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Responses of mesozooplankton communities to different anthropogenic activities in a subtropical semi-enclosed bay

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To evaluate the effects of different anthropogenic activities on zooplankton and the pelagic ecosystem, we conducted seasonal cruises in 2010 to assess spatial heterogeneity among the mesozooplankton communities of Xiangshan Bay, a subtropical semi-enclosed bay in China. The evaluation included five different areas: a kelp farm, an oyster farm, a fish farm, the thermal discharge area of a power plant, and an artificial reef, and we aimed to identify whether anthropogenic activities dominated spatial variation in the mesozooplankton communities. The results demonstrated clear spatial heterogeneity among the mesozooplankton communities of the studied areas, dominantly driven by natural hydrographic properties, except in the area near the thermal discharge outlet of the power station. In the outlet area, thermal shock caused by the discharge influenced the mesozooplankton community by decreasing abundance and biomass throughout the four seasons, even causing a shift in the dominant species near the outlet during summer from Acartia pacifica *to eurythermal and warm water taxa. Unique features of the mesozooplankton community in the oyster farm may be due to the combined effects of oyster culture and the natural environment in the branch harbour. However, kelp and fish culture, and the construction of an artificial reef did not exert any obvious influence on the mesozooplankton communities up to 2010, probably because of the small scale of the aquaculture and a time lag in the rehabilitation effects of the artificial reef. Thus, our results suggested that the dominant factors influencing spatial variations of mesozooplankton communities in Xiangshan Bay were still the natural hydrographic properties, but the thermal discharge was an anthropogenic activity that changed the pelagic ecosystem, and should be supervised.*

Keywords: thermal discharge, aquaculture, artificial reef, mesozooplankton community, Xiangshan Bay

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INTRODUCTION

Zooplankton play an important linkage role in marine planktonic food webs as consumers of primary producers and as prey for higher trophic level organisms, as well as possessing a key function in biogeochemical cycling (Stock & Dunne, 2010; Stock *et al.*, 2014). Their populations respond to environmental changes rapidly (Webber *et al.*, 2005; Fernández de Puelles & Molinero, 2008). The response of zooplankton to thermal discharge and aquaculture has been reported (Shen *et al.*, 1999; Hoffmeyer *et al.*, 2005; Dias & Bonecker, 2008; Tseng *et al.*, 2011; Li *et al.*, 2014). Most studies have revealed that temperature elevation and perturbation caused by thermal discharge affect zooplankton abundance and diversity; however, the type of change depends on the location of the plant (Tseng *et al.*, 2011), operation time (Shen *et al.*, 1999; Li *et al.*, 2014) and degree of heating (Hoffmeyer *et al.*, 2005; Dias & Bonecker, 2008), among other factors. Cage culture of fish has been thought to influence the zooplankton community generally (Dias *et al.*, 2011; Wang *et al.*, 2012; Li *et al.*, 2014). However, studies of the influence of shellfish and macroalgae cultures on mesozooplankton are limited (Pakhomov *et al.*, 2002).

Bays, as parts of the coast where the land curves inward, usually have poor water exchange conditions and a variety of intensive anthropogenic activities. In China, large-scale mariculture has been increasing since the 1980s. In 2012, the annual production of shellfish, fish, crustaceans and seaweed in China were 12.08, 1.03, 0.94 and 1.76 million tons, respectively, making it the largest aquaculture industry worldwide (COYBEC, 2013). However, the disordered development and excessive exploitation of aquaculture can cause negative environmental effects. In particular, fish cages and shrimp ponds release abundant organic and inorganic matter that accumulates in water and sediments (e.g. N and P from unconsumed feed and faecal material), resulting in potential eutrophication and phytoplankton blooms (Yang *et al.*, 2004; Dong *et al.*, 2008). Macroalgae cultivation, an environmentally friendly aquaculture method, can efficiently remove and assimilate N and P, thereby alleviating coastal eutrophication (Fei, 2004; Neori *et al.*, 2004; He *et al.*, 2008). Shellfish cultures (e.g. oysters, mussels and clams) exhibit

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strong top-down control of primary production by filtering large volumes of plankton from the water column with undefined environmental effects (Dupuy *et al.*, 2000; Huang *et al.*, 2008a; Lefebvre *et al.*, 2009). Moreover, with an increase in the number of coastal power plants to meet growing demand in recent years, dramatic temperature gradients near discharge plumes alter the thermal suitability of areas for ectotherms (Poornima *et al.*, 2005; Coulter *et al.*, 2014).

Xiangshan Bay is a subtropical semi-enclosed bay connected to the East China Sea. This bay is typically divided into seven sections (Figure S1), based mainly on hydrological factors (Huang *et al.*, 2008b). Previous studies have shown that the distribution of phytoplankton and mesozooplankton communities in these sections is in accordance with hydrological partitioning (Jiang *et al.*, 2013c; Du *et al.*, 2015). This bay has suffered from large-scale human activities aggregated in its inner and middle sections since the 1980s (Ning & Hu, 2002; You & Jiao, 2011). Fish, kelp and oyster mariculture have expanded here for three decades. A power plant located in the inner part of the bay began operation in December 2005. Intensive anthropogenic discharge results not only in increased eutrophication (Ning & Hu, 2002; You & Jiao, 2011) and phytoplankton community succession (Jiang *et al.*, 2013a, b), but also decreases the proportion of high economic value species and diminishes individual fishery resources (Tang *et al.*, 2012). To slow down the decline of marine resources, the government set up a breeding and releasing zone in the middle of the embayment in 1982. Furthermore, ~5000 m^3 of artificial reefs have been constructed in this area since 2008 to repair and optimize marine organism habitats. However, the ecological effects of these artificial reefs on phytoplankton or macrobenthos are still inconspicuous (Jiang *et al.*, 2012a; Liao *et al.*, 2014). The cumulative effects of diverse human activities in this area may cause the formation of different microhabitats, given the limited amount of water exchange in the inner sections of semi-enclosed bays (Ning & Hu, 2002).

To investigate the effects of different anthropogenic activities on the mesozooplankton communities in Xiangshan Bay, we first determined if there were spatial differences in mesozooplankton communities among five areas: kelp, oyster and fish farm areas, a thermal discharge area of the Ninghai power plant and an artificial reef. Second, we investigated whether the dominant factors influencing spatial variations in the mesozooplankton communities were the natural properties of the bay or the consequences of anthropogenic activities.

MATERIALS AND METHODS

Study area

Xiangshan Bay is a long (~60 km) and narrow embayment, with a tidal flat area of 198 km^2 and a water area of 365 km^2. Water residence times are ~80 and 60 days for 90% water exchange in the inner and middle sections, respectively (Ning & Hu, 2002). Located in a subtropical climate, the water temperature in Xiangshan Bay varies distinctly over the four seasons, with the minimum and maximum temperatures in winter during January or February, and in summer during July or August, respectively (ECBCC, 1992). The sampling areas were the inner and middle sections of Xiangshan Bay (29.48°–29.52°N and 121.47°–121.62°E), where ~70% of the area is shallower than 10 m in depth.

The oyster farm is located in Tie Harbour, a branch harbour, while the kelp and fish farms are located in the main bay. The culture acreages of these farms were ~20, 920 and 18.7 ha for the kelp, oyster and fish farms, respectively (You & Jiao, 2011). Kelp (*Laminaria japonica* Areschoug, 1851) is a coldwater species only cultivated from mid-to-late October to April of the following year in Xiangshan Bay. All of the cultivated oysters and fish are perennial species. The majority of oysters (*Ostrea plicatula* Gmelin, 1791) were harvested at 2–3 years old in winter and spring. The cultured fish, mainly Japanese seaperch (*Lateolabrax japonicas* (Cuvier, 1828)) and black seabream (*Acanthopagrus schlegelii czerskii* (Berg, 1914)), were fed on rough fish and some compound feed. The Ninghai power plant is located at the bottom of the main bay, and has a total unit capacity of 4400 MW. The artificial reef area is located to the north of Baishishan Island, in the middle section of the bay, and consists of 230 cement fish reefs (~5000 m^3) installed by the government since 2008.

Sampling and analysis

SAMPLING STRATEGY

Four cruises were conducted in this study, in January (winter), April (spring), July (summer) and November (autumn) of 2010. Eleven sampling stations were set in five different areas in each cruise, including the kelp farm area (K0, K1), the oyster farm area (O0, O1), the fish farm area (F0, F1), the thermal discharge area of the power plant (T0, T1, T2) and the artificial reef area (R0, R1) (Figure 1).

K0, O0, F0 and R0 were inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. K1, O1, F1 and R1 were control stations located 1000 m away from the edge of each area. T0, T1 and T2 were stations located 100, 500 and 1000 m away from the outlet of power station thermal discharge. T2 was located in a region with natural temperatures, without any anthropogenic activities and located in the centre of the four sampling areas (the kelp, oyster and fish farm areas, and the thermal discharge area of the power plant); therefore, T2 served as a common control station for the five areas.

MESOZOOPLANKTON COMMUNITY

Mesozooplankton samples were obtained by vertical hauls from the bottom to the surface using a plankton net (inner diameter of net mouth, 80 cm; mesh size, 505 μm; length, 140 cm), and three replicate samples were obtained at each station. The volume of filtered water was measured using a digital flow meter (Model 438115; Hydro-Bios, Kiel, Germany). All samples collected were stored in 5% formalin in 1 l plastic bottles.

In the laboratory, mesozooplankton samples were filtered through a silk sieve with a mesh size of 160 μm and then weighed with a 0.1 mg electronic balance after picking out of sundries. The wet biomass of mesozooplankton samples was calculated based on wet weight and the volume of filtered water. Taxonomic identification and enumeration was carried out using a stereoscope (Zeiss SteREO Discovery.V8) and a microscope (Leica DM2500). Adult mesozooplankton, crustacean larvae and other larvae were identified to the species,

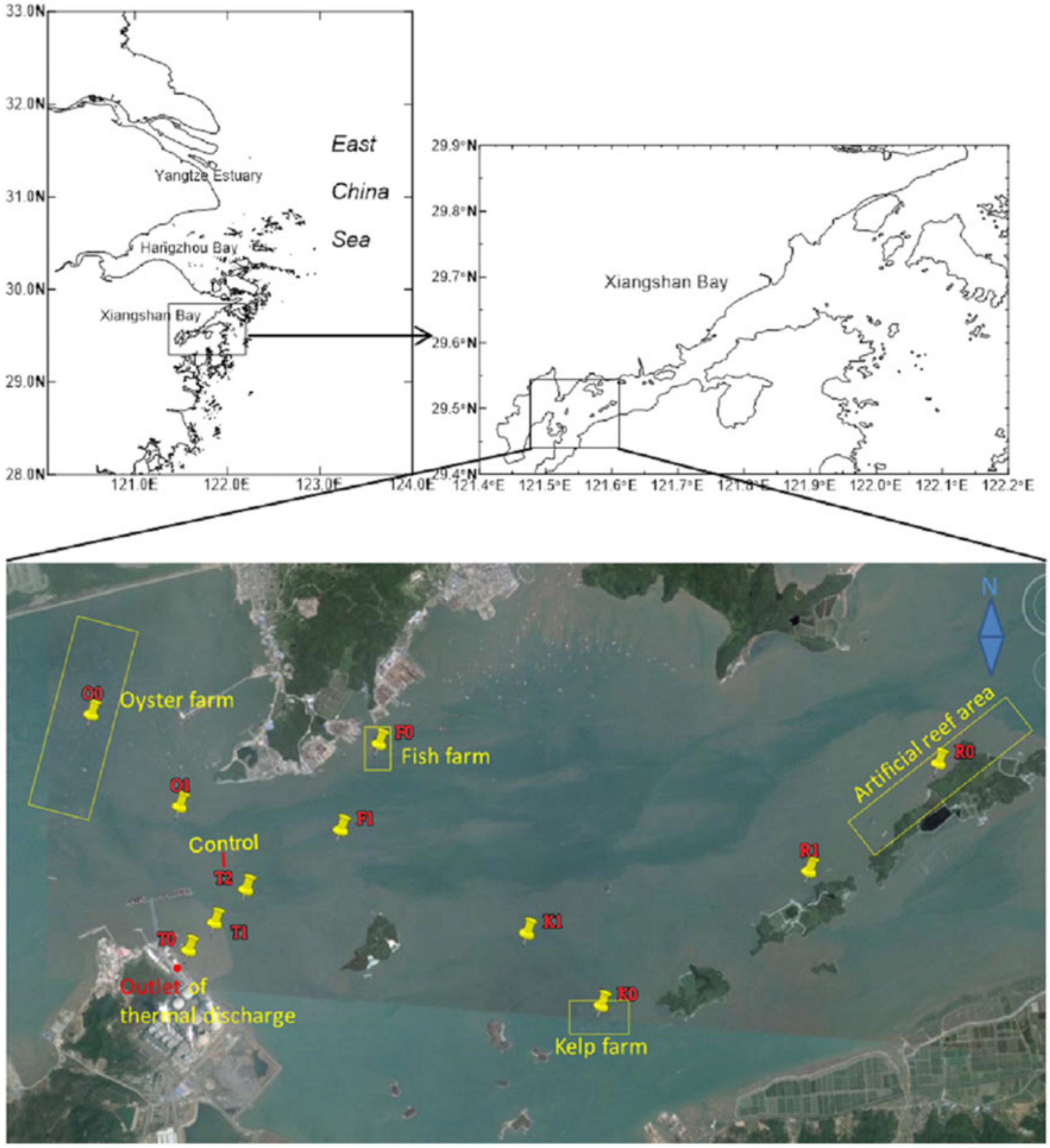

Fig. 1. Sampling stations in Xiangshan Bay, China. K0, O0, F0 and R0 were inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. K1, O1, F1 and R1were control stations located 1000 m away from the edge of each area. T0, T1 and T2 were stations located 100, 500 and 1000 m away from the outlet of power station thermal discharge. T2 acted as a common control station for the five habitats.

family and class levels, respectively. The abundance of mesozooplankton samples was calculated based on their numbers and the volume of filtered water.

ENVIRONMENTAL PARAMETERS

Surface (0.5 m depth) and bottom (0.5 m from the surface of the sediment) waters were collected at each station using a 10 l organic glass stratified hydrophore. Water depth, pH, temperature and salinity were monitored *in situ*. Water temperature and salinity were measured using a YSI model 30 salinity meter (YSI Inc., Yellow Springs, OH, USA), and pH was measured using an Orion 868 pH meter (Thermo Electron Co., Waltham, MA, USA). Dissolved oxygen (DO) was measured using Winkler titrations. For the analysis of dissolved inorganic nitrogen (DIN: NO_3-N + NO_2-N + NH_4-N), PO_4-P, SiO_4-Si, chlorophyll *a* (Chl *a*) and suspended solids (SS), 5 l water samples were stored in the dark at 0°C before being processed in the laboratory. Water samples were immediately filtered through precombusted (at 105°C for 0.5 h) and preweighed 0.45 μm pore size mixed cellulose ester filters for SS and nutrient analyses. SS were measured by the gravimetric method. Nutrients were measured according to colorimetric methods (Yin *et al*., 2001). To analyse Chl *a*, we filtered the samples through 0.70 μm pore size Whatman GF/F filters. The samples were then extracted with acetone (90% v/v) for 24 h at 4°C in the dark and fluorescently determined using a 10 AU Fluorometer (Turner Designs, USA).

DATA ANALYSIS

Species contributing a minimum of 2% to total abundance were considered dominant species. Richness was defined as the number of species. The software PRIMER 6.0

(PRIMER-E, Plymouth, UK) was used to calculate the mesozooplankton Shannon–Wiener diversity index (*H'*).

Since the mesozooplankton communities we focused on were from the entire water columns, and the values of environmental parameters in surface and bottom water were similar, due to the shallow water depth, environmental parameters were calculated by taking the average value of surface and bottom water for each station in this study.

A Kruskal–Wallis test was used to analyse the significance of differences in zooplankton community parameters (species richness, Shannon–Wiener index, biomass and abundance) among different areas, and a Mann–Whitney U test was used to analyse differences between stations inside and outside specific areas for each season. As there were no replicate samples of environmental parameters, a Friedman test was used to analyse the significance of differences in these among different areas and between stations inside and outside of these areas. Kruskal–Wallis, Mann–Whitney U and Friedman tests were carried out using SPSS 20.0. Two-way crossed analysis of similarity (ANOSIM) was used to test the significance of differences in mesozooplankton community composition among the different seasons and stations. Non-metric multi-dimensional scaling (NMDS) was used to analyse clustering of the mesozooplankton community. Bio-Env+Stepwise (BEST) and Linkage tree (LINKTREE) were used to analyse the correlation between mesozooplankton community characteristics and environmental parameters. ANOSIM, NMDS, BEST and LINKTREE were carried out in PRIMER 6.0, based on Bray–Curtis similarity.

RESULTS

Environmental parameters

Among the nine environmental parameters examined (temperature, salinity, pH, DO, SS, DIN, PO$_4$-P, SiO$_4$-Si, and Chl *a*), spatial differences among areas were only detected for temperature and dissolved inorganic phosphates (Table 1).

The differences between stations inside and outside the areas of anthropogenic activity were significant only for temperature between O0 and O1, PO$_4$-P between R0 and R1, and for temperature and SS among T0, T1 and T2 (Table 2). Further pairwise comparisons revealed that the differences in temperature and SS between T0 and T2 were highly significant ($P_T = 0.005$, $P_{SS} = 0.013$), while those between T0 and T1 were not significant ($P_T = 0.157$, $P_{SS} = 0.077$).

Mesozooplankton community

MESOZOOPLANKTON PARAMETERS

Species richness was relatively homogeneous in the five areas during spring and winter; during summer and autumn, the richness in T0 and O0 were significantly lower than those in the other three areas (Figure 2A). No differences in the Shannon–Wiener index (*H'*) were detected among the five areas during winter, however, *H'* was somewhat higher in O0 than in other areas during spring, while it was lower than in other areas during summer. Similar to species richness, *H'* values in T0 and O0 were significantly lower during autumn than those in the other areas (Figure 2B). There were significant seasonal variations and regional differences ($P < 0.05$) in mesozooplankton biomass and abundance. During winter, the biomass and abundance in the three aquaculture areas, particularly those in O0, were significantly higher than those in the other sampling areas and the control station. During summer, the biomass and abundance in T0 and O0 were lower than those in other areas (Figure 2C, D).

The differences in mesozooplankton parameters between stations inside and outside the four habitats (kelp farm, oyster farm, fish farm and artificial reef) were all insignificant ($P > 0.05$). However, in the thermal discharge area, the richness, biomass and abundance of mesozooplankton were significantly lower in T0 than in T2 during summer, while the richness was higher in T0 than in T2 during winter (Table 3).

DOMINANT SPECIES

Differences in the compositions of dominant species were observed among the five areas and between stations inside and outside the areas during spring, summer and autumn to different extents (Figure 3). In spring, the most dominant species in all stations was *Centropages abdominalis* Sato,

Table 1. Friedman analysis of differences in environmental parameters among habitats.

Parameters	Average value of four seasons						*P*
	K0	O0	F0	T0	R0	T2	
T	**17.9**^{b}	**17.7**^{b}	**17.9**^{b}	**24.8**^{a}	**17.5**^{b}	**18.7**^{b}	**0.037**
S	23.4	23.2	23.5	24.5	23.6	23.5	0.251
pH	8.1	8.1	8.1	8.1	8.1	8.1	0.373
DO	8.61	8.32	8.30	8.30	8.43	8.47	0.549
SS	20.98	15.63	28.30	33.93	31.67	16.43	0.098
DIN	0.996	0.871	0.866	0.864	0.893	0.881	0.963
PO$_4$-P	**0.080**^{b}	**0.102**^{a}	**0.080**^{b}	**0.103**^{a}	**0.074**^{b}	**0.097**^{a}	**0.016**
SiO$_4$-Si	1.370	1.357	1.347	1.332	1.348	1.360	0.656
Chl *a*	4.631	3.310	2.319	5.278	3.418	4.161	0.452

T, temperature; S, salinity; DO, dissolved oxygen; SS, suspended solids; DIN, dissolved inorganic nitrogen; PO$_4$-P, inorganic phosphate; SiO$_4$-Si, inorganic silicate; Chl *a*, chlorophyll *a*. Different lowercase letters in the same parameters indicate significant differences ($P < 0.05$).

K0, O0, F0 and R0 were stations inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. T0 was the station located 100 m away from the thermal discharge outlet of the power station. T2 was the station located 1000 m away from the thermal discharge outlet of the power station, and also the common control station for the five habitats.

Table 2. Friedman analysis of differences in environmental parameters between stations inside and outside habitats.

Parameters	Average value of four seasons										
	KFA		OFA		FFA		TDA			ARA	
	Ko	K1	Oo	O1	Fo	F1	To	T1	T2	Ro	R1
T	17.9	17.8	**17.7**^{a}	**17.9**^{b}	17.9	18.3	**24.8**^{a}	**21.9**^{ab}	**18.7**^{b}	17.5	17.6
S	23.4	23.4	23.2	23.2	23.5	23.4	24.5	23.9	23.5	23.6	23.6
pH	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
DO	8.61	8.56	8.32	8.35	8.30	8.38	8.30	8.45	8.47	8.43	8.46
SS	20.98	19.55	15.63	17.55	28.30	25.83	**33.93**^{a}	**29.50**^{ab}	**16.43**^{b}	31.67	27.51
DIN	0.996	0.836	0.871	0.898	0.866	0.878	0.864	0.874	0.881	0.893	0.882
PO_4-P	0.080	0.080	0.102	0.111	0.080	0.091	0.103	0.101	0.097	**0.074**^{a}	**0.075**^{b}
SiO_4-Si	1.370	1.383	1.357	1.374	1.347	1.378	1.332	1.330	1.360	1.348	1.320
Chl *a*	4.631	4.494	3.310	4.561	2.319	2.790	5.278	4.309	4.161	3.418	3.967

KFA, kelp farm area; OFA, oyster farm area; FFA, fish farm area; TDA, thermal discharge area; ARA, artificial reef area. Ko, Oo, Fo and Ro were stations inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. K1, O1, F1 and R1 were control stations located 1000 m away from the edge of each area. To, T1 and T2 were stations located 100, 500 and 1000 m away from the thermal discharge outlet of the power station. T, temperature; S, salinity; DO, dissolved oxygen; SS, suspended solids; DIN, dissolved inorganic nitrogen; PO_4-P, inorganic phosphate; SiO_4-Si, inorganic silicate; Chl *a*, chlorophyll *a*. Different lowercase letters in the same parameters indicate significant differences ($P < 0.05$).

1913. However, the relative abundance of *C. abdominalis* in Oo, O1 and Fo was much lower than in other stations, instead brachyuran zoea (the second most dominant organisms) were much more abundant in Oo, O1 and Fo than in the other areas. Furthermore, *Tortanus* (*Eutortanus*) *derjugini* Smirnov, 1935 was the second most dominant species in To, but was not dominant in any other area. In summer, Oo, O1 and To appeared to differ from the other test stations

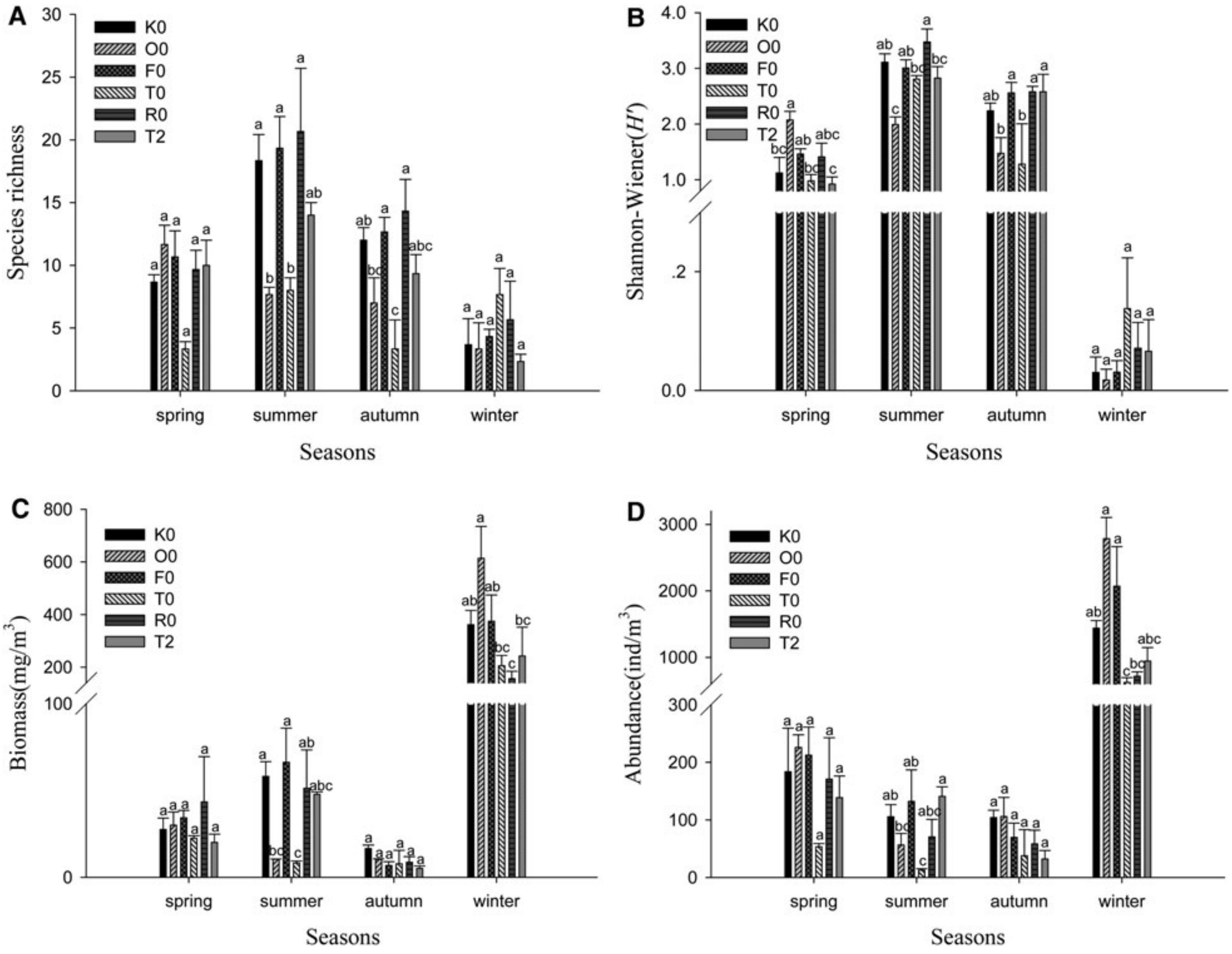

Fig. 2. (A) Species richness, (B) Shannon–Wiener index (*H'*), (C) biomass (mg m^{-3}), and (D) abundance (ind m^{-3}) of mesozooplankton in different habitats. Different lowercase letters in the same season indicate significant differences ($P < 0.05$). Ko, Oo, Fo and Ro were stations inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. To was the station located 100 m away from the thermal discharge outlet of the power station. T2 was the station located 1000 m away from the thermal discharge outlet of the power station, and also the common control station for the five habitats.

Table 3. Analysis of mesozooplankton community parameters between stations inside and outside of habitats.

Parameters	Seasons	KFA		OFA		FFA		TDA			ARA	
		Ko	K1	Oo	O1	Fo	F1	To	T1	T2	Ro	R1
Richness	Spring	8.67 ± 0.58	11.00 ± 2.00	11.67 ± 1.53	10.00 ± 1.73	10.67 ± 2.08	12.00 ± 1.00	3.33 ± 0.58	10.33 ± 0.58	10.00 ± 2.00	9.67 ± 1.53	11.67 ± 3.05
	Summer	18.33 ± 2.08	24.33 ± 4.04	7.67 ± 0.58	11.00 ± 1.00	19.33 ± 2.52	23.67 ± 4.04	**8.00 ± 1.00a**	**11.67 ± 2.31ab**	**14.00 ± 1.00b**	20.67 ± 5.03	24.67 ± 7.09
	Autumn	12.00 ± 1.00	15.00 ± 1.00	7.00 ± 2.00	10.67 ± 0.58	12.67 ± 1.15	18.67 ± 1.53	3.33 ± 2.31	4.67 ± 0.58	9.33 ± 1.53	14.33 ± 2.52	81.82 ± 17.28
	Winter	3.67 ± 2.08	2.00 ± 1.00	3.33 ± 2.08	3.00 ± 1.73	4.33 ± 0.58	4.67 ± 1.53	**7.67 ± 2.08a**	**4.33 ± 1.15ab**	**2.33 ± 0.58b**	5.67 ± 3.05	715.57 ± 324.99
H'	Spring	1.12 ± 0.28	1.31 ± 0.32	2.07 ± 0.15	1.75 ± 0.05	1.46 ± 0.93	0.58 ± 0.13	0.98 ± 0.11	1.33 ± 0.29	0.92 ± 0.13	1.41 ± 0.25	1.31 ± 0.06
	Summer	3.11 ± 0.15	3.81 ± 0.07	1.99 ± 0.13	2.27 ± 0.32	3.00 ± 0.15	3.25 ± 0.19	2.81 ± 0.06	2.92 ± 0.41	2.83 ± 0.21	3.47 ± 0.23	3.34 ± 0.04
	Autumn	2.24 ± 0.14	2.91 ± 0.12	1.47 ± 0.28	2.25 ± 0.07	2.56 ± 0.19	2.79 ± 0.05	1.28 ± 0.72	1.76 ± 0.20	2.58 ± 0.31	2.58 ± 0.10	2.81 ± 0.20
	Winter	0.03 ± 0.02	0.02 ± 0.02	0.02 ± 0.02	0.01 ± 0.01	0.03 ± 0.02	0.04 ± 0.02	0.14 ± 0.08	0.29 ± 0.20	0.07 ± 0.05	0.07 ± 0.04	0.19 ± 0.22
Biomass	Spring	27.48 ± 6.54	34.71 ± 1.23	30.02 ± 7.62	76.15 ± 20.12	34.26 ± 4.28	47.49 ± 5.00	22.44 ± 1.45	15.25 ± 4.31	20.03 ± 4.84	43.33 ± 26.19	39.19 ± 14.43
	Summer	58.06 ± 8.57	59.26 ± 19.02	10.46 ± 0.08	24.21 ± 6.07	66.21 ± 19.72	70.66 ± 13.17	**8.30 ± 1.07a**	**12.75 ± 2.24ab**	**47.73 ± 1.37b**	51.30 ± 22.06	91.56 ± 28.80
	Autumn	16.54 ± 1.93	12.25 ± 1.39	10.33 ± 0.29	7.81 ± 0.65	6.79 ± 2,17	7.31 ± 1.12	7.78 ± 7.70	7.78 ± 0.96	5.14 ± 1.27	8.67 ± 3.21	11.80 ± 2.49
	Winter	361.72 ± 53.63	145.75 ± 11.82	613.81 ± 121.04	383.32 ± 32.78	374.28 ± 100.03	190.68 ± 68.72	205.71 ± 38.52	241.95 ± 12.60	242.42 ± 109.26	156.11 ± 27.90	193.80 ± 78.92
Abundance	Spring	183.50 ± 75.67	172.39 ± 38.58	226.00 ± 21.81	291.49 ± 16.21	212.38 ± 48.94	300.65 ± 61.48	53.67 ± 5.51	81.43 ± 24.92	138.79 ± 37.44	170.90 ± 71.97	239.26 ± 120.18
	Summer	105.44 ± 21.19	119.63 ± 20.59	56.46 ± 20.10	100.34 ± 40.63	132.30 ± 54.76	140.26 ± 14.40	**13.06 ± 2.21a**	**33.89 ± 10.50ab**	**140.83 ± 16.70b**	70.56 ± 30.20	179.39 ± 71.89
	Autumn	104.17 ± 12.83	83.25 ± 9.31	106.00 ± 33.06	91.25 ± 14.83	69.76 ± 24.71	50.46 ± 14.14	37.78 ± 45.26	41.67 ± 8.82	32.22 ± 14.56	58.66 ± 23.40	81.82 ± 17.28
	Winter	1441.23 ± 113.72	570.54 ± 46.31	2785.11 ± 319.83	1635.35 ± 624.36	2071.28 ± 596.57	983.00 ± 205.18	622.35 ± 73.64	695.08 ± 131.28	945.83 ± 204.21	718.68 ± 64.07	715.57 ± 324.99

KFA, kelp farm area; OFA, oyster farm area; FFA, fish farm area; TDA, thermal discharge area; ARA, artificial reef area. Ko, Oo, Fo and Ro were stations inside the kelp farm, oyster farm, fish farm and artificial reef area, respectively. K1, O1, F1 and R1were control stations located 1000 m away from the edge of each area. To, T1 and T2 were stations located 100, 500 and 1000 m away from the power plant thermal discharge outlet. Data are presented as means ± standard deviation ($n = 3$). Data were analysed using Mann–Whitney U (KFA, OFA, FFA and ARA) and Kruskal–Wallis (TDA) one-way analysis of variance (ANOVA) tests. Bold values and different lowercase letters in the same line indicate significant differences between stations ($P < 0.05$ level).

and the control station. First, the most dominant organisms in Oo, O1 and To were brachyuran zoea, rather than *Acartia* (*Odontacartia*) *pacifica* Steuer, 1915, which was the most dominant species in other stations. *Acartia pacifica* was present in Oo and To at levels of ~20% of those in other stations. Second, more benthic species (*Gammarus* sp. and Caprellidae) were collected in To. In autumn, *Paracalanus aculeatus* Giesbrecht, 1888 was the most dominant species in Ko, K1, Fo, F1 and R1, while in the other stations and the control station the most dominant species was *A. pacifica*, with the maximal relative abundance (71.7%) at station Oo. Moreover, similar to spring, abundance of *T. derjugini* was observed at To and Oo in autumn, and this was the second most dominant species. Besides, the relative abundance of *Tortanus* (*Tortanus*) *forcipatus* (Giesbrecht, 1889) at To was much higher than any other stations. In winter, *C. abdominalis* was the sole dominant species in our study areas, and its dominance was >0.9 at all stations.

COMMUNITY COMPOSITION

Significant differences in mesozooplankton communities were detected among seasons ($R = 0.895$, $P = 0.001$) and areas ($R = 0.466$, $P = 0.001$). Pairwise tests revealed that the differences between seasons were all significant, and that those between areas were mostly significant, except that between To and Ro ($P = 0.097$). Besides, there were no significant differences between Ko, Fo or Ro and the control station (T2; $P \geq 0.093$) (Table 4).

The seasonal and spatial differences in mesozooplankton communities between the inside and outside area stations were all significant ($P < 0.05$) in the five areas of anthropogenic activity (Table 5).

Mesozooplankton communities could be classified into two groups based on 60% similarity in spring and winter, four and two groups based on 40% similarity in summer and autumn, respectively (Figure 4). However, the similarity within groups and the differences between groups were more significant in the cold season (spring and winter, 2D Stress = 0.01) than those in the warm season (summer, 2D Stress = 0.09; autumn, 2D Stress = 0.07). During spring, summer and autumn, To and T1 were always classified into a separate group, as were Oo and O1, while the other stations were always classified into one group. Thus the distribution at most stations was mainly consistent with the natural partition, except for To and T1. In winter, the three aquaculture farms (Ko, Fo, Oo) were classified into one group with O1 because of their higher biomass and abundance of mesozooplankton communities, while the other stations were classified into a separate group.

Dominant factors shaping the spatial distribution of mesozooplankton communities

We found non-linear regression between mesozooplankton community similarity and geographic distance during the four seasons (Figure 5). Thus, geographic distance was not the main factor influencing mesozooplankton spatial heterogeneity.

Correlation between mesozooplankton spatial heterogeneity and the nine measured environmental variables was significant in summer ($P = 0.02$) and autumn ($P = 0.04$), but

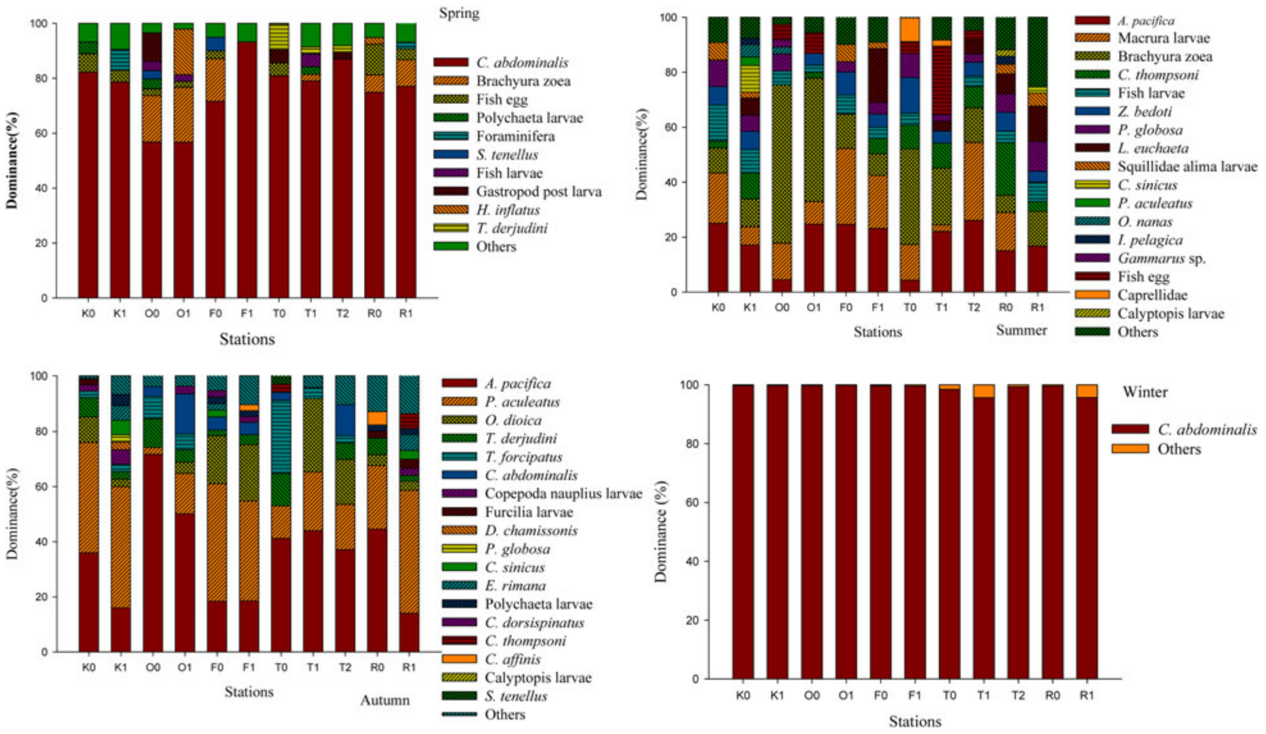

Fig. 3. Dominant mesozooplankton species at different sampling stations in each season. *C. abdominalis, Centropages abdominalis* Sato, 1913; *S. tenellus, Sinocalanus tenellus* (Kikuchi K., 1928); *H. inflatus, Heliconoides inflatus* (d'Orbigny, 1834); *T. derjugini, Tortanus* (*Eutortanus*) *derjugini* Smirnov, 1935; *A. pacifica, Acartia* (*Odontacartia*) *pacifica* Steuer, 1915; *C. thompsoni, Calanopia thompsoni* Scott A., 1909; *Z. bedoti, Zonosagitta bedoti* (Béraneck, 1895); *P. globose, Pleurobrachia globosa* Moser, 1903; *L. euchaeta, Labidocera euchaeta* Giesbrecht, 1889; *C. sinicus, Calanus sinicus* Brodsky, 1962; *P. aculeatus, Paracalanus aculeatus* Giesbrecht, 1888; *O. nana, Oithona nana* Giesbrecht, 1893; *I. pelagica, Iiella pelagica* (Ii, 1964); *O. dioica, Oikopleura (Vexillaria) dioica* Fol, 1872; *T. forcipatus, Tortanus (Tortanus) forcipatus* (Giesbrecht, 1889); *D. chamissonis, Diphyes chamissonis* Huxley, 1859; *E. rimana, Euchaeta rimana* Bradford, 1974; *C. dorsispinatus, Centropages dorsispinatus* Thompson I.C. & Scott A., 1903; *C. thompsoni, Calanopia thompsoni* Scott A., 1909; *C. affinis, Corycaeus* (*Ditrichocorycaeus*) *affinis* McMurrich, 1916. K0, O0, F0 and R0 were inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. K1, O1, F1 and R1 were control stations located 1000 m away from the edge of each area. T0, T1 and T2 were stations located 100, 500, and 1000 m away from the outlet of power station.

not in spring ($P = 0.17$) and winter ($P = 0.72$). The relationships between samples based on mesozooplankton community and environmental variables were demonstrated using LINKTREE (Figure 6).

These results suggest that temperature was the most important factor in regulating mesozooplankton spatial patterns across three seasons, and was the second-most important factor during winter (Figure 6). The temperature elevation caused by thermal discharge had influenced the mesozooplankton communities located ~500–1000 m from the thermal discharge outlet. However, the mesozooplankton communities in other areas were almost consistent with natural patterns controlled by local hydrological conditions, except in winter, when aquaculture led to significant increases in biomass and abundance of mesozooplankton communities in three farms.

DISCUSSION

Clear spatial heterogeneity was detected among the mesozooplankton communities in our study area; however, spatial

Table 4. Analysis of differences between mesozooplankton communities across seasons and sampling stations.

Seasons	*R*	*P*	Stations	*R*	*P*	Stations	*R*	*P*
Global ANOSIM	0.895	**0.001**	Global ANOSIM	0.466	**0.001**	O0 *vs* T2	0.541	**0.001**
Spr *vs* Sum	0.857	**0.001**	K0 *vs* O0	0.884	**0.001**	O0 *vs* R0	0.889	**0.001**
Spr *vs* Aut	0.955	**0.001**	K0 *vs* F0	0.280	**0.021**	F0 *vs* T0	0.790	**0.002**
Spr *vs* Win	1.000	**0.001**	K0 *vs* T0	0.733	**0.008**	F0 *vs* T2	0.177	0.093
Sum *vs* Aut	0.751	**0.001**	K0 *vs* T2	0.122	0.173	F0 *vs* R0	0.847	**0.001**
Sum *vs* Win	0.877	**0.001**	K0 *vs* R0	0.769	**0.008**	T0 *vs* T2	0.528	**0.020**
Aut *vs* Win	0.957	**0.001**	O0 *vs* F0	0.704	**0.003**	T0 *vs* R0	0.279	0.097
			O0 *vs* T0	0.728	**0.002**	T2 *vs* R0	0.187	0.184

Spr, spring; Sum, summer; Aut, autumn; Win, winter. K0, O0, F0 and R0 were stations inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. T0 was a station located 100 m from the thermal discharge outlet of the power plant. T2 was the common control station. Data were analysed by two-way crossed analysis of similarity (ANOSIM; number of permutations: 999).

$P < 0.05$ indicates significant differences between two stations.

Table 5. Differences between mesozooplankton communities across seasons and sampling stations inside and outside habitats.

Groups	KFA		OFA		FFA		TDA		ARA	
	R	*P*	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
Season	1	**0.001**	1	**0.001**	1	**0.001**	0.914	**0.001**	0.980	**0.001**
Station	0.494	**0.032**	0.571	**0.002**	0.546	**0.003**	0.540	**0.004**	0.231	**0.024**

KFA, kelp farm area; OFA, oyster farm area; FFA, fish farm area; TDA, thermal discharge area; ARA, artificial reef area. Data were analysed by two-way crossed analysis of similarity (ANOSIM; number of permutations: 999).
$P < 0.05$ indicates significant differences between two stations.

differences among the majority of environmental parameters were not significant. These discrepant results suggest that the mesozooplankton communities were somewhat more sensitive to anthropogenic activities than environmental parameters.

Our study area contained three ecological sub-zones in Xiangshan Bay (Huang *et al*., 2008b) (Figure S1): section IV (including R0) and section V (including F0, F1, K0, K1, R1, T0, T1 and T2), in the middle and bottom sections of main bay, and section VI (including O0 and O1) in a branch harbour (Tie Harbour). Our results demonstrate not only that the mesozooplankton communities in O0 and O1 are different from those at other stations, but also that there are significant differences among the five areas and between stations inside and outside each habitat. Thus, the observed spatial heterogeneity in the mesozooplankton communities was the result of both natural variations and different human activities.

Effects of thermal stress on mesozooplankton communities

Because of the long residence times of water at the bottom of Xiangshan Bay (Ning & Hu, 2002), thermal water from the Ninghai power plant was retained for a relatively long time, causing the regional temperature to increase by 0.2–8.2°C within ~1000 m from the outlet. Thermal shocks can change hydrological dynamic characteristics by, for example, leading to reduced DO and increased turbidity (Poornima *et al*., 2005). Temperature elevation and perturbation can also hasten the release of nutrients from the sediment, resulting in increased N and P and aggravating water eutrophication (Yang *et al*., 2011). These environmental changes influenced the mesozooplankton communities near the thermal discharge outlet.

The diversity of mesozooplankton varies along temperature gradients, owing to species differences in biological

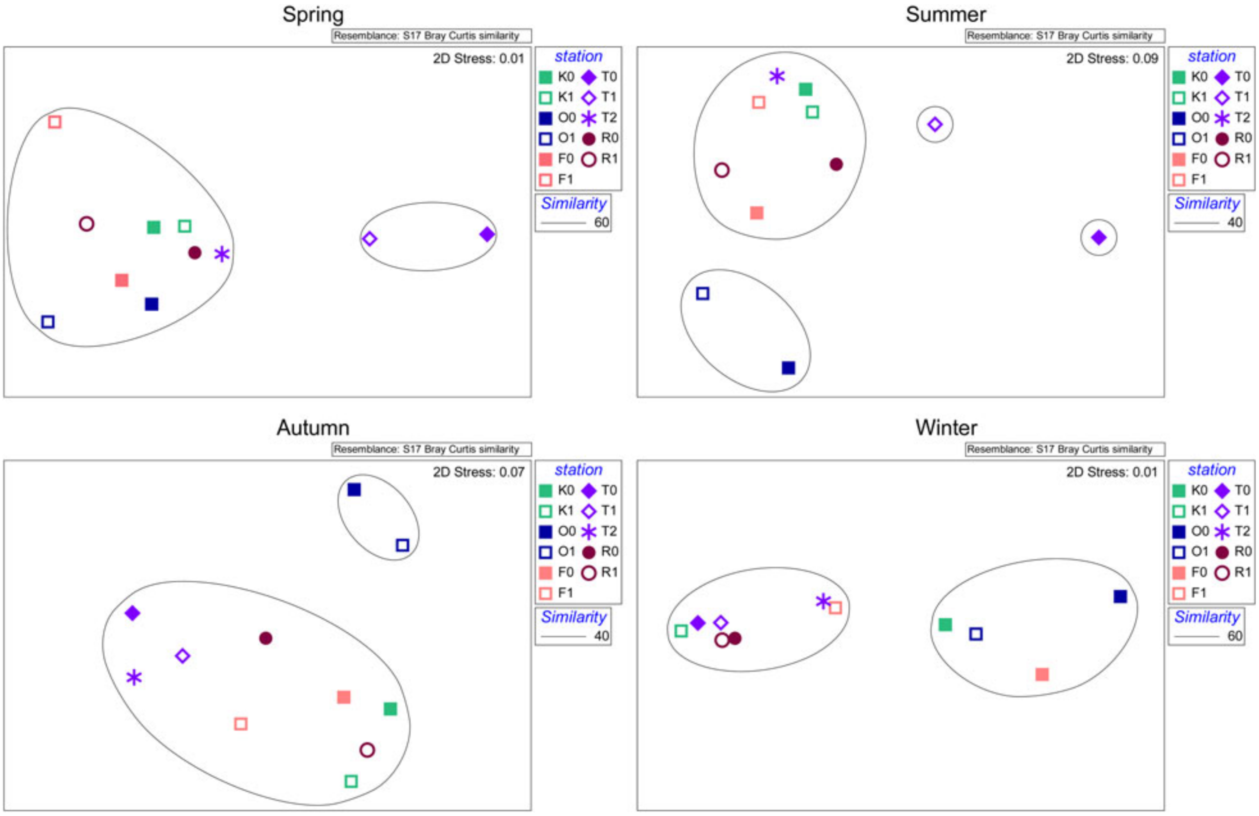

Fig. 4. NMDS plots based on a Bray–Curtis similarity matrices of mesozooplankton communities. K0, O0, F0 and R0 were inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. K1, O1, F1 and R1 were control stations located 1000 m away from the edge of each area. T0, T1 and T2 were stations located 100, 500 and 1000 m away from the outlet of power station.

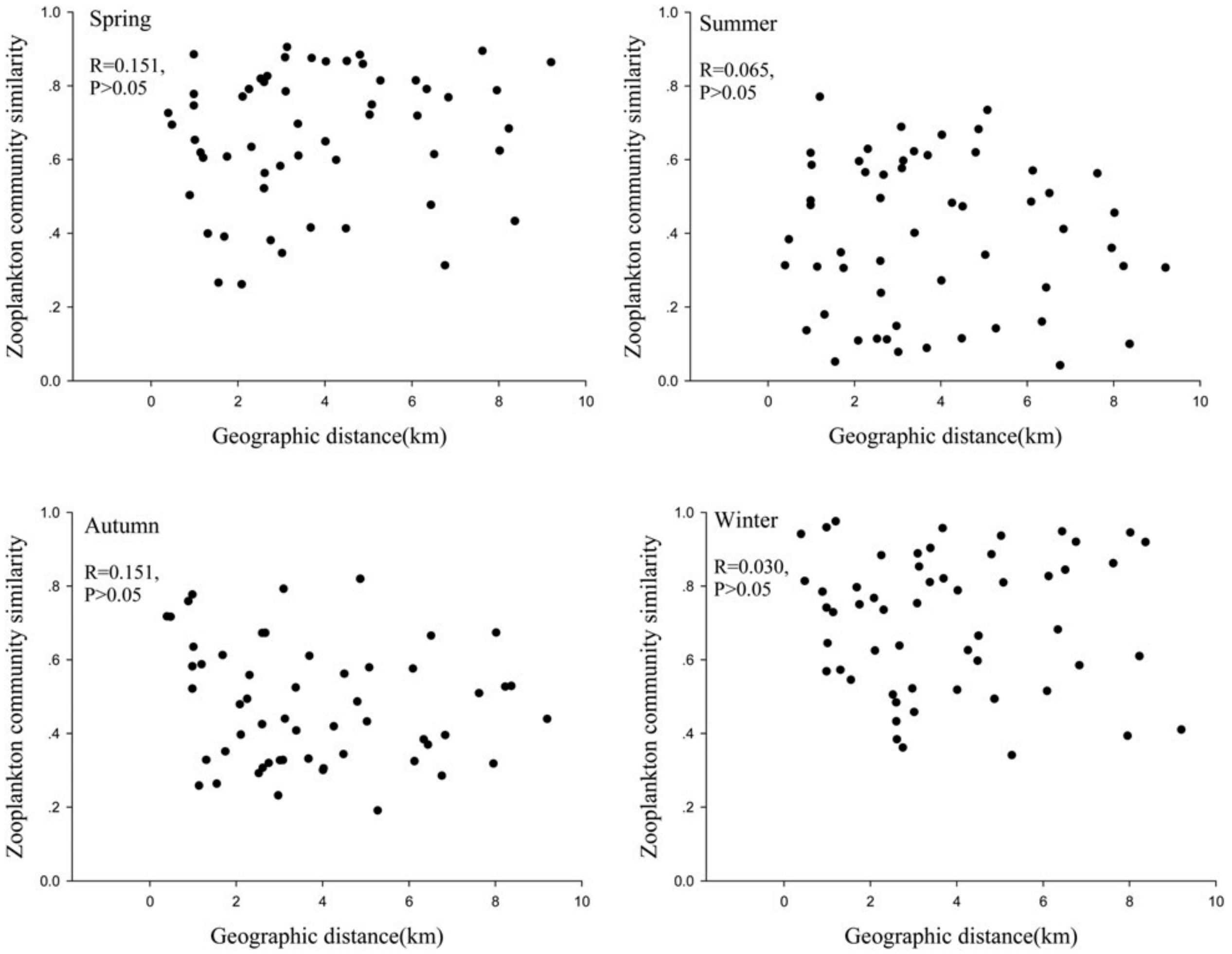

Fig. 5. Correlation between mesozooplankton community similarity and geographic distance in each season.

metabolism and ability to adapt to altered environments, and ecological effects differ between areas heated by different amounts. Species richness, abundance and diversity indices of zooplankton increase in moderately heated areas ($\Delta T < 3^\circ C$), whereas they reduce in areas with more substantial changes in temperature ($\Delta T > 3^\circ C$) (Jin *et al*., 1989; Deng *et al*., 2009). In addition, the ecological effects of thermal discharge show seasonal differences, particularly in subtropical and temperate seas with four distinct seasons. The species diversity of zooplankton normally decreases with increasing temperature in summer, with some species even vanishing, and the opposite is observed in winter (Cai, 2011; Wu *et al*., 2011). A similar phenomenon was observed in our study. The natural water temperature in Xiangshan Bay was under 30°C in summer, and *Acartia pacifica* is normally the most dominant species (ECBCC, 1992; Ning & Hu, 2002), as its optimum temperature range is 24–29°C and its optimum range of salinity is 23–25 (Wang *et al*., 2009). However, *A. pacifica* is very sensitive to thermal shock, and its mortality rate reaches 80% at 33°C (Cai, 2011). In our study, the water temperature within ~500 m of the discharge outlet exceeded 33°C in summer. Thus, the abundance of *A. pacifica* was very low, instead, the abundance of eurythermal organisms (Macrura larvae and Brachyuran zoea) and coastal warm water species (*Zonosagitta bedoti* (Béraneck, 1895)) increased compared with those in other stations. In addition, the relative abundance of *Tortanus derjugini* during spring and autumn and *Tortanus forcipatus* during autumn at the To station increased greatly, which are both estuarine brackish species, with good osmotic regulation ability and adaptability to changeable environments. These results reveal that the changeable environment around the discharge outlet may be favourable to eurythermal and euryhaline species. Moreover, more benthic mesozooplankton species (*Gammarus* sp. and Caprellidae) were collected at the To and T1 stations, owing to sediment resuspension as a result of flow shock and the shallow water.

A decrease in mesozooplankton abundance was found near the cooling water outlet in the current study. Mean total mortality values of mesozooplankton were much higher at the water discharge site because of the direct impact of thermal shock and mechanical damage during entrainment, as well as the indirect impact of increases in water temperature in plume and channel areas (Hoffmeyer *et al*., 2005). Strong thermal effluent flow and shallow water are abiotic factors with potential to reduce the biomass and abundance of zooplankton, especially crustaceans (Tseng *et al*., 2011; Czerniawski & Domagała, 2013). The biomass and abundance of mesozooplankton during summer were especially low, mainly because the excess temperature exceeded the maximum tolerable by some species. A previous study demonstrated that the abundance of mesozooplankton near

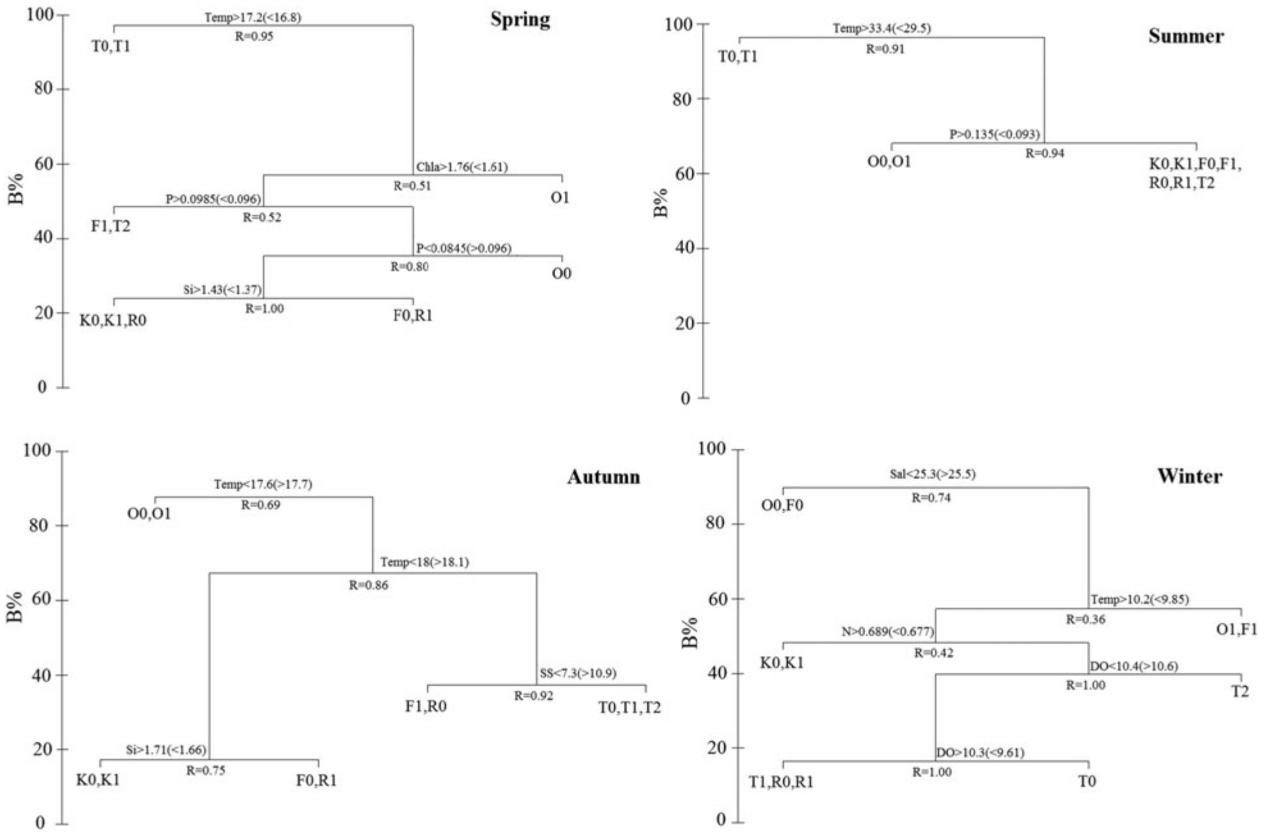

Fig. 6. Linkage trees based on relationships among mesozooplankton communities and environmental parameters. B%, absolute measure of group differences; Temp, temperature; Sal, salinity; DO, dissolved oxygen; SS, suspended solids; N, dissolved inorganic nitrogen; P, inorganic phosphate; Si, inorganic silicate; Chl *a*, chlorophyll *a*. K0, O0, F0 and R0 were inside the kelp farm, oyster farm, fish farm and artificial reef areas, respectively. K1, O1, F1 and R1 were control stations located 1000 m away from the edge of each area. T0, T1 and T2 were stations located 100, 500 and 1000 m away from the outlet of power station.

the outlet was lower than that at the expanding cage-culture area 5 years after the Daya Bay Nuclear Power Plant began to operate (Shen *et al*., 1999). However, the opposite pattern of mesozooplankton distribution was found after 8 years (Li *et al*., 2014), suggesting that the response of mesozooplankton to power plants may change over time. Hence, further work is required to determine the status and mechanism of changes in mesozooplankton abundance near the thermal outlet over an extended timescale. Serving as an important linkage role in marine planktonic food webs, mesozooplankton is an important food source for fish. The decrease in mesozooplankton abundance near the cooling water outlet, together with the thermal shock effects, may indirectly reduce the abundance and richness of fish assemblages in the localized area. However, further work is required to verify this notion.

Centropages abdominalis was the absolutely dominant species in winter across the entire study area, whose abundance accounted for 95–99% of total mesozooplankton. The phenomenon was in accordance with a monthly survey report recording that *C. abdominalis* was the main species in the bottom of Xiangshan Bay during the spring (since the end of January) and reached a peak value in the March (Bo, 1984). The suitable temperature and salinity conditions were the possible reasons for the bloom of *C. abdominalis*. Because this copepod was a coastal low-salinity species, its optimal feeding temperature range was 10–15°C, and optimal growth salinity range was 20–27 (Lin *et al*., 2002), which were well within the temperature and salinity ranges during winter in our survey. However, the abundance (381.9–3147.9 mg m^{-3}) observed at the end of January 2010 had been much greater compared with the peak level (374.4 mg m^{-3}) in the early 1980s (Bo, 1984). The discharge of the Ninghai power plant was probably a key reason for the rising trend in abundance and outbreak in advance of *C. abdominalis*, by raising the water temperature up to 9.6–18.4°C at the end of January, which was just 8–12°C during February and March in the early 1980s (Bo, 1984). Similar to the observed change in zooplankton, the variation in phytoplankton community caused by the temperature elevation has previously been detected in our study area, with phytoplankton blooms occurring during the winter and winter–spring transition (Jiang *et al*., 2012b), and dominant species shifting from diatoms alone to dinoflagellates and diatoms caused by the temperature elevation associated with eutrophication (Jiang *et al*., 2013a).

Integrated effects of natural regionalization and oyster culture on mesozooplankton communities

The mesozooplankton community in the oyster farm was significantly different from those of the other areas across the four seasons. One possible reason for this is that the oyster farm is located in Tie Harbour, a unique ecological sub-zone. The phytoplankton communities in this branch harbour also differ greatly from those in the main bay (Jiang *et al*., 2013b). Another possible reason is the filter feeding and competition effect of the suspended oysters. As demonstrated by many previous studies, cultured bivalves filter large amounts of water when filter-feeding, which affects microplankton communities (phytoplankton and heterotrophic protists; cell diameter, 5–110 μm) (Lam-hoai & Rougier, 2001; Trottet *et al*., 2008a, b). In contrast, mesozooplankton are reported to act as food competitors of cultured bivalves (Lam-hoai & Rougier, 2001). Another possible factor influencing the mesozooplankton community is that the oyster farm was surrounded by water with a 1°C temperature elevation caused by power plant large thermal discharges (82.5 $m^3 s^{-1}$), and the long water residence time (80 d) in the inner bay, which may lead to a slight thermal effect (Jiang *et al*., 2013b).

For the above reasons, the mesozooplankton in the oyster farm showed unique profiles in the different seasons. During winter, when the water temperature was sufficiently low for oyster growth (~10°C), the energy budget for oysters and plankton prey consumption was lower, reducing the food competition pressure for mesozooplankton. Synchronously, the slight water temperature elevation influenced by the thermal discharge was beneficial for phytoplankton reproduction (Jiang *et al*., 2012b) and the dominant mesozooplankton species *C. abdominalis* (Lin *et al*., 2002). Thus, the biomass and abundance of mesozooplankton in the oyster farm were the highest in winter. During summer, when the highest metabolism and growth rates occur, the oysters and biofouling assemblages that attach to the rafts filter large volumes of microalgae and microzooplankton from the water column (Mazouni *et al*., 2001). Due to the resulting deficiency of available food, the diversity, biomass and abundance of mesozooplankton in the oyster farm were all significantly lower than those of the other stations in this season. For the same reasons, the biomass of mesozooplankton in the oyster farm was at the average level for the entire area during spring and autumn. The dominant species in the oyster farm were different from those in the other stations, but were similar to T0, which may be related to the selective filter-feeding of the oysters and the influence of the thermal discharge. In summary, the mesozooplankton characteristics in the oyster farm suggest that extended periods of oyster culture could significantly affect the plankton community inside the farm.

Negligible influence of kelp and fish farming on mesozooplankton communities

The results of our study suggested no obvious influences of kelp and fish farming on zooplankton communities. Some specific attributes observed inside the two farms may reflect some characteristics of the two culture methods; however, their ecological effects on mesozooplankton communities were negligible.

Kelp beds are thought to provide a refuge for a variety of marine organisms by damping waves, changing hydrodynamic flow, offering substrata for epiphytic species, and altering the abundances of predators and prey (Eckman *et al*., 1989; Miller & Page, 2012). In our study, the biomass and abundance of mesozooplankton were slightly higher than the average value for the entire study area in the kelp farm during times of kelp growth (autumn and winter), and those at K0 were higher than at K1. Another study of kelp beds reported results consistent with ours, indicating that the substantial detritus associated with kelp may offer an important food source for mesozooplankton in nearby waters (Pakhomov *et al*., 2002).

In the fish farm, the biomass and abundance of mesozooplankton were a little higher compared with the average values in the entire study area during periods of slow fish growth (winter), but differences were negligible during the other seasons. In addition, biomass and abundance at F0 were higher than those at F1 during winter, but lower in spring. These observations may be related to fish feeding and water quality. Compared with historical data, the annual average values of DIN (0.866 $mg\,l^{-1}$) and PO_4-P (0.077 $mg\,l^{-1}$) in the fish farm in 2010 were higher than those in 2000 (0.823 $mg\,l^{-1}$ and 0.029 $mg\,l^{-1}$, respectively), but the N/P ratio (24.95) was lower than that in 2000 (59.20) (Ye *et al*., 2002), although the nutrient concentration in the fish farm was not significantly higher than those in the other study areas. Consequently, the biomass and B/A (biomass/abundance) ratio of mesozooplankton declined, except in January (because of the advance bloom of *C. abdominalis*) under the stress of long-term eutrophication (Wang *et al*., 2003) (Table 6). These observations verify previous studies indicating that total mesozooplankton biomass decreases, whereas the relative proportion of microzooplankton increases with increasing eutrophication (Uye, 1994; Suikkanen *et al*., 2013; Barbone *et al*., 2014). Furthermore, the dominance of *Oikopleura* (*Vexillaria*) *dioica* Fol, 1872 in the fish farm was higher than in the other areas. *Oikopleura dioica*, an Appendicularian, is a planktonic grazer with high filtering rates that can easily adapt to different environmental conditions because of its reproductive cycles (Hopcroft & Roff, 1995). Increased food availability and eutrophication may underlie the increased dominance of *O. dioica* in the fish farm.

In conclusion, the highly similar mesozooplankton at the K0, F0 and T2 stations is probably due to the fact that they are located at the same ecological sub-zone in Xiangshan Bay, with similar hydrological (circulation, temperature and salinity) and nutrient conditions (Jiang *et al*., 2013b). Another possible explanation is that the two aquaculture scales were too small to demonstrate ecological effects here. However, the phytoplankton community parameters were significantly different between the kelp and fish farms (Jiang *et al*., 2012b), which may be because phytoplankton are the primary producers in ecosystems, and could be particularly influenced by environmental factors. On the basis of this hypothesis, the higher trophic levels in the two farms in our study area would not be expected to have changed, given the negligible variation in zooplankton.

Table 6. Comparison between mesozooplankton parameters measured in the fish farm in 2000 (Wang *et al*., 2003) and 2010.

Sampling month	Biomass ($mg\,m^{-3}$)		Abundance ($ind\,m^{-3}$)		Biomass/ Abundance ($mg\,ind^{-1}$)	
	2000	2010	2000	2010	2000	2010
January	4.36	374.28	29.42	2071.28	0.15	0.18
April	97.70	34.26	552.14	212.38	0.18	0.16
July	85.42	66.21	118.01	132.29	0.72	0.52
October/November	8.50	6.79	39.76	69.76	0.21	0.10

Lack of influence of artificial reef on mesozooplankton over a short time period

Creating artificial habitats in the sea is a popular compensatory tool to mitigate and restore the loss and degradation of natural habitats. The process involves repairing and building living habitats for aquatic organisms, as well as changing the local hydrodynamic pattern to generate upwelling and vortex flow (Seaman, 2007; Bulleri & Chapman, 2010). Several previous studies of artificial reefs, or other artificial upwelling structures, found that the abundance and individual weight of mesozooplankton usually increased compared with the previous habitat or control areas, but the trends of changes in species diversity are controversial (Yanagi & Nakajima, 1991; Zhang *et al.*, 2006; Chen *et al.*, 2013; Jeong *et al.*, 2013). In our study, the biomass, abundance and dominant species of mesozooplankton in the artificial reef area were all consistent with the average values in the entire study area, and there was no significant difference in mesozooplankton community composition between the artificial reef area and the control station. The results suggest that this artificial reef had no significant influence on mesozooplankton up to 2010. Another study carried out in this area during 2010 also found no significant variation in net-phytoplankton between the artificial reef area and control area (Jiang *et al.*, 2012a). However, investigation of mesozooplankton in this area conducted during the summers of 2011 and 2012 demonstrated that diversity and evenness increased to differing degrees (Chen *et al.*, 2013). One possible reason is that the artificial reefs included in this study, which comprised 230 concrete reefs of 5000 m^3, could be too small to alter the mesozooplankton community. Another possible explanation is that any compensatory effects of artificial habitats would show a considerable time lag before emerging and that the artificial reef had not had sufficient time (from 2008 to 2010) to settle and demonstrate ecological effects. Thus, continuous monitoring of the plankton community near this area is required to illuminate the ecological effects of the artificial reef.

CONCLUSION

This study demonstrates that there was clear spatial heterogeneity in the mesozooplankton communities in the inner and middle sections of Xiangshan Bay. However, the natural hydrographic properties were still the dominant factors regulating the spatial distribution of mesozooplankton communities in the majority of study areas. Nevertheless, the thermal discharge from the power plant clearly influenced the mesozooplankton communities in a radius of ~500–1000 m from the outlet. Furthermore, the mesozooplankton community in the oyster farm was also mildly impacted by filter feeding and competition effects of cultured oysters.

Regarding the effect of anthropogenic activities on the whole ecosystem, simple predictions of how the mesozooplankton community may influence lower or higher trophic levels is difficult, since biocenosis at every trophic level is affected by abiotic environmental factors directly, as well as indirectly by the biotic influences exerted by food chain. Simultaneously, both the natural environment and anthropogenic activities are complex and changeable in the bay. Thus, we believe that, if conditions allow, biocenosis should be surveyed and analysed comprehensively at different trophic levels. Furthermore, the species interaction networks should be considered.

SUPPLEMENTARY MATERIAL

The supplementary material for this article can be found at https://doi.org/10.1017/S0025315416001995

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