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Community composition, abundance and biomass of zooplankton in Zhangzi Island waters, Northern Yellow Sea*

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Abstract Samples were collected monthly from the sea area around Zhangzi Island, northern Yellow Sea, from July 2009 to June 2010. Vertical net towing was used to examine spatial and temporal variability in zooplankton abundance and biomass. Overall, *Calanus sinicus* and *Saggita crassa* were the dominant species found during the study period, while the amphipod *Themisto gracilipes* was dominant in winter and spring. Vast numbers of the ctenophore species of the genus *Beroe* were found in October and November. It was not possible to count them, but they constituted a large portion of the total zooplankton biomass. Zooplankton species diversity was highest in October, and species evenness was highest in April. Zooplankton abundance (non-jellyfish) and biomass were highest in June and lowest in August, with annual averages of 131.3 ind./m^3 and 217.5 mg/m^3, respectively. Water temperature may be responsible for the variations in zooplankton abundance and biomass. *Beroe* biomass was negatively correlated with other zooplankton abundance. Long-term investigations will be carried out to learn more about the influence of the environment on zooplankton assemblages.

Keyword: zooplankton; abundance; biomass; diversity index; Zhangzi Island waters

1 INTRODUCTION

Zhangzi Island is one of the most important aquaculture bases in northern China, located in the south of the Changshan Archipelago (CA), 50 km from the coastline in the northern Yellow Sea. Since 1998 the CA area has been an important mariculture area for the Japanese scallop *Patinopecten yessoensis*. Off Zhangzi Island, waters shallower than 50 m have been used for bottom-sowing culture. A recent study suggested that chlorophyll *a* (Chl *a*) concentration might be depressed because of dense bivalve culture (Zhang et al., 2008). The cascade effects on zooplankton have not been investigated until now.

The zooplankton community in the Zhangzi Island area may be influenced by various physical events in addition to mariculture activities. First, the Yellow Sea Cold Bottom Water (YSCBW) is the most important physical character in summer. Its distribution, defined with a 12.5°C isothermal line at 25 m, covers all Yellow Sea areas below this depth (Song et al., 2009). The strength of the YSCBW was observed correlated with survivorship of cultured scallop (Du et al., 1996). As an over-summering cites, the YSCBW was suggested to be the most important factor influencing zooplankton distribution in the Southern Yellow Sea in summer (Sun et al., 2002). Second, the Yellow Sea Warm Current (YSWC), which flows into the Yellow Sea from the south of

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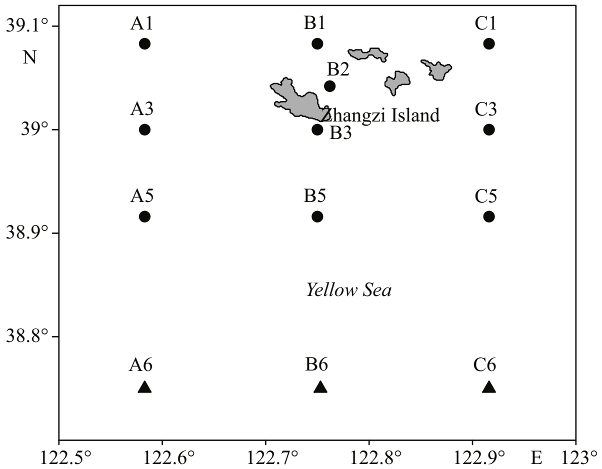

Fig.1 Sample sites of cruises from 2009 to 2010 off Zhangzi Island

Black dots: sites in mariculture area; black triangle: sites in open water.

Cheju Island, can reach as far as the Bohai Strait (Bao et al., 2009). It has been established that zooplankton assemblage in the southern Yellow Sea can be influenced significantly by the YSWC (Wang and Zuo, 2004). Third, rivers in northern China undergo severe seasonal fluctuation in freshwater discharge, with frequent episodic flood events in summer. During the flood season, surface dilution can occupy a large area in the northern Yellow Sea and exert obvious negative influences both on mariculture and on planktonic species.

Despite the environmental complexity, data on annual zooplankton variation are limited, and we found no annual investigation since the Census of Marine Life in 1958. In present study, an area extending from the mariculture region to the YSCBW areas was covered, in order to understand zooplankton species composition and the relationship between environmental factors and zooplankton abundance.

2 MATERIAL AND METHOD

2.1 Sample collection

Samples were collected monthly at the same set of stations (Fig.1) in Zhangzi Island waters from July 2009 to June 2010, using a conical plankton net (mouth diameter: 0.8 m; mesh size: 500 μm) towed vertically from bottom to surface. The samples were fixed with 5% formalin solution, and then counted under a dissecting microscope. Temperature and salinity were measured with AAQ1183-1F CTD (Alec Electronics Co., Japan). To measure total Chl *a* concentrations, 500 mL natural seawater was filtered through 0.45 μm cellulose acetate (CA). The membranes were extracted from 90% acetone (v/v) in a refrigerator for 24 h (≤0°C), and then measured with a Turner Designs Model 7200 fluorometer.

2.2 Data analysis

Thirteen stations were divided into two groups according to geographic differences. Sites A6, B6, and C6 were located in the YSCBW area away from the nearshore (referred to here as 'open water stations'); the remainder were in the bottom seeding culture area (the 'mariculture area').

The dominance index (Y) was calculated according to the following equation (Dufrêne and Legendre 1997):

$$Y=(n_i/N)\times f_i, \tag{1}$$

where n_i represented the abundance of species i, N was the total abundance of all species, f_i was the appearance frequency of species i and $Y>0.02$ was adapted as the criterion for a dominant species.

To measure biomass, zooplankton samples were filtered through bolting silk and jellyfish were separated as these contain considerable moisture and impurities. After vacuum filtering and weighing on an electronic balance, according to the filtrate volume, translate them to wet weight (mg/m^3).

Biodiversity analysis used PRIMER V5.2 (Plymouth Routines In Multivariate Ecological Research) which was exploited by Plymouth Marine Laboratory (PML).

The Shannon-Weaver Index (H') species diversity index (Shannon and Weaver, 1949) provided community richness and uniformity information, using the equation:

$$H'=\sum_{i=1}^{s}(P_i)\log_2 P_i\ , \tag{2}$$

where P_i represented the proportion of species i in the samples. For example, if the total number of the sample was N, the individual number of species i was n_i, so $P_i=n_i/N$.

Margalef's index (d) was used to provide information on species numbers and abundance. The equation was:

$$d=(S-1)/\log_2 N, \tag{3}$$

where S represented the number of species in samples and N was the abundance of zooplankton.

Pielou's evenness index (J) was used:

$$J'=H'/\log_2 S. \tag{4}$$

The sample stations map was generated in Golden Software surfer 9.0. The difference in zooplankton abundance in different areas was evaluated statistically using Independant samples t-test with SPSS V19.0.

3 RESULT

3.1 Environmental conditions

Annual average surface sea temperature (SST) ranged from 5.29°C to 23.09°C (Fig.2), with the highest of 26.13°C observed in August. The bottom sea temperature (BST) varied between 2.22°C and 15.7°C. According to surface and bottom temperatures, thermal stratification existed between July and September, with the largest thermal difference in July. The SST and BST difference decreased as the YSCBW disappeared.

Annual average surface salinity ranged from 30.77 to 32.26. Obvious dilution by fresh water was observed in June, July and August with salinities of 31.10, 30.77 and 30.90, respectively. The average bottom salinity was less variable, ranged from 31.79 to 32.28.

Chl *a* concentration ranged between 0.26 and 0.57 mg/L, with the exception of an average of 1.10 mg/L in August and an average of 0.84 mg/L in March. The highest Chl *a* concentration value 7.32 mg/L, was recorded in August at B2 station

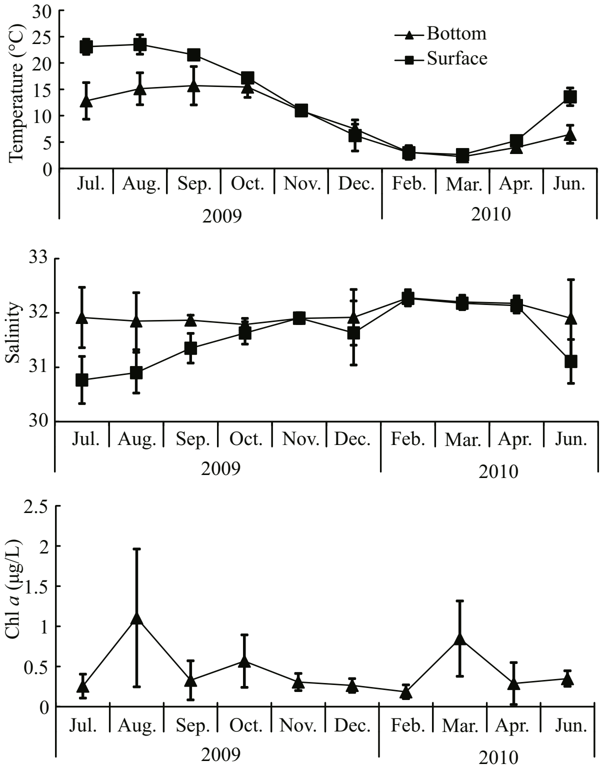

Fig.2 Monthly variations in temperature, salinity and Chl *a* concentration in Zhangzi Island waters

3.2 Zooplankton composition

We identified 36 zooplankton species in Zhangzi Island waters, including the larval stages of different groups (Table 1). Most were Arthropods (19 species), which formed 52.7% of the total number, followed by Chaetognatha, represented by three species. Cnidaria, Ctenophora and Chordata were each represented by two species. Protozoa were represented by only one species.

Calanus sinicus, *Saggitta crassa*, *Labidocera bipinnata*, *Themisto gracilipes* and *Euphausia pacifica* were encountered as perennials throughout the whole year. Cladocera with a wide range of tolerance to salinity and temperature, such as *Penetia avirostris* and *Pseudevadne tergestina*, mainly appeared from July to October. In general, more warm oceanic species such as *Sagitta bedoti*, *S. enflata*, *Lucifer intermedius*, *Eurytemora pacific* and *Doliolum denticulatum* were only recorded in October and November. Jellyfish, including *Proboscidactyla flavicirrata*, *Obelia bidentata*, *Pleurobrachia globosa* and *Beroe cucumis*, *Pontellopsis tenuicauda*, *Centropages abdominalis*, *Labidocera euchaeta* and *Corycaeus affinis* appeared only in July, September, October and November. Harpacticoid copepod species and fish eggs were also found. Warm oceanic species in the strict sense can hardly be distinguished.

3.3 Dominant zooplankton species

Calanus sinicus and *Sagitta crassa* were the dominant species throughout the survey (Table 2), and *C. sinicus* was the most abundant species off Zhangzi Island. The degrees of preponderance reached 0.926, 0.863 and 0.636 in June, July and September, respectively. *Sagitta crassa* had a degree of preponderance degree as high as 0.506 and 0.365 in October and February, respectively. *Themisto gracilipe* was the dominant species in winter and spring, and its highest degree of preponderance was 0.259. *Labidocera bipinnata*, *Acartia hongi*, *Noctiluca scintillans* and *Ophiopluteus* spp. larvae were the dominant species in spring, with highest degrees of preponderance for each species being 0.063, 0.072, 0.031 and 0.023, respectively. *Penilia avirostris*, which prefers low salinity, was the dominant species only in September, with a degree of preponderance of 0.024.

3.4 Annual variation in zooplankton biomass and abundance

Zooplankton biomass and abundance varied seasonally in Zhangzi Island waters. Two peaks of non-jellyfish zooplankton biomass were observed

Table 1 Zooplankton species in Zhangzi Island waters

Phylum	Species	Month									
		Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Mar.	Apr.	Jun.
Protozoen	*Noctiluca scintillans* (Macartney) Kofoid & Swezy				+	+			+	+	+
Chaetognatha	*Sagitta crassa* (Tokioka)	+	+	+	+	+	+	+	+	+	+
	Sagitta bedoti (Béraneck)					+					
	Sagitta enflata (Grassi)					+		+			
Arthropoda	*Calanus sinicus* (Brodsky)	+	+	+	+	+	+	+	+	+	+
	Centropages abdominalis (Sato)	+					+	+			
	Paracalanus parvus (Claus)	+	+	+	+	+	+	+	+		
	Eurytemora pacific (Sato)					+					
	Labidocera bipinnata (Tanaka)	+	+	+	+	+	+	+	+	+	+
	Labidocera euchaeta (Giesbrecht)	+	+	+	+		+				
	Pontellopsis tenuicauda (Giesbrecht)			+	+		+			+	
	Acartia pacifica (Steuer)	+	+	+			+	+			
	Acartia hongi (Soh & Suh, 2000)						+	+	+	+	+
	Corycaeus affinis (McMurrich)	+	+	+	+	+	+				
	Oithona similis (Claus)				+		+		+	+	+
	Penetia avirostris (Dana)	+	+	+	+						
	Pseudevadne tergestina (Claus)	+	+	+							
	Harpacticoid			+	+	+	+		+	+	+
	Acanthomys longirostris (Li, 1936)							+		+	+
	Euphausia pacifica (Hansen)	+	+	+	+	+	+	+	+	+	+
	Lucifer intermedius (Hansen)				+						
	Lucifer hanseni (Nobili)				+						
	Themisto gracilipes (Guérin)	+	+	+	+	+	+	+	+	+	+
Cnidaria	*Proboscidactyla flavicirrat* (Brandt)	+		+	+	+					
	Obelia bidentata (Clark)					+					
Chordata	*Pleurobrachia globosa* (Moser)					+					
	Beroe cucumis (Fabricius)				+	+					
Echinodermata	*Doliolum denticulatum* (Quoy & Gaimard)				+						
	Salpa fusiformis (Cuvier)				+						
Larve	*Asteroidea larva* (Echinodermata)						+				
	Brachyura megalopa larva (Decapoda)	+	+	+	+	+	+			+	+
	Macrura larva (Decapoda)	+	+								
	Porcellana zoea larva (Decapoda)	+	+	+							
	Alima larva (Stomatopoda)	+	+	+	+						
	Ophiopluteus larvae (Echinodermata)									+	
	Fish egg	+	+	+	+	+		+			

(Fig.3), the major one being in June (496.1 mg/m³) and the minor one in December (366.77 mg/m³). The highest zooplankton abundance was recorded in June (531.6 ind./m³). Both lowest zooplankton biomass (95.44 mg/m³) and abundance (38.19 ind./m³) occurred in August. The annual averages of zooplankton biomass and abundance were 217.5 mg/m³ and 131.3 ind./m³, respectively.

Table 2 Dominant species in different months in Zhangzi Island waters

Species	2009						2010			
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Mar.	Apr.	Jun.
Calanus sinicus	0.863	0.695	0.636	0.338	0.416	0.592	0.577	0.580	0.291	0.926
Sagitta crassa	0.101	0.240	0.257	0.506	0.338	0.344	0.365	0.235	0.190	0.022
Penilia avirostris			0.024							
Themisto gracilipe						0.041	0.029	0.027	0.259	
Labidocera bipinnata								0.031	0.063	0.022
Acartia hongi								0.072	0.068	
Noctiluca scintillans									0.031	
Ophiopluteus									0.023	

Table 3 Zooplankton diversity indices in Zhangzi Island waters

Cruise	2009						2010			
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Mar.	Apr.	Jun.
S	15	16	18	24	19	17	12	11	14	11
H'	1.03	1.49	1.49	1.73	1.57	1.24	1.23	1.66	1.81	0.68
D	0.88	1.15	1.23	1.56	1.22	0.77	0.53	0.80	0.75	0.60
J	0.37	0.56	0.46	0.51	0.50	0.46	0.55	0.61	0.67	0.25

3.5 Biological diversity

Not only can zooplankton diversity reveal the characteristics of the zooplankton community, but it can also reveal habitat traits. The average species diversity indices (*H'*), richness (*d*) and evenness (*J*) were 1.39, 0.95 and 0.49, respectively (Table 3). The species diversity was identical with evenness; species number was in conformity with richness.

The peak value of species number appeared in October, with a high richness index of 1.56. During this period, the intensity of the YSCBW receded, and some warm oceanic species, such as jellyfish and tunicates, appeared. The high value of species diversity and evenness indices emerged in April, with values as high as 1.81 and 0.67, respectively.

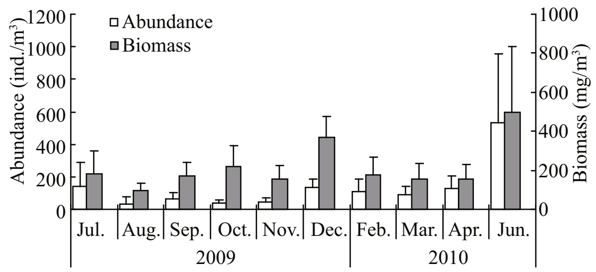

Fig.3 Monthly abundance and biomass of zooplankton in Zhangzi Island waters

4 DISCUSSION

4.1 Effect of environmental factors on zooplankton composition

The investigation found that constituents of the zooplankton were clearly different from the nearshore of Xiao Changshan Island (Wang, 2003), maybe the sample stations we set with deep water had long distance from the off-shore. Low-temperature high-salinity species such as *Calanus sinicus* dominated our whole survey. Some neritic low-salinity species such as *Penetia avirostris*, *Labidocera bipinnata* and *Acartia hongi* emerged as dominant species only in summer and early spring.

In summer (July to September 2009), seasonal rivers such as the Yalu River were in a period of high flow (Gao et al., 2003). With the freshwater input to the ocean, significant salinity decrease was detected; the dominance of cladocera more suited to a low salinity environment indicated that river discharge may influence zooplankton assemblage in this area. In winter, YSWC can reach as far as the Bohai Strait (Bao et al., 2009), and may bring tropical species with the warm current. In our study, with the disappearance of the YSCBW, some warm-ocean species, *Sagitta bedoti*, *S. enflata* and *Lucifer intermedius*, appeared in October and November, 2009. Positive and significant correlation was found between sea bottom temperature

Table 4 Spearman correlation coefficients between zooplankton species abundance and environmental factors

Cruise time	Abundance (ind./m³)									
	2009						2010			
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Mar.	Apr.	Jun.
SST	0.372	0.644*	0.219	0.382	0.141	0.108	-0.148	-0.704**	-0.196	-0.131
BST	-0.583*	-0.574*	-0.154	0.628*	0.108	0.388	-0.167	-0.604*	0.271	0.106
SSS	0.469	0.552	-0.231	-0.514	0.027	0.151	-0.084	-0.426	0.213	-0.362
BSS	0.461	0.372	0.220	-0.694**	-0.013	0.272	-0.111	-0.519	0.204	-0.070
Surface Chl *a*	0.688**	-0.362	-0.06	0.230	-0.424	-0.282	0.017	0.182	0.024	0.425
Bottom Chl *a*	0.408	-0.343	-0.286	0.271	0.144	-0.102	0.304	-0.196	-0.106	0.133
Biomass	0.871**	0.790**	0.900**	0.163	0.019	0.725**	0.052	0.861**	0.242	0.914**

Note: ** represent significant correlation at 0.01 level; * represent significant correlation at 0.05 level.

and zooplankton abundance in October (Table 4), but tropical species with obvious characteristic in strict sense can hardly be distinguished; perhaps the intensity of the warm current was not strong enough to bring the tropical species to the northern Yellow Sea. In early spring (March and April 2010), *Labidocera bipinnata* and *Acartia hongi* appeared as dominant species off Zhangzi Island. *Labidocera bipinnata* is a typical species of neritic low salinity (Qi, 2008). Recent study suggested that *A*. *hongi* was a dominant species in coastal waters of the Yellow Sea that were characterized by low salinity, low temperature and high eutrophication (Shim and Choi, 1996; Youn and Choi, 2003). The abundance increased from February to April, with a peak value in May in Kyeonggi Bay (Youn and Choi, 2007). In our study, *L*. *bipinnata* appeared throughout the year, but as a dominant species only in spring. *Acartia hongi* appeared in winter and spring, but as a dominant species only in spring. This trend was similar to previous studies.

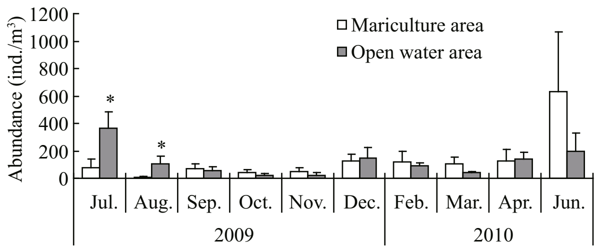

Fig.4 Annual zooplankton abundance in mariculture and open water areas off Zhangzi Island

* represent significant difference at 0.05 level.

4.2 The relationship between zooplankton abundance and YSCBW

In summer, the YSCBW played an important part in zooplankton distribution. Throughout the survey, zooplankton abundance in the open water area was obviously lower than in the mariculture area except in July and August ($P<0.05$) (Fig.4), when YSCBW exist with high intension. The abundance of *Calanus sinicus* and *Themisto gracilipe* in the mariculture area was lower than in the open water area. *Calanus sinicus* occupied 85.5% and 70.0% of total zooplankton abundance in July and August, respectively. The abundance of *C*. *sinicus* was 54.85, 0.79 ind./m³ in July and August in the mariculture area; and 341.51, 82.87 ind./m³ in July and August in the open water area. In the southern Yellow Sea *C*. *sinicus* was found to be concentrated inside the YSCBW, using this strategy to avoid high-temperature damage to benefit the population (Zhang, 2003). In the northern Yellow Sea. YSCBW played similar role as over-summering city *T*. *gracilipe* was a typical species in the YSCBW, its distribution being consistent with the depth of the YSCBW (Zhu, 2008). In our study, the abundance of *T*. *gracilipe* was 0.57, 0.27 ind./m³ in the mariculture area; and 3.42, 1.49 ind./m³ in the open water area in July and August. Zooplankton abundance in July and August had significantly negative correlation with sea bottom temperature (Table 4).

4.3 The influence of *Beroe* blooms on zooplankton abundance

Zooplankton is preyed on by jellyfish, and a bloom of *Beroe* may decrease the abundance of other zooplankton species. The number of jellyfish was low in July and September. A bloom of the ctenophore *Beroe* was observed in October and November (Fig.5), with an average biomass of 38.91 mg/m³ and 216.14 mg/m³, respectively.

Copepods formed a large proportion of the zooplankton, ranging from 34% to 92% over the whole year. Copepod abundance ranged from 14.36 ind./m³ to 497.04 ind./m³ over the whole year.

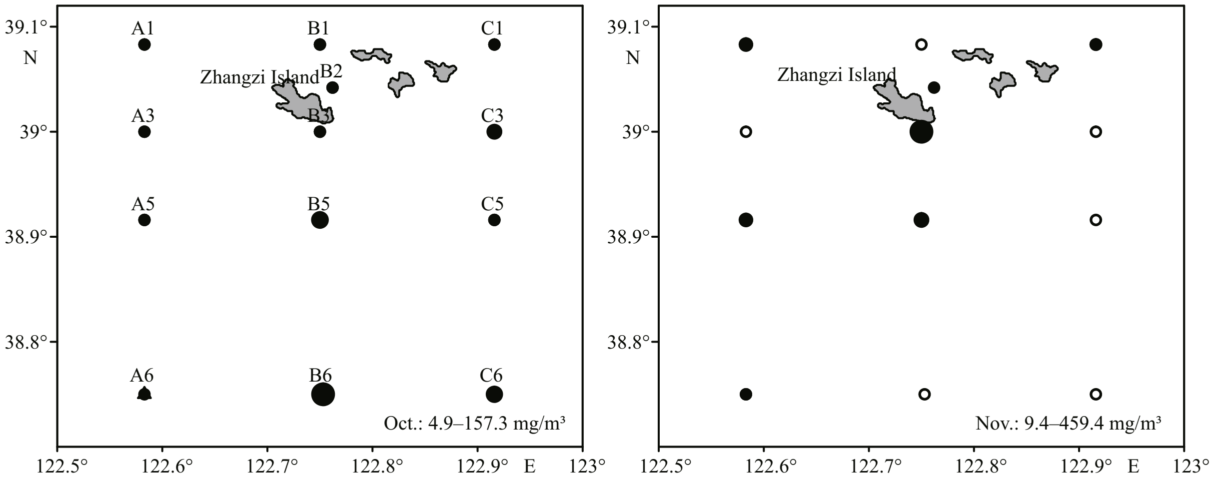

Fig.5 Geographical biomass of jellyfish in Zhangzi Island waters in October and November

Open circles represent stations at which no jellyfish were found, and sizes of the filled circles are in proportion to the biomass of jellyfish (mg/m³).

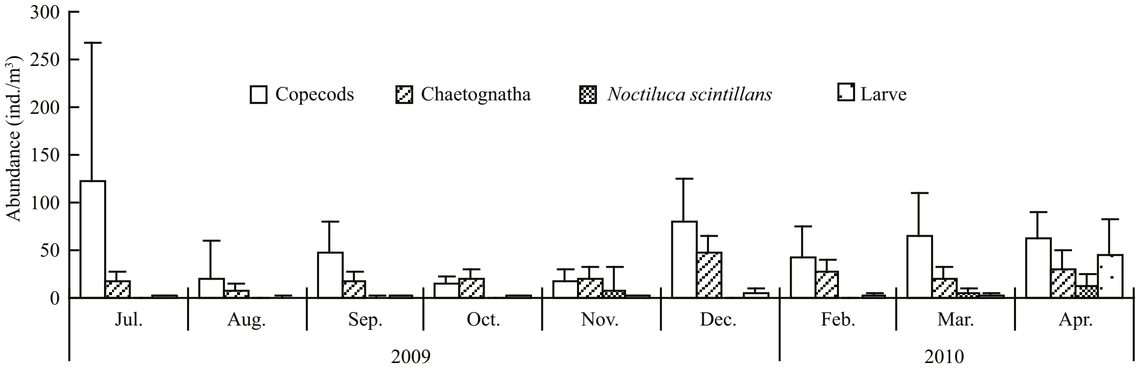

Fig.6 Copepods Chaetognatha, *Noctiluca scintillans* and larve abundance in Zhangzi Island waters

In October and November, the abundance was 14.36 ind./m³ and 16.38 ind./m³, respectively, lower than the abundance in other months. The influence of jellyfish on the Chaetognatha, *Noctiluca scintillans* and larve was not obvious (Fig.6).

According to our results, significant negative correlation was observed between jellyfish and zooplankton abundance by geographical distribution in October. In November, no relationship was found: jellyfish biomass was as high as 383.2 mg in station C1, but the abundance of zooplankton was not low. This illustrated that jellyfish influenced zooplankton abundance over a long time period.

4.4 Zooplankton abundance and biomass variations

During this investigation, zooplankton abundance and biomass in summer were higher than in winter (Fig.3). The seasonal variable trend was in line with *C. sinicus*, which greatly influenced the total abundance. With the input runoff from the Yalu River, some low-salinity neritic species, such as *Penetia avirostris* and *Pseudevadne tergestina*, moved into offshore station, enhancing species abundance. The dilution caused by the freshwater and a short period of rainfall resulted in rapid phytoplankton growth. In July, positive and significant correlation was found between Chl *a* concentration and zooplankton abundance and biomass (Table 4). Chl *a* concentration was an important factor in regulating zooplankton biomass in summer.

4.5 Long-term comparison

The first annual investigation of zooplankton in the northern Yellow Sea was the marine census of 1959. At this time the dominant species were *Calanus sinicus*, *Sagitta crassa*, *Themisto gracilipe*, *Labidocera bipinnata* and *Centropages abdominal*. Although the main dominant species didin't change, some low salinity neritic species such as *Penetia avirostris* and *Pseudevadne tergestina* didn't appear in the whole year. *Acartia* spp. were not dominant in summer, although numbers were higher in the northern Yellow Sea than off Zhangzi Island. During a 2006 investigation, zooplankton abundance was 266.3 ind./m³ in winter higher than in Zhangzi Island (133.1 ind./m³), and 525.1 ind./m³ in summer, lower than off Zhangzi Island (531.6 ind./m³) (Zhu, 2008). The species diversity index in the northern Yellow Sea was higher than off Zhangzi Island both in winter and in summer, over the entire area investigated.

5 CONCLUSION

Calanus sinicus and *Sagitta crassa* were dominant species off Zhangzi Island. No tropical species were brought by the YSWC. In summer, the YSCBW played an important part in protecting the *C. sinicus* population in the northern Yellow Sea. Jellyfish may decrease zooplankton abundance. We found no direct significant influence from mariculture on the zooplankton community. Annual average zooplankton biomass and abundance were 217.5 mg/m³ and 131.3 ind./m³. The average species diversity index (H'), richness index (d) and evenness index (J) were 1.39, 0.95 and 0.49, respectively. The highest species diversity (1.81) and evenness index (0.67) emerged in April. The richness index was highest in October (1.56).

6 ACKNOWLEDGEMENT

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