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Zooplankton community size-structure change and mesh size selection under the thermal stress caused by a power plant in a semi-enclosed bay

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Abstract

Zooplankton samples were collected using 505, 160 and 77 μm mesh nets around a power plant during four seasons in 2011. We measured total length of zooplankton and divided zooplankton into seven size classes in order to explore how zooplankton community size-structure might be altered by thermal discharge from power plant. The total length of zooplankton varied from 93.7 to 40 074.7 μm. The spatial distribution of meso-zooplankton (200 –2 000 μm) populations were rarely affected by thermal discharge, while macro- (2 000 –10 000 μm) and megalo-zooplankton (>10 000 μm) had an obvious tendency to migrate away from the outfall of power plant. Thus, zooplankton community tended to become smaller and biodiversity reduced close to power plant. Moreover, we compared the zooplankton communities in three different mesh size nets. Species richness, abundance, evenness index and Shannon–Wiener diversity index of the 505 μm mesh size were significantly lower than those recorded from the 160 and 77 μm mesh size. Average zooplankton abundance was highest in the 77 μm mesh net ((27 690.0±1 633.7) ind./m^3), followed by 160 μm mesh net ((9 531.1±1 079.5) ind./m^3), and lowest in 505 μm mesh net ((494.4±104.7) ind./m^3). The ANOSIM and SIMPER tests confirmed that these differences were mainly due to small zooplankton and early developmental stages of zooplankton. It is the first time to use the 77 μm mesh net to sample zooplankton in such an environment. The 77 μm mesh net had the overwhelming abundance of the copepod genus *Oithona*, as an order of magnitude greater than recorded for 160 μm mesh net and 100% loss through the 505 μm mesh net. These results indicate that the use of a small or even multiple sampling net is necessary to accurately quantify entire zooplankton community around coastal power plant.

Key words: zooplankton, coastal power plant, temperature elevation, size class, community structure, mesh size selection

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1 Introduction

Zooplankton is the dominant plankton in marine systems and important to aquatic food webs. Therefore, quantitative assessments are necessary to properly evaluate their role. Among the many variables that may influence the accuracy of zooplankton sampling, such as shape and size of the net, towing speed, filtration performance and so on, mesh size selectivity is commonly regarded as the major sources of error (Vannucci, 1968). The efficiency of a given mesh size depends on taxonomic composition and size-structure of the assemblage to be sampled. Although many studies attempted to evaluate mesh size effects (Tseng et al., 2011; Riccardi, 2010; Antacli et al., 2010), there are still no universal mesh size that correctly sample all zooplankton groups under different productivity conditions. This is because zooplankton community size-structure within the different environment changes over space and time.

Coastal power stations generally use seawater as cooling water. The temperature of the seawater used as cooling water increases by 6–10°C in tropical area cooling systems and by 8–12°C in temperate areas, and then released into near-shore environments (Şundri and Gomoiu, 2009; Tunowski, 2009; Bamber, 1995). Temperature is a very important ecological parameter, large volumes of thermally heated water may exceed the thermal limits of some coastal zooplankton species and can result in the replacement of large zooplankton with smaller ones (Mäkinen et al., 2017; Rice et al., 2015; Yvon-Durocher et al., 2011). Several researchers have reported the impact of temperature increase on zooplankton due to power plant, usually in terms of the mortality of zooplankton, changes of abundance and biomass in the cooling channel system and long-time observations of species composition changes (Chew et al., 2015; Tunowski, 2009; Alden, 1979; Evans et al., 1986; Davies and Jensen, 1975). However, no work has ever been performed on the spatial distribution changes in organism size across the area of heating pollution from power plant to understanding how zooplankton community size-structure might be altered by power plant. Organism size often plays a

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key role in determining zooplankton community structure, which is a key driver of rates of carbon sequestration and nutrient cycling (Law et al., 2000).

The location for the present study, the Xiangshan Bay is a semi-enclosed bay located on the East China Sea, with long water residence times in the inner and middle sections of about 80 and 60 d, respectively, for 90% water exchange (Jiang et al., 2012). The Guohua Power Plant was constructed on the bottom of the Xiangshan Bay in 2005, where the exchange of seawater is slow. The area of surface heating pollution caused by waste discharge from the Guohua Power Plant is about 1.63 km^2, and the distance over which temperature is increased ranges from 1 to 2 km (Miao et al., 2010). Zooplankton net with 505 μm mesh size is the most commonly used to study the zooplankton community in the Xiangshan Bay (Wang et al., 2003, 2009, 2011; Liu et al., 2004; Du et al., 2013, 2015, 2017). The 160 μm mesh size net is also used occasionally (Du et al., 2013, 2017). The 77 μm mesh size net is never used to sample zooplankton in such an environment. A better understanding of the change of zooplankton community structure near power plant will only be possible when suitable and comparable sampling methodologies are used.

In this study, we evaluated the zooplankton community in the increased water temperature areas of the Guohua Power Plant using three different mesh size (505, 160 and 77 μm) sample nets. We synthesized all data of zooplankton abundance and body total length from three different mesh size nets to understand the potential impacts of temperature elevation from power plant on zooplankton community size-structure. We also compared the effects of three different net mesh sizes on abundance and community structure of zooplankton. To our knowledge this is the first study carefully comparing mesh efficiency across the area of heating pollution from a power plant, and may serve as a basis for future research.

2 Materials and methods

2.1 *Study site*

The Xiangshan Bay is located in Ningbo within Zhejiang Province of China, which has an area of ~563 km^2 and average depth of 10 m. The Guohua Power Plant is located at the bottom of the Xiangshan Bay, where temperature elevated water is unable to exchange or diffuse in time. Based on the warming range of discharged thermal water from the Guohua Power Plant and the sampling depth limitations of vessels, samples were taken at ten stations which are shown in Fig. 1. Ten stations were arranged along a 2-km transect near the outfall of the Guohua Power Plant, covering the assumed most impacted Sections D2 (including Station S04, 0.2 km away from the outfall), D7 (including Stations S03, S05 and S08, 0.7 km away from the outfall), D12 (including Stations S02, S06 and S09, 1.2 km away from the outfall) and D20 (including Stations S01, S07 and S10, 2.0 km away from the outfall).

2.2 *Sampling methods and identification*

Sampling cruises were conducted in the Xiangshan Bay seasonally in February 26, May 24, August 28 and November 25 of 2011. A total of 120 zooplankton samples were taken by a vertical tow net from 1 m above the bottom to the surface at a speed of 0.5 m/s using plankton nets with different mesh sizes: 40 samples were taken using net I (505 μm mesh size, 145 cm long, 50 cm mouth diameter), 40 samples using net II (160 μm mesh size, 140 cm long, 32 cm mouth diameter) and 40 samples using net III (77 μm mesh size, 140 cm long, 37 cm mouth diameter). The base of the net was equipped with a heavy weight to ensure vertical tows. The filtered water volume was determined by a mechanical flow meter (Hydro-Bios, Germany) at the mouth of the net. Environmental measurements were made simultaneously with zooplankton sampling. Depth, temperature and salinity were determined *in situ*. Surface (0.5 m depth) and bottom (50 cm above the seafloor) temperature were recorded from an attached thermometer in a Nansen sampler (Hydro-Bios, Germany). Surface and bottom salinity were measured with a salinity meter (Horiba U-50, Japan). Temperature and salinity in this study is the average of surface and bottom values.

The samples collected were immediately preserved with 5% formaldehyde. In the laboratory, zooplankton samples were split into sub-samples containing nearly 200 individuals by a zooplankton splitter (Hydro-Bios), and then identified, quantified and measured total length (TL) under a stereomicroscope (Olympus SZX9) or microscope (Olympus BX41). All individuals in a subsample were identified to the lowest taxonomic level possible according to the descriptions of Zheng et al. (1982) and Zheng et al. (1984). The whole samples were analyzed for rare species. All biological abundance data were presented in ind./m^3. The total

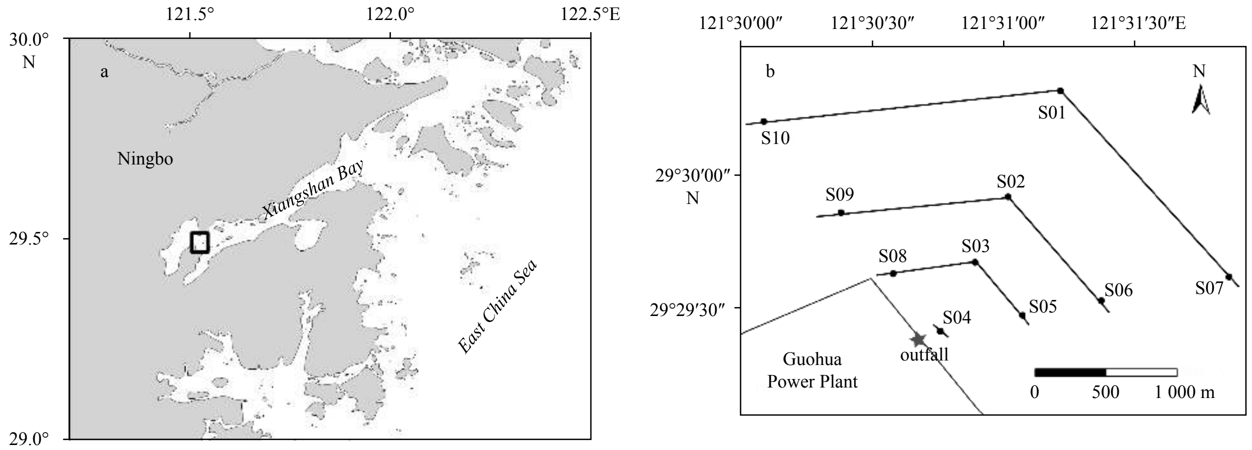

Fig. 1. Geographical position of the Guohua Power Plant (square frame in a) in the Xiangshan Bay and the location of sampling stations (points in b) near the Guohua Power Plant. Star in b represents the position of outfall of Guohua Power Plant. The four sections are labelled with black lines in b.

length of at least 30 individuals of dominant species and whole rare species was measured. Our total length data was pooled into seven size classes according to Cushing et al. (1958) and Dussart (1965): 20–200 μm (micro-zooplankton), 200–500 μm (small meso-zooplankton), 500–1 000 μm (medium meso-zooplankton), 1 000–2 000 μm (large meso-zooplankton), 2 000–5 000 μm (small macro-zooplankton), 5 000–10 000 μm (large macro-zooplankton) and > 10 000 μm (megalo-zooplankton).

2.3 *Data processing*

To understand the temperature difference caused by power plant between sampling stations, we used the lowest station water temperature as the datum mark in each season, and calculated the increment temperature (Δt) between station temperature and the datum mark. The diversity of zooplankton was evaluated using species richness, Shannon–Wiener diversity index (H') and Pielou's evenness index (J') calculated using PRIMER (Ver. 6.1.15) software. Differences in diversity indices of four sections, abundance and diversity indices of three net mesh size groups were compared using one-way ANOVA with Tukey's post-hoc honesty test, performed in R 3.2 software. The dominance (Y) of each species was expressed as $Y = (n_i/N)\cdot f_i$, in which n_i is the number of individuals of the i-th species, N is the total number of individuals, and f_i is the occurrence frequency of i-th species. We identified the dominant species as the one with Y>0.02 (Xu and Chen, 1989). The percentage abundance reduction for each species was described by Pansera et al. (2014) as AR = $[(n_1-n_2)/(n_{\text{eff}})]\times100\%$, where n_1 and n_2 are the abundance of i-th species in first net and second net samples, and n_{eff} is the highest species abundance between two nets. One-way ANOSIM was used to estimate the differences among the three net mesh size groups. In case of significant differences (P<0.001) the zooplankton species most contributing to the differences were recognized using a similarity percentage analysis (SIMPER, Clarke et al., 2014).

3 Results

3.1 *Environmental parameters*

In the Xiangshan Bay, the annual mean depth ranged from (7.0±2.1) m (Section D2) to (14.4±8.3) m (Section D12). The average salinity was highest in February (28.3±0.3), and lowest in August (22.8±0.4), and it was globally constant in four different sections (Table 1). August had the highest average temperature of (29.6±0.6)°C, followed by May ((21.5±1.1)°C), November ((18.5±0.6)°C) and February ((12.1±1.9)°C). The increment of temperature (Δt) among stations were different in four seasons, with a peak of 7.83°C in February, 4.86°C in May, 1.99°C in August and 2.71°C in November. The spatial distribution of temperature was uneven. The minimum temperature was at Stations S01, S02 and S09, and the high temperature was at Stations S04 and S08. In generally, decreasing temperatures were found at increasing distances away from the drain outlet of the power plant (Fig. 2).

3.2 *Size class composition*

Combined with 120 samples data from three different mesh size nets, we identified 77 zooplankton species belonging to 13 taxa (which included 9 species that were identified to genus level) and 18 pelagic larvae. The annual average abundance from 120 samples was (12 571.8±1 138.7) ind./m³. The total length of zooplankton varied from 93.7 to 40 074.7 μm. Zooplankton total length divided into seven size classes in Table 2. Micro-zooplankton (20–200 μm) were mainly consisted by *Tintinnopsis butschlii*, *Difflugia* sp. and Trochophore. Meso-zooplankton (200–2 000 μm) can be subdivided into three classes: small meso-zooplankton (200–500 μm) were mainly made up of copepods nauplius larva, eggs, *Oithona brevicornis*; medium meso-zooplankton (500–1 000 μm) were mainly consisted like copepods larva, *Oithona fallax*, *Paracalanus aculeatus*; large meso-zooplankton (1 000–2 000 μm) were formed with *Centropages abdominalis*, *Centropages tenuiremis*, *Oikopleura dioica* and so on. Macro-zooplankton (2 000–10 000 μm) can be subdivided into two classes: small macro-zooplankton (2 000–5 000 μm) were mainly composed of *Eucalanus crassus*, *Calanus sinicus*, *Eucalanus subcrassus*; large macro-zooplankton (5 000–10 000 μm) contained 5 species, such as *Zonosagitta bedoti*, *Pseudeuphausia sinica* and *Acanthomysis brevirostris*. We only found 4 species *Zonosagitta nagae*, *Abyssisagitta pulchra*, *Acetes japonicas*, *Squillidae alima* larva belonging to megalo-zooplankton (>10 000 μm).

3.3 *Community size-structure of sections*

Combined with the abundance of 120 zooplankton samples from three different mesh size nets, we found the annual average abundance was highest in Section D2, followed by Sections D12 and D20, and lowest in Section D7 (Fig. 3). Higher abundance of micro-zooplankton (20–200 μm) was observed in Sections D12 and D20, averaging 931 and 894 ind./m³, respectively. Meso-zooplankton (200–2 000 μm) were the main component of four sections, while the abundance was highest in Sections D2 and D12 and lowest in D7. Highest abundance of small macro-zooplankton (2 000–5 000 μm) was found in Section D20, up to 2 times greater than other sections. Large macro-zooplankton (5 000–10 000 μm) and megalo-zooplankton (>10 000 μm) were more abundant in Sections D12 and D20, which were disappeared in D2. Table 3 showed increasing individual mean length at increasing distances away from the drain outlet of the power plant. Shannon–Wiener diversity index and evenness index in Sections D7 and D12 were the highest, followed by D20, and lowest in D2. After one-way ANOVA and Tukey's test, there were no significant differences in diversity indices compared for four sections.

3.4 *Three mesh-size communities*

The 505 μm mesh size community had the lowest annual average abundance of (494.4±104.7) ind./m³. A total of 42 zooplankton species (which included 5 species that were identified to genus level) and 7 pelagic larvae were identified, and mainly belong to large meso-zooplankton (1 000–2 000 μm) (Fig. 4). For

Table 1. Mean salinity of sampling months in four sections (mean±SD)

Month	Month average	Section			
		D2	D7	D12	D20
February	28.3±0.3	28.4±0.1	28.2±0.2	28.3±0.5	28.3±0.3
May	25.7±1.6	26.5±0.1	25.6±1.8	26.0±0.7	25.0±2.1
August	22.8±0.4	22.9±0.2	22.8±0.2	22.7±0.2	22.8±0.5
November	24.7±0.3	25.1±0.3	24.9±0.2	24.7±0.2	24.6±0.2

Note: D2, D7, D12 and D20 stand for sections at a distance of 0.2, 0.7, 1.2 and 2 km away from the outfall of the power plant, respectively.

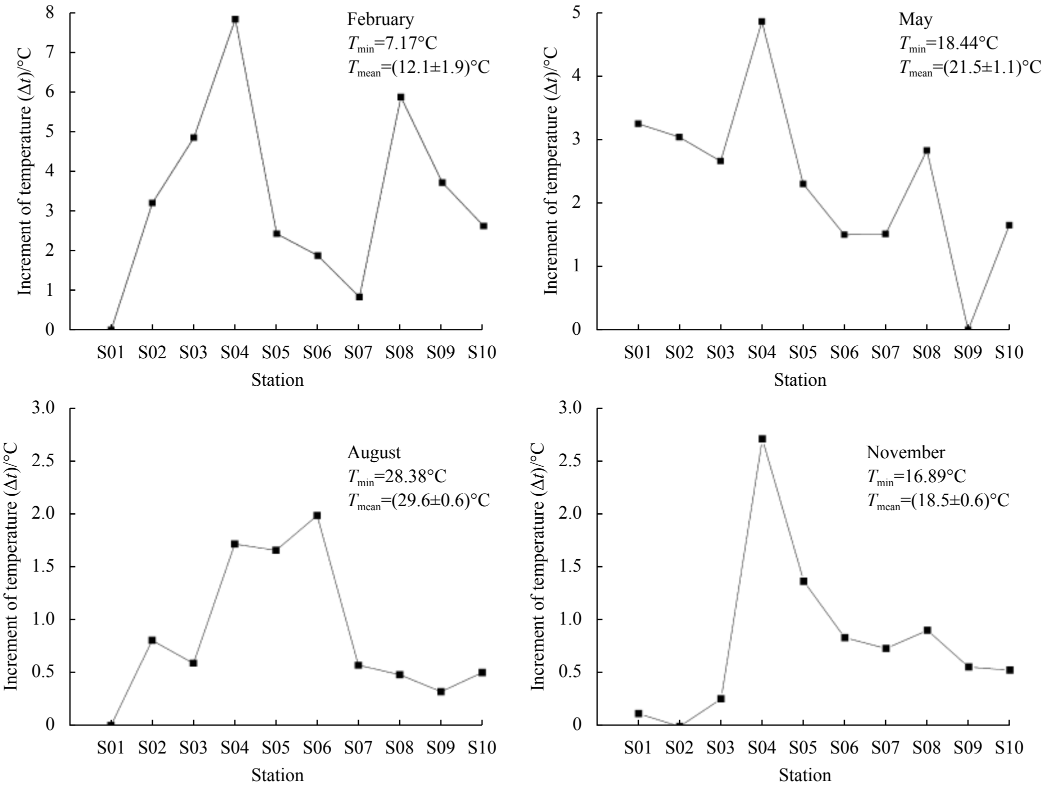

Fig. 2. Variations of increment of temperature (Δ*t*) at each sampling stations and the minimum and mean temperature (mean±SD) in four seasons.

Table 2. Main species of different size-class zooplankton

Size class	Main species
20–200 μm	*Tintinnopsis butschlii*, *Difflugia* sp., Trochophore
200–500 μm	copepods nauplius larva, eggs, *Oithona brevicornis*
500–1 000 μm	copepods larva, *Oithona fallax*, *Paracalanus aculeatus*
1 000–2 000 μm	*Centropages abdominalis*, *Centropages tenuiremis*, *Oikopleura dioica*
2 000–5 000 μm	*Eucalanus crassus*, *Calanus sinicus*, *Eucalanus subcrassus*
5 000–10 000 μm	*Zonosagitta bedoti*, *Pseudeuphausia sinica*, *Acanthomysis brevirostris*
>10 000 μm	*Zonosagitta nagae*, *Abyssisagitta pulchra*, *Acetes japonicus*

Note: In the same size group, species are listed in descending order according to abundance, and only the top 3 species are listed.

the 160 μm mesh size community, annual average abundance was (9 531.1±1 079.5) ind./m^3, containing 47 species (which included 3 species that were identified to genus level) and 16 pelagic larvae. The predominant zooplankton component was mesozooplankton (200–2 000 μm) (Fig. 4). The 77 μm mesh size community had the highest annual average abundance of (27 690.0±1 633.7) ind./m^3 and the highest number of zooplankton species (61, which included 6 species that were identified to genus level) and 15 pelagic larvae, which mainly consisted of meso-zooplankton (200–2 000 μm) and micro-zooplankton (20–200 μm) (Fig. 4). Species richness, abundance, evenness index and Shannon–Wiener diversity index of the 505 μm mesh size were significantly lower than those recorded from the 160 μm mesh size (p<0.05) and the 77 μm mesh size (p<0.05). Significant differences between the 160 μm and 77 μm mesh sizes was only found in species richness (p<0.05) and abundance (p<0.05), while evenness and Shannon–Wiener indices were similar (p>0.05) (Table 4).

3.5 *Dominant species in three different mesh size nets*

In the zooplankton assemblage sampled by the 505 μm mesh net, *C. abdominalis* was the dominant species; it had an abundance reduction (AR) of 77.1% with the 160 μm mesh catches, and 39.5% with the 77 μm mesh catches. *Paracalanus crassirostris* was dominant in both the 160 μm mesh net and 77 μm mesh net, which was underestimated using the 505 μm mesh net, with losses of 100% (AR n_{II}-n_{I} and AR n_{III}-n_{I}). The other numerically important species were *Acartia clausi*, *C. tenuiremis* and *Paracalanus parvus*, which were the most efficiently sampled with the 160 μm mesh net. The 77 μm mesh net caught great number of smaller zooplankton. *Oithona brevicornis*, *Oithona fallax* and *Oithona similis* were dominant species only in 77 μm mesh net samples. Abundance of *Oithona* spp. in the plankton samples collected with a 77 μm mesh net was an order of magnitude greater than in samples taken with 160 μm mesh nets. We estimated a loss of 82.5%–97.2% of *Oithona* copepod individuals through the 160 μm mesh net, and 100% loss through the 505 μm mesh net (Table 5 and Fig. 5).

3.6 *Mesh size effects*

Differences related to mesh size were examined by ANOSIM

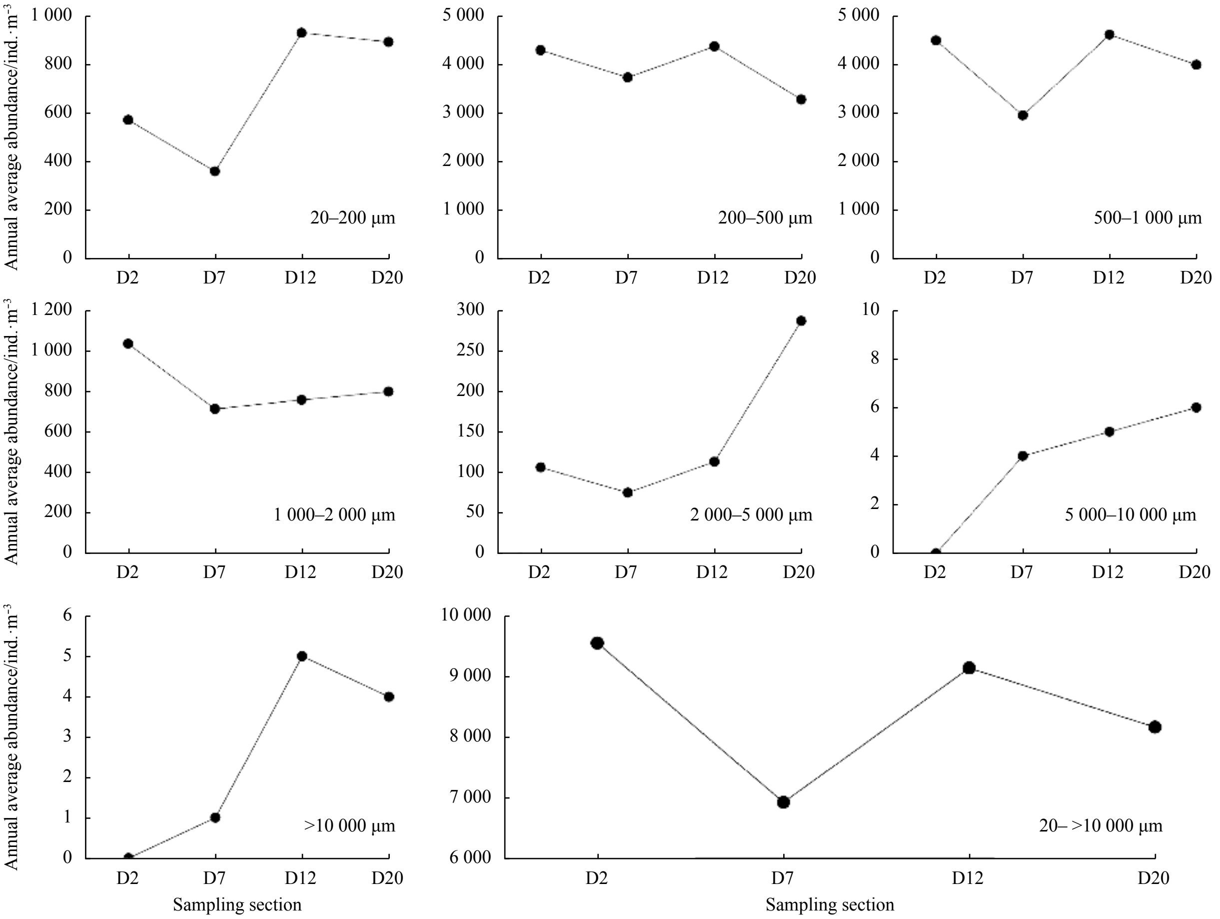

Fig. 3. Annual average zooplankton abundance of four sampling sections in different size-class (20–200 μm, 200–500 μm, 500–1 000 μm, 1 000 –2 000 μm, 2 000–5 000 μm, 5 000–10 000 μm, >10 000 μm and 20– >10 000 μm). D2, D7, D12 and D20 stand for sections at a distance of 0.2, 0.7, 1.2 and 2 km away from the outfall of the power plant, respectively.

Table 3. Individual mean length, Shannon–Wiener index and evenness index in four sections

	Section			
	D2	D7	D12	D20
Individual mean length/μm	600.7	659.1	672.5	726.2
Shannon–Wiener index	1.27 ± 0.16^{a}	1.56 ± 0.32^{a}	1.57 ± 0.44^{a}	1.43 ± 0.24^{a}
Evenness index	0.51 ± 0.09^{a}	0.61 ± 0.12^{a}	0.60 ± 0.14^{a}	0.57 ± 0.08^{a}

Note: Diversity indices with same letters (a) among sections in the superscript mean no significant difference at 0.05 levels. D2, D7, D12 and D20 stand for sections at a distance of 0.2, 0.7, 1.2 and 2 km away from the outfall of the power plant, respectively.

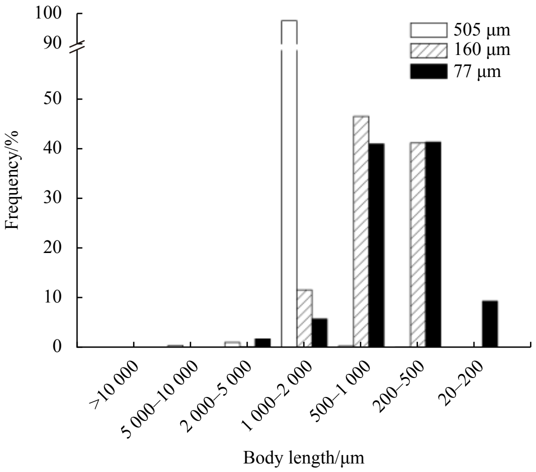

Fig. 4. Size frequency distribution of zooplankton in three different mesh size nets.

and SIMPER tests (Table 6). The ANOSIM test evaluated significant differences among the three mesh size nets (p=0.001). The SIMPER analysis showed that the average dissimilarity between the 505 μm mesh net and the 160 μm mesh net was 90.7%. Copepod larvae were major contributors to this dissimilarity, followed by *O. brevicornis* and eggs. The highest average dissimilarity (94.8%) was found between the 505 μm mesh net and the 77 μm mesh net. The contributions to this dissimilarity were almost equally distributed between copepod larvae and copepod nauplius larvae. The lowest average dissimilarity (62.3%) was seen between the 160 μm mesh net and 77 μm mesh net, which was mostly due to copepod nauplius larvae, *O. fallax* and copepod larvae.

4 Discussion

The results presented here could provide some novel insights into how thermal discharge from power plant might change the spatial distribution of different size-class zooplankton in coastal

Table 4. Differences (mean±SD) among three different mesh size nets in the annual average abundance (ind./m^3) and diversity indices (species richness, evenness index and Shannon–Wiener diversity index)

Mesh size	Abundance	Species richness	Evenness	Shannon–Wiener
net I	494.4±104.7^{c}	42±0.3^{c}	0.5±0.3^{b}	1.1±0.7^{b}
net II	9 531.1±1 079.5^{b}	47±0.4^{b}	0.7±0.1^{a}	1.9±0.4^{a}
net III	27 690.0±1 633.7^{a}	61±0.4^{a}	0.6±0.1^{a}	2.0±0.5^{a}

Note: Mean values with different letters (a, b, c) in the superscript are significantly different at the 0.05 level among mesh, net I = 505 μm mesh size, net II = 160 μm mesh size, and net III = 77 μm mesh size.

Table 5. Dominant species, dominance and abundance reductions (AR, %) recorded from each mesh size net (net I=505 μm mesh size, net II=160 μm mesh size, and net III=77 μm mesh size)

Dominant species	net I	net II	net III	AR n_{II}–n_{I}	AR n_{III}–n_{I}	AR n_{III}–n_{II}
Centropages abdominalis	0.49	–	–	–77.1	–39.5	62.2
Acartia clausi	–	0.03	–	100	100	–63.9
Centropages tenuiremis	–	0.02	–	100	100	–84.5
Paracalanus crassirostris	–	0.03	0.04	100	100	70.2
Paracalanus parvus	–	0.06	–	100	100	–89.6
Oithona brevicornis	–	–	0.05	100	100	92
Oithona fallax	–	–	0.06	100	100	97.2
Oithona similis	–	–	0.03	100	100	82.5

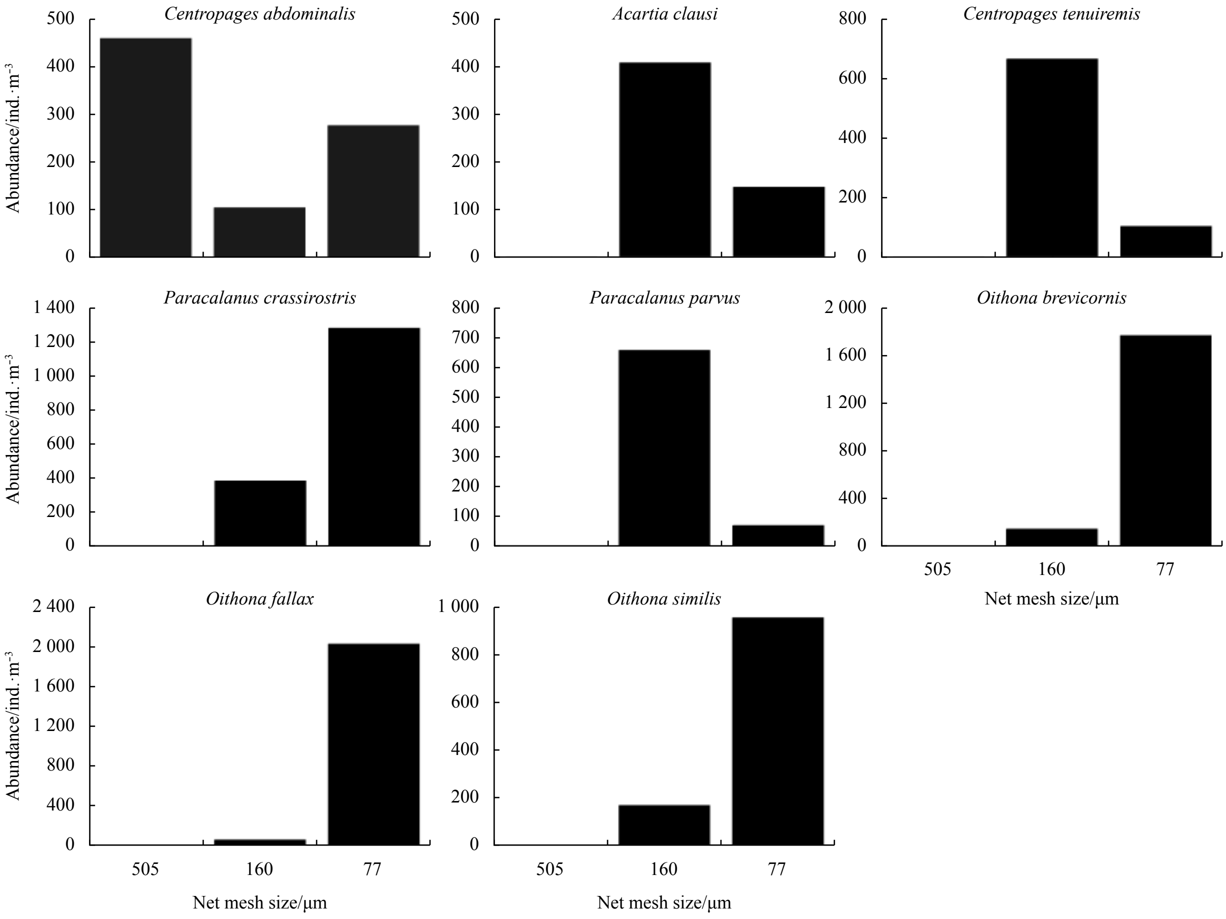

Fig. 5. Abundance of dominant species (*Centropages abdominalis*, *Acartia clausi*, *Centropages tenuiremis*, *Paracalanus crassirostris*, *Paracalanus parvus*, *Oithona brevicornis*, *Oithona fallax*, *Oithona similis*) identified in three different mesh size nets.

ecosystems. Figure 3 showed the abundance of meso-zooplankton (200–2 000 μm) population did not exhibit distinct changes in four sections, and was highest in Section D2, suggesting that their spatial distributions were rarely affected by thermal discharge from power plant. Macro- (2 000–10 000 μm) and megalo-zooplankton (>10 000 μm) had an obvious tendency to migrate away from the power plant, especially for *E. crassus*, *C. sinicus*, *S. bedoti*, *S. nagae*. This was largely determined by the different thermal windows of the large and small species (Stabeno et al., 2012; Chew et al., 2015, Lloyd et al., 2011). The large zooplankton were sensitive to the thermal stress and their abundance might decrease, while small zooplankton were tolerant to the thermal

Table 6. ANOSIM and SIMPER showing the differences in zooplankton communities among three different mesh size nets

		net I, net II	net I, net III	net II, net III
ANOSIM	R	0.7	0.8	0.4
	p	0.001	0.001	0.001
SIMPER	Average dissimilarity/%	90.7	94.8	62.3
	Discriminating species 1	copepod larvae	copepod larvae	copepod nauplius larvae
	Contribution/%	9.9	8.2	6.5
	Discriminating species 2	*Oithona brevicornis*	copepod nauplius larvae	*Oithona fallax*
	Contribution/%	5.3	8.1	4.1
	Discriminating species 3	eggs	*Oithona brevicornis*	copepod larvae
	Contribution/%	5.3	5.2	3.8

Note: Six discriminating species are listed in the table (net I = 505 μm mesh size, net II = 160 μm mesh size, and net III = 77 μm mesh size).

addition and might become the dominant species near the power plant. Similar differential sensitivity among zooplankton taxa had been observed when they pass through cooling systems of power plants (Evans et al., 1986; Davies and Jensen, 1975). Comparative laboratory experiments had shown that there was a significant negative correlation between the critical thermal maximum and body length (Jiang et al., 2009).

Recently, owing to the changing climate, a shift from larger to smaller zooplankton around the world under the seawater temperature increase has been reported (Mäkinen et al., 2017; Rice et al., 2015; Yvon-Durocher et al., 2011). They found two types of changes can occur at the community level: A change in proportion as endemic, smaller zooplankton become more relatively abundant and/or a shift in diversity as small warm-water species are gained or larger cool-water species are lost. This study contributed to develop this understanding further by documenting the effects of increased seawater temperature caused by power plant on zooplankton community size-structure. Macro-zooplankton and megalo-zooplankton were almost disappeared in Section D2 and the individual mean length in D2 was about 4/5 of that in D20, indicating the obvious miniaturization of individuals in D2. However, zooplankton abundance of D2 was the highest in all sections after the migration of large zooplankton, which meant a large number of small zooplanktons were gathered in the outfall of the Guohua Power Plant, such as *O. brevicornis*, *O. fallax*, *O. similis*, *A. clausi*, *P. aculeatus*, copepods nauplius larva, copepods larva. Similarly, Wang et al. (2011) revealed that small zooplankton *A. clausi* was adapted to increased seawater temperature after power plant built in the Xiangshan Bay, therefore its abundance increased and became dominant species. A mesocosm experiment from Yvon-Durocher et al. (2011) showed that zooplankton biomass was unaffected by warming of ~4°C, which meant warming would increase the prevalence of small species after forcing large species migrated away from power plant. As a consequence, the composition of zooplankton communities tended to become smaller sized near the Guohua Power Plant. The species diversity based on the abundance of particular species was reduced compared with history data (Liu et al., 2004; Du and Wang, 2014). Finally, a disturbed and degenerate marine ecosystem near coastal power plants might be a result of the structure and functional change of zooplankton community.

In the Xiangshan Bay, micro-phytoplankton was extremely abundant and contributed 86% of the total chlorophyll *a* concentration and 89% of the primary productivity (Liu et al., 1998). Thermal discharge of power plant increased the steepness of the community size spectrum primarily by increasing the prevalence of small phytoplankton (Yvon-Durocher et al., 2011). It already promoted microalgal growth in regions adjacent to receiving waters after nuclear power station operated in the Xiangshan Bay (Jiang et al., 2012). Zooplankton are often size selective when feeding on phytoplankton, typically consuming the largest size classes possible (Porter, 1973). This suggests that the downsized zooplankton may result from adaptation to the downsized phytoplankton. In addition, increased thermal discharge from power plant can lead to increased thermocline and the dinoflagellates were favored in these stratified water columns (Jones and Gowen, 1990), which may can explain why highest zooplankton abundance was found in Section D2.

Furthermore, our result pointed out that the mesh size of sampling nets can have a significant impact on the monitoring of zooplankton assemblage. Our samples collected with 505, 160, 77 μm mesh nets revealed striking differences in the zooplankton structure and abundance near the Guohua Power Plant (Fig. 4 and Table 4). The 505 μm mesh net captured <2% of the zooplankton compared to 77 μm mesh net, while zooplankton abundance was underestimated by 34.4% using the 160 μm mesh net. Diversity indices of 505 μm mesh net were significantly lower than the 160 μm and 77 μm mesh net, while 160 μm and 77 μm mesh net values were similar. The ANOSIM and SIMPER tests confirmed that the differences estimated by the three mesh nets mainly involved smaller species and the early developmental stages (Table 6). The densities of smaller zooplankton species have often been underestimated in previous studies using large mesh sizes, which were particularly focused on the genus *Oithona* (Gallienne and Robins, 2001; Turner, 2004; Hwang et al., 2007; Vannucci, 1968; Nielsen and Sabatini, 1996). Compares with 77 μm mesh net, we estimated a loss of 82.5%–97.2% of *Oithona* copepod individuals through the 160 μm mesh net, and 100% loss through the 505 μm mesh net. Other copepods like *Paracalanus* spp., with a body diameter ranging from 500 to 900 μm, were similar to the diameter of *Oithona* spp. We also estimated a high loss rate for these groups in the 505 μm and 160 μm mesh nets. Moreover, pelagic larvae were also the biases taxa in terms of total numbers lost.

In general, the minimum total retention width of a particular mesh is a linear function of pore size, which should be about 3/4 of the size of the smallest organism to be sampled (Bernhard et al., 1973). Therefore, the 505, 160 and 77 μm mesh would efficiently sample organisms >676 μm, >213 μm and >103 μm, respectively. In present study, the total length of zooplankton varied from 93.7 to 40 074.7 μm, and zooplankton mainly consisted of meso-zooplankton (200–2 000 μm) (Figs 3 and 4). It meant the ≤160 μm mesh nets were more appropriate to quantitatively sample zooplankton assemblages near the Guohua Power Plant. These results suggest that the finer mesh size than that commonly used (505 μm) for zooplankton sampling highlights the numerical and functional importance of the small zooplankton fraction, which had seldom been taken sufficiently into account previously. Since the shift from larger to smaller zooplankton had happened near coastal power plant, it is necessary to use a small or even multiple sampling net to accurately estimate abundance and diversity indices of the entire zooplankton community at the highest taxonomic levels (Tseng et al., 2011). It allows direct inter-comparisons between different gears providing valuable background to support researchers when deciding between them, and it expands knowledge of community structure (Antacli et al., 2010). More research should be conducted to assess the long-term response of the zooplankton under the thermal addition of coastal power plants using a small or even multiple sampling net.

5 Conclusions

In our study, large zooplankton was sensitive to the thermal stress and migrated away from the power plant, while small zooplankton was tolerant to the thermal addition and become the dominant species. Therefore, zooplankton community tended to become smaller sized and biodiversity reduced in natural sea area close to the coastal power plant. Moreover, the data from three different mesh size nets demonstrated that commonly used large zooplankton sampling nets could be unsuitable for use around coastal power plants since the shift from larger to smaller zooplankton had happened. We strongly suggest the need of a small or even multiple sampling net for a broader view of the zooplankton community, considering the smaller sized zooplankton species and early developmental stages as key components of the plankton food web. Our results would be useful to formulate sampling regulation and serve as a basis for future research near the power plants.

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