as such, their distribution can provide evidence for the movement of water mass boundaries and material conveyance (Gasca & Shih 2001, Gasca 2003). However, more detailed ecological work on hyperiid amphipods is required in little-known areas, particularly in the tropical and subtropical seas.

The Beibu Gulf is a semi-enclosed gulf with a surface area of 12.84×10^4 km^2, located in the northwest of the South China Sea and surrounded by the land territories of China and Vietnam. The region has a tropical to subtropical climate (Zhao et al. 2007). Knowledge of the hyperiid amphipods in Beibu Gulf waters is quite limited — the general composition and distributional patterns of these crustaceans in the oceanic waters of the Beibu Gulf and adjacent areas remain largely unknown. The earliest surveys regarding the hyperiid fauna of the Beibu Gulf were conducted between 1997 and 1999 (Tang 2006) and 2001 and 2002 (Jia et al. 2004, 2005). In those surveys, 62 species were identified in the entire northern part of the South China Sea, including the Beibu Gulf. Unfortunately, neither survey analyzed hyperiid species abundance, biomass or community structure in the Beibu Gulf. The aim of the present study was to investigate the seasonal variation in taxonomic composition, abundance, diversity and community structure of hyperiid amphipods in the eastern Beibu Gulf, as well as the environmental factors that influence these patterns.

MATERIALS AND METHODS

Study area and sample analysis

Four cruises were conducted in the eastern Beibu Gulf (17° 13′ to 21° 29′ N, 107° 38′ to 109° 49′ E) in spring (12 April to 1 May 2007), summer (15 July to 7 August 2006), autumn (14 October to 15 November 2007) and winter (25 December 2006 to 22 January 2007). Samples were collected at 76 stations (Fig. 1) using Plankton Net I (0.505 mm mesh size, 50 cm diameter, 145 mm length, used at depths <30 m) and Plankton Net L (0.505 mm mesh size, 80 cm diameter, 280 mm length, used at depths >30 m) on the RV 'Shi-Yan 2' (tonnage 1129) which is managed under the South China Sea Institute of Oceanology, Chinese Academy of Sciences. The net was hauled vertically from bottom to surface at a speed of 0.5 m s^{-1}. The samples were fixed *in situ* in 5% buffered formalin seawater. In total, 304 samples were taken between 2006 and 2007 in the eastern Beibu Gulf.

Real-time data on depth (m), temperature (°C) and salinity of surface water were collected and determined using SBE 917 CTD during sampling time. Dissolved oxygen (DO; mg dm^{-2}) was detected using the iodimetry method, electronic nephelometers were used to determine turbidity (ZD; NTU), and the fluorometric method was used for the quantitative analysis of chlorophyll *a* concentration (chl *a*; mg m^{-3}) of surface water. All above methods were conducted according to the national standard methods of China (Office of the State Oceanic Administration 2006). All data were provided by the Office of the '908' Project, Xiamen University.

Hyperiid amphipod analysis

Hyperiid amphipods were identified and counted under a stereomicroscope (Nikon-SMZ1000) and taxonomically resolved to species level wherever possible in accordance with Shih & Chen (1995), Zeidler (1992, 1998), and Vinogradov et al. (1996). Density was standardized to ind. m^{-3}, taking into account the volume of water filtered by the net.

The diversity indices we calculated included seasonal turnover rate (R), dominance (Y), Shannon-Wiener species diversity (H'), Pielou evenness (J') and simplicity index (C) (Magurran 1988). These 5 diversity indices provide 5 different meanings from 5 different angles: R reveals species change among seasons, Y indicates the most dominant species, H' provides number ratios of individuals, J' indicates the differences among individuals of each species, and C indicates proportion of the sample's species number in the total. Taken together, these 5 indices can provide a comprehensive description of community structure.

R is the ratio of the different species number to the total species number in 2 seasons.

H' was calculated as:

$$H' = -\sum_{i=1}^{S} (N_i/N) \log_2 (N_i/N) \quad (1)$$

where N_i is the number of individuals of the ith species in the sample and N is the total number of individuals.

Y was calculated as:

$$Y = (N_i / N) \times f_i \quad (2)$$

where f_i is the frequency of the ith species at a station. A value of $Y \geq 0.015$ indicates that a species is dominant.

J' was calculated as:

$$J' = H'/\log_2 S \quad (3)$$

where S is the total number of species. The value of J' ranges between 0 and 1.

C was calculated as:

$$C = \sum(n_i/N)^2 \quad (4)$$

Statistical analysis

We conducted partial correlation analysis and multiple linear regressions between species richness of the Hyperiidea and 3 environmental factors (water depth, temperature, and salinity) using SPSS 11.0 software. Multiple linear regressions used stepwise regression analysis. Mean square variance of total amphipod abundance, 3 dominant species' abundance and diversity indices were completed using SPSS 11.0.

We determined the quantitative classification and ordination of the hyperiid amphipods community in the eastern Beibu Gulf using 2-way indicator species analysis (TWINSPAN) and detrended canonical correspondence analysis (DCCA). TWINSPAN is based on reciprocal averaging ordination, and is best envisaged in terms of samples characterized by species' abundances. It was performed using WinTWINS 2.3 software. DCCA was used to evaluate the correlations between environmental variables and community structure. The normality of the environmental variables and species abundance was checked using a Monte Carlo test, and variables were $\log(x + 1)$ transformed to improve normality and homoscedasticity for multivariate statistical analyses. These analyses were performed using the CANOCO 4.5 software package.

RESULTS

Composition, diversity and abundance of hyperiid amphipods

In total, 81 species of the Hyperiidea were identified, of which 49 species appeared in summer, 33 in spring, 31 in winter and 30 in autumn. A species list of all taxa observed is provided in the Supplement at www.int-res.com/articles/suppl/b020p209_supp.pdf.

The seasonal turnover rate (R) in spring–summer (63.33%) was the lowest, and higher in summer–autumn (70.49%), autumn–winter (75%) and in winter–spring (70%). Only 9 Hyperiidea species (11.11% of the total number of species) appeared year-round, indicating that there is a high turnover rate of Hyperiidea in the eastern Beibu Gulf, and therefore stability between seasons.

Abundance was highest in summer and lowest in winter. The highest value (9.8 ind. m^{-3}) occurred at Stn HB08 in summer. In spring, high abundance areas (>2 ind. m^{-3}) were found between Guangxi and Hainan Island, and to the south of Hainan Island. In summer, high abundance areas occurred around the Bailongwei Island and to the southwest of Hainan Island. In autumn, Hyperiidea abundance was much lower at each station than in summer. In winter, abundance was at its lowest, with only Stn B28 (2.1 ind. m^{-3}) recording high abundance.

Variances of N, H', J' and C are shown in Table 1. Most of the variation occurred among seasons, with little variance among stations within a single season. H' was highest (1.71) in winter and lowest (1.23) in spring; J' was highest (0.84) in winter and lowest (0.71) in autumn; and C was lowest (0.35) in winter and highest (0.48) in spring. Both the H' and J' were

Table 1. Factorial designs (ANOVA) derived from season and stations to total amphipod abundance, 3 dominant species' abundance and diversity indices in the Beibu Gulf. *p < 0.05; **p < 0.01

	df	*F*	p
Total abundance			
Season	3	10.105	0.000**
Stations	75	0.820	0.842
Lestrigonus bengalensis			
Season	3	5.712	0.001**
Stations	75	0.873	0.752
Hyperioides sibaginis			
Season	3	12.829	0.000**
Stations	75	0.921	0.657
Tullbergella cuspidata			
Season	3	14.322	0.000**
Stations	75	0.862	0.773
H' diversity			
Season	3	5.668	0.001**
Stations	75	2.305	0.000**
C simplicity index			
Season	3	1.489	0.218
Stations	75	0.866	0.764
J' evenness index			
Season	3	10.032	0.000**
Stations	75	1.410	0.029*

highest in winter. In spring, H' was at its lowest and C at its highest.

The geographic distribution of H' in spring, summer and autumn was similar: values rose from north to south, and from inshore to offshore. A region of H' >1 occurred near Bailongwei Island and off the southwest coast of Hainan Island. In winter, the planktonic amphipod species were less common, and the measurable H' indices rendered point-like or plate-like distribution. The values were high only at the stations near Sanya City, where Stn H12 recorded a value of 3.02.

Three dominant species occurred during the 4 seasons: 3 in spring, and 2 each in summer, autumn and winter. Variances in abundance are shown in Table 1. Seasonal turnover rates for these species were low. *Lestrigonus bengalensis* was dominant in all seasons. It was dominant in spring ($Y = 0.08$) and it was most dominant in summer (0.18), autumn (0.24) and winter (0.18). *Hyperioides sibaginis* was dominant in spring (0.03), summer (0.09) and autumn (0.02), while its frequency and abundance were low during the winter. *Tullbergella cuspidata* was the most dominant species in spring (0.28) and dominant in winter (0.02).

The total number of Hyperiidea in the eastern Beibu Gulf was largely determined by these dominant warm-water species which tolerate a wide range of salinity. The Hyperiidea in the eastern Beibu Gulf had shallow-water ecological characteristics in the low-latitude continental shelves.

In spring, amphipods were found at all stations apart from those in the coastal waters. The stations which recorded more than 5 species were typically those near Bailongwei Island in the central Beibu Gulf, and Sanya City. The highest value recorded was 12 species at a single station. Near Bailongwei Island in the central Beibu Gulf, *Lestrigonus bengalensis* and *Tullbergella cuspidata* were the dominant species. Their contribution to the total density of planktonic amphipods reached 56.07%. In the open South China Sea near Sanya City, *Hyperioides sibaginis* was the dominant species.

In summer, many more stations near Bailongwei Island in the central and the southern Beibu Gulf recorded more than 5 species; the maximum number was 19 species at Stn J82. *Hyperioides sibaginis*, *Lestrigonus bengalensis*, *L. macrophthalmus*, *Tullbergella cuspidata* and *L. schizogeneios* were the dominant species in both areas. In the southern Beibu Gulf, other dominant species included *Brachyscelus crusculum*, *Phronimopsis spinifera*, *Phronima bucephala* and *Hyperoche martinezi.*

In autumn, the planktonic amphipod species were found to the west of southern Hainan Island (Yinggehai Town offshore sea area). Few species were distributed along the coastal areas of Guangxi Province and Hainan Island. The main species were *Lestrigonus bengalensis*, *Brachyscelus crusculum* and *Thyropus typhoides.*

In winter, both species richness and distribution were significantly reduced: species were sporadically distributed in the northern and central Beibu Gulf, with a few species occurring just to the south of Sanya City. The main species were similar to those found during autumn.

Species richness horizontal distributions of the planktonic amphipods in the eastern Beibu Gulf showed significant differences among seasons. From spring to winter, the area or stations which had more than 2 species gradually receded from the north to the southwest.

Species richness and environmental factors

We conducted a partial correlation analysis between Hyperiidea species richness and 3 environmental factors in the eastern Beibu Gulf (Table 2). Water depth had a significant positive correlation with species richness (p = 0.01) during all 4 seasons. Temperature had a significant negative correlation with species richness (p = 0.01) in summer and winter. Salinity did not significantly impact species richness.

Table 2. Partial correlation analysis between Hyperiidea species richness and 3 environmental factors in the Beibu Gulf. **p < 0. 01 (2-tailed)

Environmental factors	Spring	Summer	Autumn	Winter
Depth (m)	0.5924**	0.6398**	0.4031**	0.5690**
Salinity	−0.0397	−0.0519	0.0149	0.2203
Temperature (°C)	0.0005	−0.4306**	0.1106	−0.3182**

Table 3. Regression equations of Hyperiidea species richness, depth and temperature in the Beibu Gulf. p < 0.001 for all equations

Seasons	Regression equation	r	F
Spring	y = 0.06depth − 0.559	0.66	56.26
Summer	y = 0.093depth − 0.731temp − 2.831	0.87	113.84
Autumn	y = 0.057depth − 0.955	0.55	31.58
Winter	y = 0.075depth − 0.292temp + 4.315	0.67	29.44

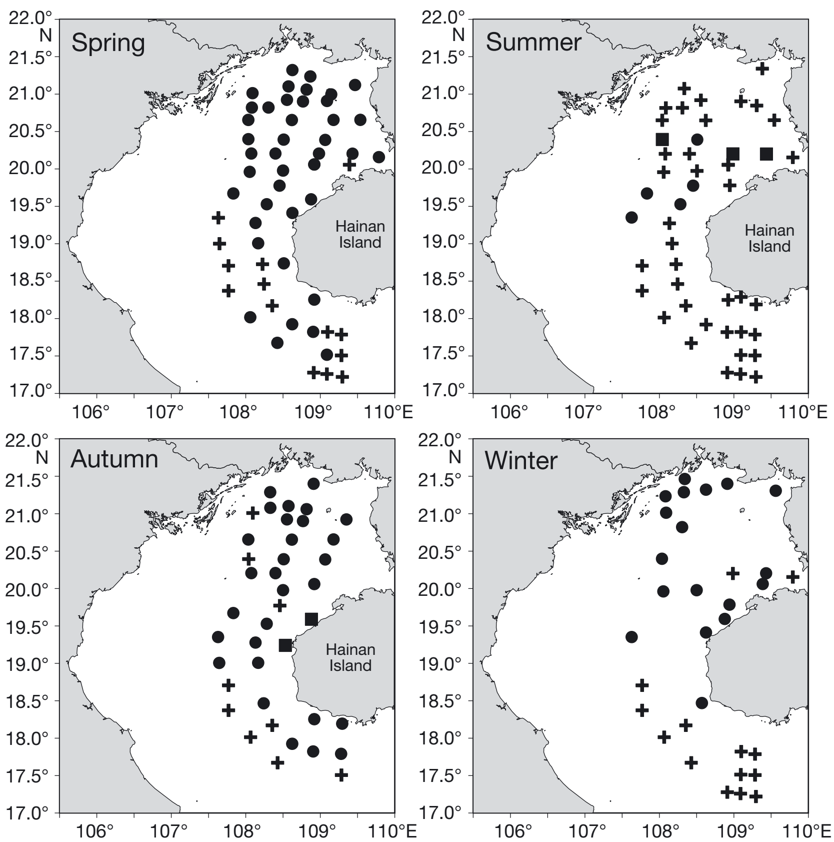

Fig. 2. Groups of Hyperiidea community composition at each site in Beibu Gulf from multivariate analyses in 4 seasons. (●) Group I; (+) Group II; (■) Group III

Multiple linear regression analysis revealed that the regression equation in summer had the best fit (r = 0.87, F = 113.84) (Table 3). Water depth was correlated with species richness (p< 0.001) during all 4 seasons. Temperature was correlated with species richness at p< 0.001 in summer and winter.

Seasonal variation in species composition

In spring and winter, all stations were divided into 2 large groups (Fig. 2) based on TWINSPAN analysis. Group I included stations mainly located in the northern part of the Gulf and along the coast of Hainan Island, whereas Group II included offshore stations to the southwest of Hainan Island.

Results of *t*-tests showed significant differences in the main environmental factors between Group I and Group II in spring and winter (Table 4). In spring, environmental factors between the 2 groups were all significantly different (p < 0.05), except for pH; DO, temperature, salinity, and water depth were significantly different at p = 0.00. During the winter, there were significant differences only for depth (p = 0.00), DO (p = 0.01) and temperature (p = 0.03) between the 2 groups.

In summer and autumn, TWINSPAN analysis identified 3 groups (Fig. 2): Group I occurred in the waters near Bailongwei Island. Group II included most of the stations in the eastern Beibu Gulf; this group contained the most species and showed higher diversity. Group III included only a few stations, and was surrounded by Groups I and II.

In summer (Fig. 2), Group III included Stns J21, J19 and J08. These stations were in the western part of Qiongzhou Strait, and included only 3 species of planktonic amphipods: *Lestrigonus bengalensis, Tullbergella cuspidata* and *L. shoemakeri*. In autumn (Fig. 2), only *L. bengalensis* and *Pseudolycaea* sp. were identified at Station J41 to the southwest of Baimajing Town of Hainan Island, while only *Pseudolycaea* sp.

Table 4. Environmental factors and their *t*-tests between Group I and Group II in spring and winter

Environmental factors	Spring			Winter		
	Group I	Group II	p	Group I	Group II	p
Turbidity (NTU)	2.64 ± 1.75	1.59 ± 1.16	0.05	3.88 ± 2.84	10.65 ± 21.71	0.30
Dissolved oxygen (mg l^{-1})	7.24 ± 0.35	6.79 ± 0.23	<0.001	7.33 ± 0.40	7.15 ± 0.14	0.01
pH	8.28 ± 0.02	8.28 ± 0.01	0.83	8.26 ± 0.04	8.24 ± 0.03	0.09
Temperature (°C)	22.83 ± 2.00	25.07 ± 0.94	<0.001	22.38 ± 2.30	23.42 ± 1.11	0.03
Salinity	33.63 ± 0.42	34.14 ± 0.29	<0.001	33.43 ± 0.64	33.67 ± 0.55	0.25
Chl *a* (mg m^{-3})	1.13 ± 0.63	0.57 ± 0.52	0.05	1.26 ± 0.97	0.81 ± 0.47	0.13
Depth (m)	44.98 ± 21.48	75.15 ± 23.65	<0.001	48.26 ± 24.24	75.5 ± 26.76	<0.001

was identified at Station J51 to the northwest of Basuo Town of Hainan Island. These 2 stations formed Group III.

Community and environmental factors

The results of DCCA ordination revealed that the environmental variables significantly affected the hyperiid amphipod community ($p < 0.05$). A Monte Carlo test of the first axis of the DCCA analysis revealed $p = 0.02$ in spring, $p = 0.02$ in autumn, and $p = 0.04$ in winter, indicating good sorting quality of the first axis over the 3 seasons. In summer, the significance value of the first axis was $p = 0.06$, while the significance value of all axes was $p = 0.002$. The first and second axes formed 45.8 and 20.6 % of the total variance in spring, 28.0 and 17.2 % in summer, 35 and 21.3 % in autumn, and 42.7 and 19.4 % in winter.

In spring (Fig. 3), the first DCCA axis had strong loadings for DO ($r = -0.7759$), chl *a* (−0.7516), water depth (0.7029), ZD (−0.6047), salinity (0.5516) and temperature (0.3908). Environmental factors in the second axis included temperature (0.6315), salinity (0.4665), depth (0.5201) and chl *a* (−0.3692). The pH arrow line was shortest, and its correlation coefficients were small. The main environmental factors affecting the planktonic amphipod community in spring were, in turn, temperature, salinity, depth, DO and chl *a*.

Group I was mainly distributed in the second, third and fourth quadrant. This group's distribution was somewhat concentrated, indicating a preference for similar environmental conditions. The stations in Group I had higher values of DO, higher chl *a*, lower water depth, lower salinity and lower temperature. Group II was mainly distributed in the first quadrant, which was characterized by deep water, high salinity, and high water temperature.

In summer (Fig. 3), the first DCCA axis had strong loadings on water depth ($r = -0.9326$), chl *a* (0.6936), temperature (0.6716), DO (0.6231) and ZD (0.4240). The most relevant variable on the second axis was pH (−0.5002), followed by DO (−0.4980). Water depth had the highest loading, indicating that it was the most significant environmental factor influencing the planktonic amphipod community.

The stations of Group I had high temperature and chl *a*, and were mainly located in the first quadrant. Group II showed a broad range of environmental factors. Group III occurred almost exclusively in the fourth quadrant, and had shallower water depth, low salinity, high pH and high DO. It was located mainly to the south of Bailongwei Island.

In autumn (Fig. 3), the first DCCA axis had strong loadings on water depth ($r = -0.8451$), chl *a* (0.5358) and pH (−0.5146). The most relevant factor on the second axis was temperature (−0.8214), followed by DO (0.4421), ZD (−0.3454) and chl *a* (0.3403).

Group I was located in the right part of the first quadrant, near the first axis. It had the lowest water depth, the highest chl *a* values and moderate temperatures and DO concentrations. Group II mainly occurred in the first, second and fourth quadrants, while Group III occurred in the first, second and third quadrants. Thus, Group I was very different from Groups II and III.

In winter (Fig. 3), the first DCCA axis had strong loadings on chl *a* ($r = -0.6322$), ZD (−0.6144), water depth (0.5483) and DO (−0.51731). The most relevant variable on the second axis was DO (−0.3359) followed by temperature (0.3134) and depth (0.2465). Group I occurred in areas with high concentrations of chl *a* and DO. Group II occupied the entire deep water area, with high values of temperature and salinity. Groups I and II can be clearly distinguished.

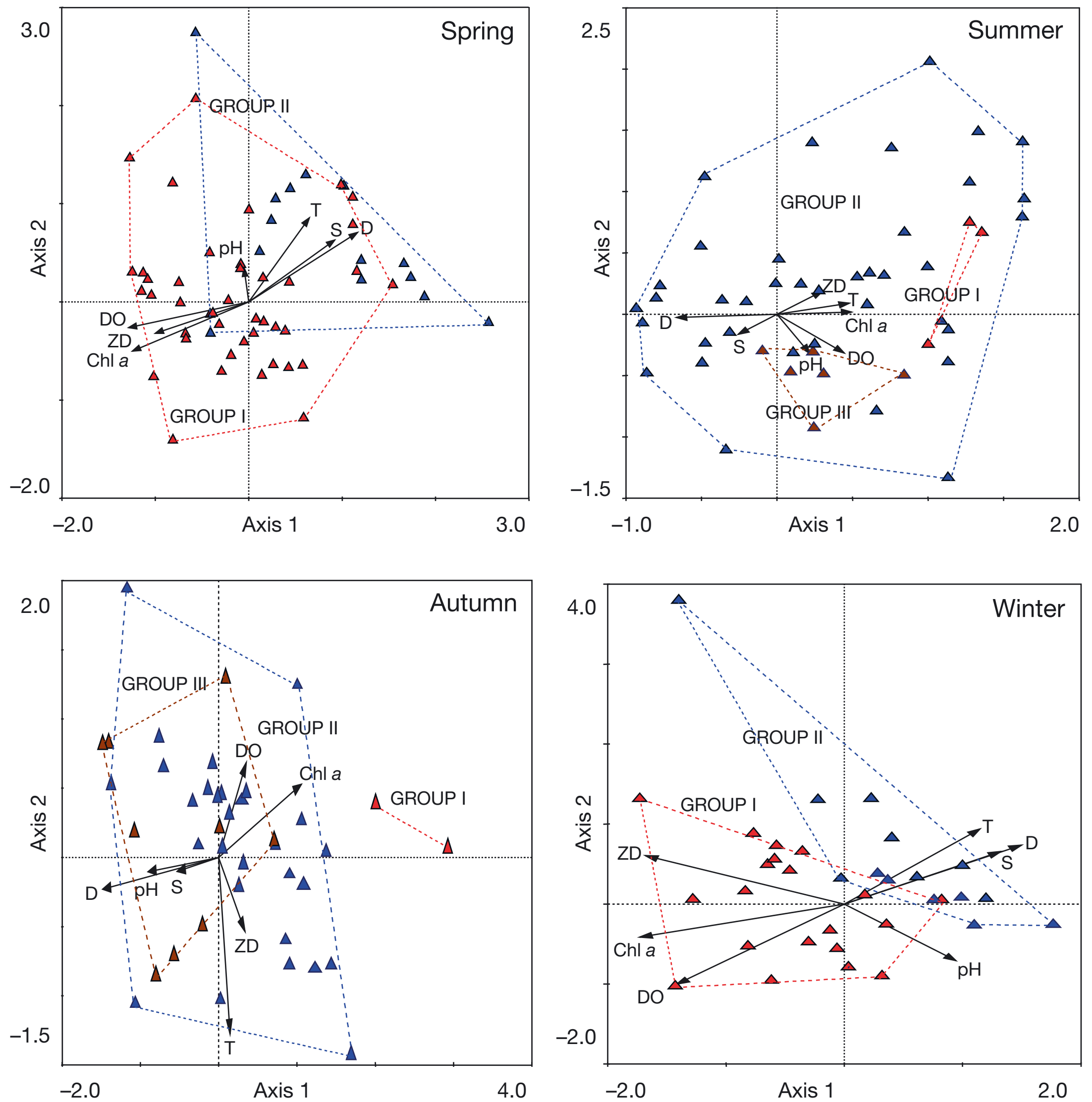

Fig. 3. Results of detrended canonical correspondence analysis (DCCA) revealing the relationships of sampling sites and environmental factors in 4 seasons. Chl a = chl *a* concentration in (mg m^{-3}); D = water depth (m); DO = dissolved oxygen (mg l^{-1}); S = salinity; T = temperature (°C); ZD = turbidity (NTU)

DISCUSSION

A typical tropical-subtropical neritic community

Hyperiid amphipods from other regions of the South China Sea have been studied previously (Lin & Chen 1994, Lin et al. 1996, Jia et al. 2004, Li et al. 2004). In the central regions of the South China Sea, 94 species of Hyperiidea have been recorded (Lin & Chen 1994). The distribution of Hyperiidea in this region is affected by the low salinity water mass (32.50 to 33.60) from the sea shelf, and the high salinity water mass (34.70 to 35.33) from the ocean. The dominant species (*Lestrigonus bengalensis, Hyperietta vosseleri* and *Phronimopsis spinifera*) are oceanic, warm-water species. Thus, their community is a typical, low-latitude tropical pelagic community (Lin & Chen 1994).

In the northern part of the South China Sea, 62 planktonic amphipod species have been identified (Jia et al. 2004, Li et al. 2004), with the dominant species the same as those recorded in our study. Our results indicated that the hyperiid amphipod community in the Beibu Gulf is composed of euryhaline warm-water species.

In our study area, the coastal waters of the Beibu Gulf are affected mainly by land runoff. Particularly in summer, the salinity of the coastal waters near the Beilunhe Estuary of Guangxi Province was lowest with a value of 27.07. Other areas were affected by open sea water flowing through the gulf mouth, forming a large, high-salinity (>34) area. There was a large range of salinity values in the Beibu Gulf, and temperatures ranged from 17.67 to 31.33°C. Our results show that the planktonic amphipods in the eastern Beibu Gulf were typical, tropical-subtropical neritic communities.

There are at least 2 Hyperiidea groups present in the Beibu Gulf year-round. One group, found inside the gulf, is a coastal community adapted to the low-salinity water mass from the sea shelf. The other group is located in the mouth of the gulf, and is adapted to the open South China Sea. The group inside the gulf is mainly comprised of euryhaline, warm-water species, such as *Lestrigonus bengalensis, Hyperioides sibaginis* and *Tullbergella cuspidata*. Species diversity is low in this region. The high-diversity group from the open part of the South China Sea is mainly composed of pelagic, warm-water species, including *Brachyscelus crusculum, Thyropus typhoides* and *Lycaea pulex*.

Relationship between water masses and the Hyperiidea

The Beibu Gulf is a semi-enclosed gulf, and therefore has complex topography, currents and water masses that result in the formation of many water fronts. The entire Beibu Gulf could be generally divided into masses, i.e. coastal water, mixed water, outer Beibu Gulf water (South China Sea water) etc. (Chen 1986, Chen et al. 2011). The intrusion of South China Sea water into the south of the Beibu Gulf has been investigated in various physical oceanographic studies (Chen 1986, Sun 2005, Chen et al. 2011).

As a result of the influence of the southwest monsoon and the northeast wind, as well as seasonal changes of Guangxi coastal continental runoff, South China Sea open sea and coastal water masses intrude and decline seasonally. Therefore, Group I inside the gulf and Group II from the South China open sea also show distinct seasonal variations.

In spring, the open-sea group (Group II) occupied the area to the southwest of Hainan Island, but low-salinity (<34) water to the southwest of Yinggehai Town separated the group. In summer, the southwest monsoon prompted the open-sea group to move into the Beibu Gulf, and mostly arrived at the north end of the gulf. However, to the south of Bailongwei Island, the water salinity was as low as 33 due to runoff from the Honghe River. Thus, a group of euryhaline, warm-water species were located inside the gulf. In autumn, the monsoon weakened, but runoff was still strong, and the open-sea group returned to the waters south of Basuo Town. The group inside the gulf occupied the middle and northern part of the gulf. In winter, species richness and abundance plummeted. However, traces of the open-sea group could still be found to the southwest of Hainan Island, and in the water near Sanya City. In addition, pushed by the northeast winds, the water along the coast of western Guangdong Province drove the open-sea group through the Qiongzhou Strait to a few stations in the west mouth.

In summary, euryhaline species were widely distributed in Beibu Gulf and found in high densities, whereas pelagic species were always abundant to the southwest of Hainan Island. The range and expanded orientation of the density area of some pelagic species (such as *Brachyscelus crusculum*, *Phronimopsis spinifera* and *Thyropus typhoides*) was in keeping with the territory of the subsurface water of the South China Sea, which invaded the Beibu Gulf from the bottom across the southern mouth of the gulf. In spring and winter, the planktonic amphipods of Groups II and III were oceanic warm-water species, and their distribution area was almost identical to the range of the South China Sea water mass in the Beibu Gulf.

Acknowledgements. This study was funded by a Marine Public Welfare Industry Research Project (No. 201005012), the National Natural Science Foundation of China (No. 41276133 and J1210050), State Oceanic Administration Project 530-03-02-02-03 and the project of Chinese Offshore Investigation and Assessment (908-01-ST09) from the State Oceanic Administration of the People's Republic of China. We thank the crew of the RV 'Shi-Yan 2' and colleagues for their assistance in sample collection. We appreciate the real-time data of environmental factors provided by the '908' office, Xiamen University. Professor John Hodgkiss of The University of Hong Kong is thanked for his assistance with English.

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Editorial responsibility: Alistair Poore, Sydney, New South Wales, Australia

Submitted: April 17, 2013; Accepted: December 29, 2013
Proofs received from author(s): April 10, 2014