



# Seasonal Variation of Zooplankton Communities and the Effects of Environmental Factors in the Seawater Near Taishan Nuclear Power Station

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## ABSTRACT

In the seawater near Taishan Nuclear Power Station, Zooplankton community composition and abundance, the biomass of major taxa, vertical distribution pattern, together with several environmental factors were investigated to evaluate the variation tendency as the seasons change. The structure characteristics of the zooplankton community were analyzed by Margalef species richness (d), Shannon-wiener species diversity index (H'), Pielou evenness index(J'), zooplankton dominant (Y), and dominant species replacement rate (R). There are 48 species within 11 classes of zooplankton identified, including 32 species of copepods. Zooplankton species richness changed obviously in the four seasons, Spring saw the highest (8010.00 ind.m<sup>-3</sup>), followed by winter (5100.00 ind.m<sup>-3</sup>), autumn (1713.75 ind.m<sup>-3</sup>), and summer (1196.25 ind.m<sup>-3</sup>). Similar trends were observed for the wet biomass, which was highest in spring (215.90 mg.m<sup>-3</sup>), followed by winter (181.70 mg.m<sup>-3</sup>), summer (78.56 mg.m<sup>-3</sup>), and autumn (24.69 mg.m<sup>-3</sup>), which gave an annual average of 125.21 mg.m<sup>-3</sup>. The results indicate that the abundance and biomass in spring were significantly higher than those in other seasons. Altogether 8 dominant species were identified along the whole year: *Acrocalanmus gibber*, *Bestiolina amoyensis*, *Paracalanus parvus*, *Acartia danae*, *Mesocyclops leuckarti*, *Noctiluca scientillans*, *Penilla avirostris*, and *Lucifer penicilliger*. The annual average Shannon-Wiener diversity index, Margalef diversity index, Pielou evenness index were 1.75, 1.83, and 0.74, respectively. The effects of environmental factors on the zooplankton community were studied by R and canonical correspondence analysis (CCA). According to Pearson correlation analysis and canonical correspondence analysis, the most important environmental factors influencing the changes of zooplankton species composition, abundance and distribution were water temperature, salinity, and pH in the whole year.

## INTRODUCTION

Nuclear power has played an important role in energy development. However, due to warmer waters brought by heatwaves, many nuclear facilities have already reduced their output in the recent decade. More and more people begin to pay close attention to the threat of nuclear power stations on marine life and the coastal environment, particularly after the Fukushima incident. Nuclear reactors are located near a river or the ocean since they are the most water-intensive energy-producing technology. That may bring temperature drainage, residual chlorine, radioactive materials, and other problem (Chen et al. 2017, Jiang & Hou, 2015, Jiang & Wang 2020, Muthulakshmi et al. 2019).

Zooplankton communities are the vital secondary producers and main drivers of the biological pump in the Marine food web (Muthulakshmi et al. 2019, Goncalves

et al. 2012, Wu et al. 2011, Steinberg & Landry 2017). Since they are highly sensitive to environmental conditions, zooplankton communities are good indicators of the coastal environment change impacts and have been widely used to study such changes and their impacts (Batchelder et al. 2013). Buesseler et al. (2016) had found that when the temperature reached 37.0°C ~ 37.6°C, large zooplankton disappeared and Copepods dropped dramatically in the eastern Indian Ocean due to thermal drainage. Taishan Nuclear Power Station is located about 1.2 km to the northeast of Chixi town, Taishan city in Guangdong province.

There have been relevant studies on the zooplankton community in the coastal waters (Alagan et al. 2020, Asgari & Steiner, 2017, Lin, et al. 2021, Maja et al. 2018, Richardson et al. 2019, Sonia et al. 2019, Thirunavukkarasu et al. 2020), however, few studies on zooplankton community

characteristics in the waters near the nuclear power plant have been reported (Ding et al. 2019).

In this paper, four quarterly background surveys of the zooplankton community in this area from 2015 to 2016 were investigated, focusing on its community structure, abundance distribution, and seasonal changes. The relationship between the zooplankton community and several environmental factors including temperature, salinity, pH, and nutrient salts was also discussed. Our result intended to provide fundamental information for the sustainable utilization of resources in the seawater near Taishan Nuclear Power Station.

## MATERIALS AND METHODS

### Study Site

The zooplankton samples were collected in the seawater near Taishan Nuclear Power Station from Dec. 2015 to Sept. 2016, including 10 points along the coast station (S1-S10) and another 10 offshore (S11-S20) (Fig. 1).

### Sampling

The 20 stations were sampled quarterly from December 2015 to September 2016 for reflecting their variation in four seasons: winter (20-21, December 2015), spring (28-30, March 2016), summer (25-26, June 2016), and autumn (21-23, September 2016).

At each station, water temperature, salinity, and pH were

measured in situ with a multi-parameter water quality meter along with sample collection. For quantitative investigation, 5 L water samples were collected from different sampling sites by an organic glass water extractor and then filtered by a 25# plankton net (with 200 64- $\mu\text{m}$  apertures); And then 50 mL was collected in plastic bottles and immediately fixed with 5% formalin solution. The identifications were analyzed by Olympus SZ61 stereomicroscope after being settled and concentrated to 5 mL. The phyletic analysis was conducted referring to the Chinese Marine plankton map, and Chinese phytoplankton map, and Chinese zoological freshwater copepods.

### Data Analysis

The structure characteristics of the zooplankton community were analyzed by Margalef species richness ( $d$ ), Shannon-wiener species diversity index ( $H'$ ) (Shannon & Weaver 1949), Pielou evenness index ( $J'$ ) (Pielou 1969), zooplankton dominant ( $Y$ ) and dominant species replacement rate ( $R$ ) (Walkusz et al. 2009, Zervoudaki et al. 2009), calculated as below:

$$\text{Species richness index: } d = (S - 1) / \log_2(N) \quad \dots(1)$$

( $S$  - the number of phytoplankton species,  $N$  - the number of individuals of all species)

$$\text{Species diversity index: } H' = \sum (n_i/N) \log_2(n_i/N) \dots(2)$$

( $n_i$  - the total number of individuals of the  $i^{\text{th}}$  species,  $N$  - the total number of individuals of all species)

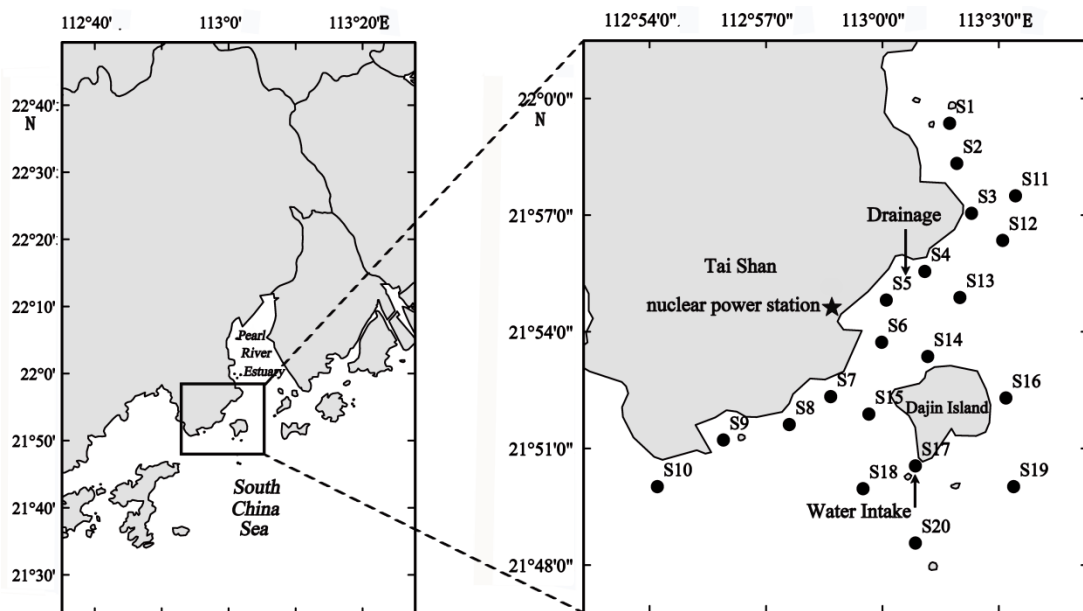


Fig. 1: Map of the different sampling stations. Intake point: Coastwise (S1-S10) and Offshore (S11-S20).

Species evenness index:  $J' = H'/\log 2S$  ... (3)

( $H'$  - the diversity index,  $S$  - the number of species in the sample)

Dominant index:  $Y = \frac{n_i}{N} f_i$ ,  $\geq 0.02$  indicates dominant species ... (4)

( $n_i$  - the total number of the  $i^{\text{th}}$  species,  $f_i$  - the frequency of this species in each sample,  $N$  - the total number of all samples)

Replacement rate of dominant species:  $R = \frac{a+b-2c}{a+b-c} \times 100\%$  ... (5)

( $a$ ,  $b$  - dominant species of the two adjacent periods;  $c$  - the number of common dominant species.)

The R Programming Language *cor* and *cor.test* functions were used for correlation analysis. The biodiversity of the zooplankton community was analyzed by large multivariate statistical software PRIMER6.0. Redundancy analysis (RDA) was performed on zooplankton species and environmental data using Canoco5.0. Canonical-correlation analysis (CCA) was conducted between six water environmental factors (water temperature, salinity, pH, COD, nitrate-nitrogen, and labile phosphate) measured at 20 stations and the abundance of 25 optimal zooplankton species.

## RESULTS

### Species Composition

A total of 48 species of zooplankton taxa (excluding 13 planktonic larvae) belonging to 11 taxonomic groups were identified in seawater around Taishan as shown during the seasonal surveys in Table 1. At the taxonomic level, copepods were numerically the most abundant with 32 species recorded (RA 66.67%), followed by Sergestidae (RA 6.25%, 3 species). The taxonomic groups with 2 species were Cladocera, Rotifera, and Hydromedusae, respectively. The rest classes that had only 1 species recorded were Planktonic mollusks, Cumacea, Isopoda, and Amphipoda, respectively.

The community was predominant by low salt neritic ecological groups, such as *Acartia clausi*, *Acartia pacifica*, *Acartia spinicauda*, *Euterpina acutifrons*, *Labidocera sinilobata*. There were also a few estuarine groups recorded (such as *Sinocalanus tenellus*, *Schmackeria poplesia*, *Centropages tenuiremis*), as well as salty groups (such as *Paracalanus parvus*, *Acartiella sinensis* Shen, *Centropages furcatus*) and tropical groups (such as *Acartia danae*, *Acrocalanmus gibber*, *Acartia erythraea*, *Lucifer intermedius*) (Table 1). In terms of seasonal variation, autumn and winter saw the most complex zooplankton community with 28 species, followed by summer (19 species) and spring (15 species) successively.

### Zooplankton Abundance and Biomass

In the present study, the zooplankton abundance showed a noticeable change among the study stations and between different seasons (Fig. 2). Zooplankton abundance ranged from 75.00 to 9600.00 ind.m<sup>-3</sup> in all the samples investigated with an annual average of 4005.00 ind.m<sup>-3</sup>. The highest average abundance was observed in spring (8010.00 ind./m<sup>3</sup>) and followed by winter (5100.00 ind.m<sup>-3</sup>), autumn (1713.75 ind.m<sup>-3</sup>), and summer (1196.25 ind.m<sup>-3</sup>). It presented seasonal changes as: spring > winter > autumn > summer.

The biomass of zooplankton samples ranged from 2.63 to 815.10 mg.m<sup>-3</sup> with an annual average of 125.21 mg.m<sup>-3</sup>. The total biomass of zooplankton showed similar trends with the zooplankton abundance. In general, maximum biomass occurred in spring (215.90 mg.m<sup>-3</sup>), and then followed a declining trend in the order of winter (181.70 mg.m<sup>-3</sup>), summer (78.56 mg.m<sup>-3</sup>), and autumn (24.69 mg.m<sup>-3</sup>), showing obvious seasonal changes (Fig. 3).

From the perspective of the horizontal distribution shown in Figs. 2-3, the abundance and biomass of zooplankton in near-shore samples collected in spring were significantly different from those in open-sea samples but similar in the other three seasons. In spring, zooplankton abundance and biomass were dramatically higher in near-shore than in open-sea samples with 3.50 times and 3.22 times, respectively. The zooplankton was mainly distributed in the neritic area, while its abundance and biomass were low. This distribution pattern of zooplankton was contributed by the high abundance of *Noctiluca scintillans* as shown in Table 2. The zooplankton showed different distribution patterns in summer, which was mainly distributed in the estuary region to the north of the sampling station and higher compared to other stations (Fig. 2). This is because the *N. scintillans* is still dominant in the summer (Table 2). In addition, the zooplankton was mainly distributed in the southern part of the sampling area in autumn, because *Penilla acirostris* and *Tortanus forcipatus* largely appeared (Table 2) and planktonic larvae were detected at the same time. However, the abundance distribution of zooplankton was relatively uniform in winter (Fig. 2), mainly dominated by copepods (Table 2).

### Dominant Zooplankton Species and Their Seasonal Variations

In the present study, 8 dominant species were found in surface seawater near Taishan during the investigation (not including 2 phytoplankton). Apparently, there were substantial seasonal changes in the zooplankton dominant species, from *A. gibber*, *Bestiolina amoyensis*, *P. parvus*, *Acartia danae*, and *Mesocyclops leuckarti* in winter, *N. scintillans* in spring and summer to *P. acirostris* and *Lucifer penicilliger* in autumn.

Table 1: Species composition of surface zooplankton.

S.No	Family/Species	Ecotype	S.No.	Family/Species	Ecotype
<b>Copepod</b>			<b>Cladocera</b>		
1	<i>Cyclops vicinns</i>	Freshwater	36	<i>Ecadne tergestina</i>	
2	<i>Pseudodiaptomus inopinus</i>	Freshwater	37	<i>Penilla acirostris</i>	
3	<i>Acartia clausi</i>	Nearshore low Salinity	<b>Rotifers</b>		
4	<i>Acartia pacifica</i>	Nearshore low Salinity	38	<i>Brachionus plicatilis</i>	Wide-temperature- salinity group
5	<i>Acartia spinicauda</i>	Nearshore low Salinity	39	<i>Asplanchna priodonta</i>	Freshwater group
6	<i>Paracalanus crassirostris</i>	Nearshore low Salinity	<b>Hydra jellyfish</b>		
7	<i>Euterpina acutifrons</i>	Nearshore low Salinity	40	<i>Moerisia</i> sp.	
8	<i>Microsetella norvegica</i>	Nearshore low Salinity	41	<i>Aequorea conica</i>	
9	<i>Oithona brevicornis</i>	Nearshore low Salinity	<b>Protozoan</b>		
10	<i>Oithona simplex</i>		42	<i>Noctiluca scintillans</i>	
11	<i>Oithona nana</i> Giesbrecht		<b>Amphipoda</b>		
12	<i>Bestiolina amoyensis</i>	Nearshore low Salinity	43	<i>Gammaridea</i> sp.	
13	<i>Labidocera euchaeta</i>	Nearshore low Salinity	<b>Phytoplankton mollusks</b>		
14	<i>Labidocera sinilobata</i>	Nearshore low Salinity	44	<i>Creseis acicula</i>	
15	<i>Tortanus forcipatus</i>	Nearshore low Salinity	<b>Cumacea</b>		
16	<i>Tortanus dextrilobatus</i>	Nearshore low Salinity	45	<i>Cumacea</i> sp.	
17	<i>Temora turbinata</i>	Nearshore low Salinity	<b>Isopods</b>		
18	<i>Acartia danae</i>	Tropical taxa	46	<i>Microniscus</i> sp.	
19	<i>Acartia erythraea</i>	Tropical taxa	<b>Other</b>		
20	<i>Acartia negligens</i>		47	<i>Cypridina bairdii</i>	
21	<i>Candacia</i> sp.	Tropical taxa	<b>Planktonic larvae</b>		
22	<i>Acrocalanus gibber</i>	Tropical taxa	49	Zoea larvae (Brachyura)	
23	<i>Mesocyclops leuckarti</i>	Tropical taxa	50	Nauplius larvae (Cirripedia)	
24	<i>Sinocalanus tenellus</i>	Tropical taxa	51	Nauplius larvae (Copepoda)	
25	<i>Schmackeria poplesia</i>	Tropical taxa	52	Copepoda larvae	
26	<i>Sinocalanus laevidactylus</i>	Tropical taxa	53	Ophiuroidea	
27	<i>Centropages tenuiremis</i>	Tropical taxa	54	<i>Cylla serrata</i>	
28	<i>Paracalanus parvus</i>	Wide salinity group	55	Gastropoda larvae	
29	<i>Acartiella sinensis</i> Shen	Wide salinity group	56	Mysidacea larvae	
30	<i>Centropages furcatus</i>	Wide salinity group	57	Polychaeta larvae	
31	<i>Pseudodiaptomus penicillus</i>		58	Macrura larvae	
32	<i>Canthocalanus pauper</i>		59	Penaenus orientalis	
Sergestidae			60	Eriocheir sinensis	
33	<i>Lucifer hansenii</i>		61	Eriocheir sinensis	
34	<i>Lucifer penicilliger</i>	Warm water species	Total = 61		
35	<i>Lucifer intermedius</i>	Tropical taxa			

To understand how the dominant species changed in different seasons, the replacement rate of the dominant species and the population turnover rate were calculated. The replacement rate of dominant species in spring-summer, summer-autumn, autumn-winter, and winter-spring was

calculated as 0%, 100%, 100%, and 100%, respectively. Successively, the population turnover rate was 53.57%, 77.27%, 76.79%, and 67.44%, respectively. Except for the same dominant species were found in spring and summer, the corresponding replacement rate was above 50%. As a result,

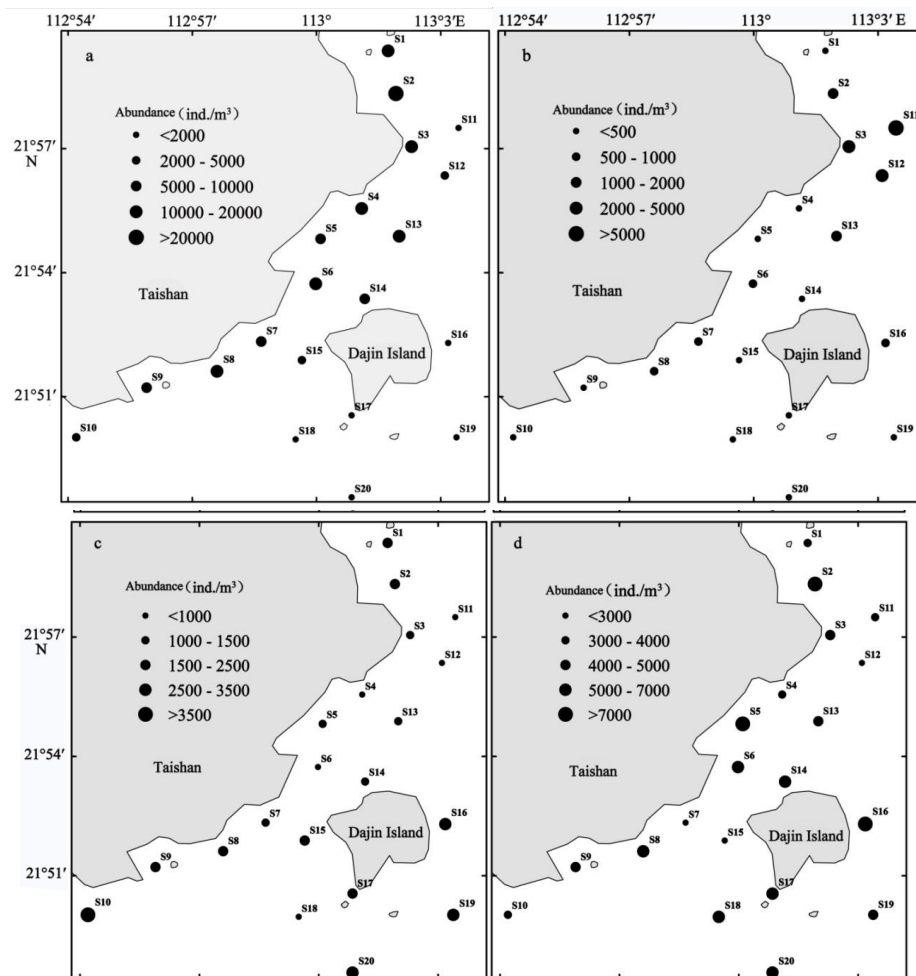


Fig. 2: Average abundance of zooplankton in different seasons (a: Spring, b: Summer, c: Autumn, d: Winter) from Dec. 2015 to Sep. 2016.

the seasonal replacement rate of zooplankton was relatively high in the whole year.

### Species Diversity and Seasonal Variation

As shown in Table 3, the abundance index such as Pielou's index ( $d$ ), the diversity index ( $H'$ ), and the Evenness index ( $J'$ ) during investigation time across seasons exhibited a common trend. Pielou's index ( $d$ ) was in the range of 0.2–3.1, with an annual average of 1.75. The diversity index ( $H'$ ) was in the range of 0.00–3.28, with an annual average of 1.83. The Evenness index ( $J'$ ) was in the range of 0.09–1.00, with an annual average of 0.74. The zooplankton diversity index over the 4 seasons in 2015–2016 was the lowest in spring and followed an increasing trend till winter. While at other times, these values were lower due to the explosive growth of some dominant species.

### Effects of Environmental Factors

Environmental factors play important roles in the seasonal succession of the zooplankton community. As showed in Table 4, the results of correlation analysis were performed to evaluate the influence of environmental factors (water temperature, salinity, pH, COD, nitrate-nitrogen, and labile phosphate) on the zooplankton community (species, abundance, biomass, and diversity index). The population and abundance of zooplankton were found to be positively correlated with salinity and pH, while negatively correlated with COD. Zooplankton biomass was positively correlated with nitrate-nitrogen and labile phosphate, while negatively correlated with water temperature. The diversity index of zooplankton was positively correlated with water temperature, salinity, and pH, while negatively correlated with COD and nitrate-nitrogen.



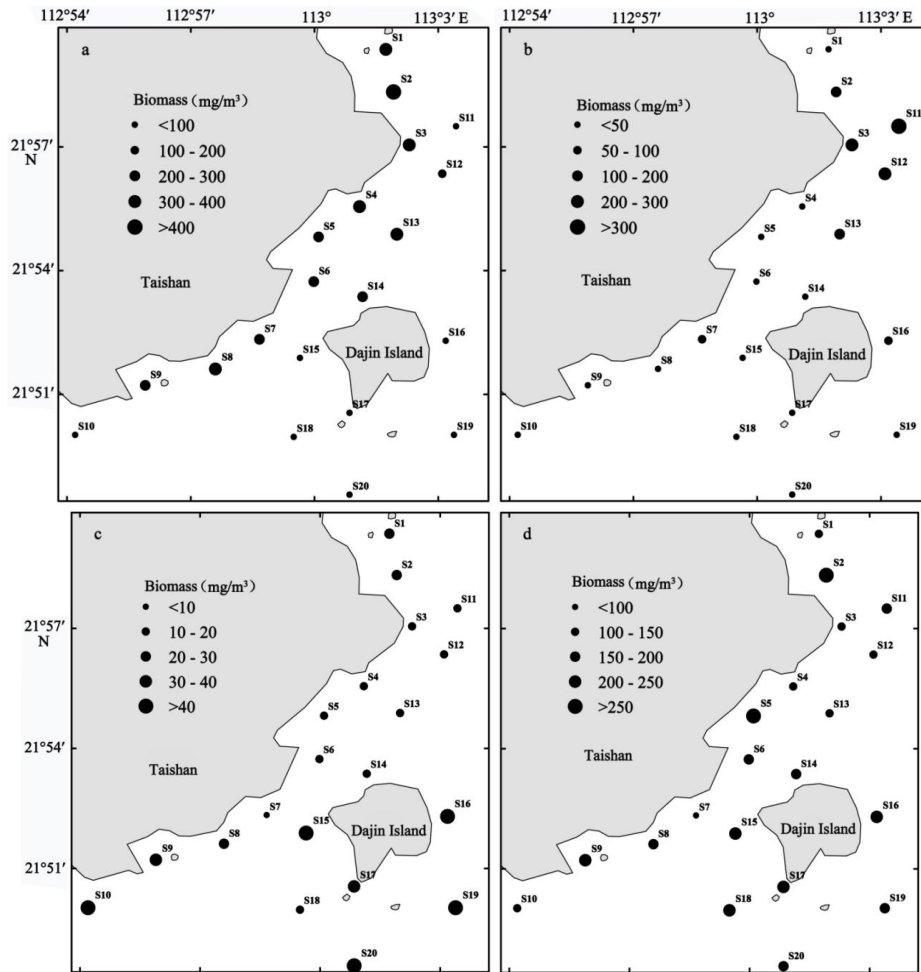


Fig. 3: Horizontal distribution of average biomass of zooplankton in different seasons (a: Spring, b: Summer, c: Autumn, d: Winter) from Dec. 2015 to Sep. 2016.

Table 2: Dominant species of zooplankton.

No.	Dominants	Spring				Summer				Autumn				Winter			
		f%	A	A%	Y	f%	A	A%	Y	f%	A	A%	Y	f%	A	A%	Y
1	<i>Acrocalanus gibber</i>	*	*	*	*	*	*	*	*	5.0	18.75	1.22	-	13.00	780	15.29	0.13
2	<i>Bestiolina amoyensis</i>	*	*	*	*	*	*	*	*	*	*	*	*	5.29	450	5.56	0.05
3	<i>Paracalanus parvus</i>	*	*	*	*	5.0	7.5	0.63	-	15	18.75	1.22	-	16.41	930	11.48	0.16
4	<i>Acartia danae</i>	5.0	3.75	0.05	-	10	18.8	1.57	-	40	56.25	3.67	0.01	2.65	300	3.70	0.03
5	<i>Mesocyclops leuckarti</i>	*	*	*	*	*	*	*	*	*	*	*	*	2.12	270	3.33	0.02
6	<i>Noctiluca scintillans</i>	90	7642.5	95.41	0.86	100	915	76.49	0.76	10	11.25	0.73	-	*	*	*	*
7	<i>Penilla acirostris</i>	*	*	*	*	*	*	*	*	55	247.5	16.14	0.09	*	*	*	*
8	<i>Lucifer penicilliger</i>	*	*	*	*	*	*	*	*	75	165	10.76	0.08	*	*	*	*

f% - frequency of occurrence; A - abundance (ind.m<sup>3</sup>); A% - abundance percentage; Y - dominance

Note: Means the dominance  $Y < 0.01$ , \*means not shown

Table 3: Seasonal variation of diversity and evenness of zooplankton.

Season	Pielou's index ( <i>d</i> )		Diversity index ( <i>H'</i> )		Evenness index ( <i>J'</i> )	
	Mean	Range	Mean	Range	Mean	Range
Spring	0.93	0.33-2.49	0.62	0.00-2.35	0.29	0.09-0.96
Summer	1.28	0.62-2.23	1.55	0.64-2.45	0.80	0.28-0.97
Autumn	2.03	0.69-3.05	2.47	1.38-3.22	0.90	0.79-0.99
Winter	2.75	1.95-3.75	2.66	2.00-3.28	0.98	0.91-1.00
Annual Mean	1.75	0.33-3.75	1.83	0.00-3.28	0.74	0.09-1.00

Table 4: Pearson correlation analysis between parameters of zooplankton and environmental factors.

Environment factors	Number of species		Abundance		Biomass		Diversity index	
	<i>R</i>	<i>P</i>	<i>R</i>	<i>P</i>	<i>R</i>	<i>P</i>	<i>R</i>	<i>P</i>
Temperature T	-0.040	0.724	-0.144	0.203	-0.577	0.000**	0.257	0.021*
Salinity S	0.468	0.000**	0.363	0.000**	-0.074	0.515	0.503	0.000**
pH	0.456	0.000**	0.625	0.000**	-0.210	0.062	0.728	0.000**
Chemical Oxygen Demand COD	-0.272	0.015*	-0.683	0.000**	0.167	0.139	-0.622	0.000**
nitrate-nitrogen (NO <sub>3</sub> )	-0.187	0.100	-0.005	0.967	0.395	0.000**	-0.268	0.016*
labile phosphate (PO <sub>4</sub> )	0.035	0.756	0.205	0.068	0.435	0.000**	-0.094	0.409

Note: \*indicated *P* level was 0.05. \*\*indicated *P* level was 0.01

To further explore the correlations between zooplankton community structure and environmental factors, the canonical correlation analysis (CCA) between the abundance of 25 optimal zooplankton species and six water environmental factors was conducted, as showed in Table 5.

All the characteristic values of CCA sequencing explain 18.7% of the variation degree of zooplankton. The characteristic values of the first two sequencing axes were 0.662 and 0.529, which together explain 15% of the change degree of the zooplankton community. The correlation coefficients between 25 species and 6 water environmental factor sequencing axes (the first axis and the second axis) were 0.956 and 0.886, indicating a close correlation between the zooplankton and the water environmental factors. Thus, the results of CCA were credible. Furthermore, the Monte Carlo test showing that the first axis was significantly different from other axes ( $P < 0.01$ ) made the ranking results of CCA analysis more convincing.

The distinct clusters in species biplot of CCA analysis clearly revealed that the zooplankton spatio-temporal variation may be caused by different environmental variables. Furthermore, among all the environmental variables, the most important factors affecting the structure of the plankton community were COD, pH, and salinity, which is consistent with Pearson correlation analysis results shown in Table 4. In addition, CCA results divided 25 species of major zooplankton into three groups. The species of group I, including *A. gibber*, *B. amoyensis*, etc., were positively correlated with salinity, pH, and labile phosphate, while

negatively correlated with COD. On the contrary, group III (*P. acirostris*, *C. larva*, etc.) was positively correlated with COD but negatively correlated with salinity, pH, and labile phosphate. Group II (*L. penicilliger*, *C. furcatus*, etc.) presented a positive correlation with temperature and a negative correlation with nutrient salts.

Zooplankton species number 1-8 is shown in Table 2. 9. *Centropages furcatus* 10. *Acartia spinicauda* 11. *Oithona brevicornis* 12. *Schmackeria poplesia* 13. *Cycylla serrata* 14. *Paracalanus crassirostris* 15. Nauplius larvae 16. Copepoda larva 17. *Acartia pacifica* 18. *Canthocalanus pauper* 19. *Sinocalanus tenellus* 20. *Lucifer intermedius* 21. *Penaenus orientalis* 22. *Eriocheir sinensis* 23. *Eriocheir sinensis* 24. *Temora turbinata* 25. *Labidocera sinilobata*

Table 5: Summary statistics for the axes of CCA performed on zooplankton.

items	Sequencing axis			
	1	2	3	4
Characteristic value	0.662	0.529	0.172	0.123
Correlation of species and environmental factors	0.956	0.886	0.710	0.713
Cumulative percentage of species	8.30	15.0	17.1	18.7
Cumulative percentage of the relationship between species and environment	41.1	74.0	84.7	92.3
Four sort the total eigenvalues	7.96			
Sum of all canonical eigenvalues	1.61			

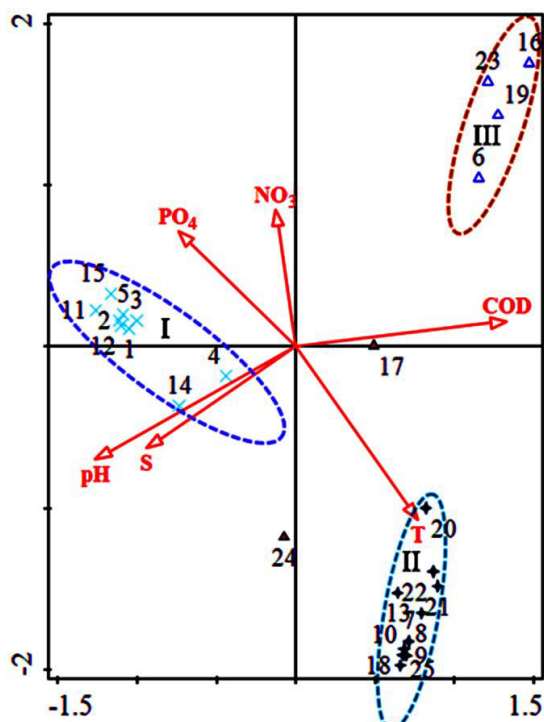


Fig. 4: Canonical correlation analysis between zooplankton species and environmental factors.

## DISCUSSION

### Effects of Environmental Factors and Phytoplankton

In the water, environmental conditions are complex and changing, affecting zooplankton species and communities. Temperature, salinity, and phytoplankton were the important factors influencing the distribution of zooplankton. During this study, a significant variation of water temperature exhibited a seasonal pattern: which increased after spring and reached a maximum in summer, decreased in autumn, and dropped to a minimum in winter. While the salinity showed higher values in winter and autumn than in spring and summer.

The concentration and rich nutrient content of phytoplankton were significantly correlated with the water quality characteristics in different seasons (Alagan et al. 2020, He et al. 2018, Lin et al. 2021, Shi et al. 2018, 2020, Wang et al. 2020). These environmental conditions affected the distribution of zooplankton and thus caused seasonal changes of the zooplankton community (Muthulakshmi et al. 2019, Thirunavukkarasu et al. 2020). Pearson correlation showed that all six environmental factors had affected zooplankton in different aspects, while pH, salinity, and temperature were the most significant factors that influenced the 25 major zooplankton species.

The number of phytoplankton peaked in spring because of adequate nutrient salt, which had reached the level of red tide. With abundant food, low temperature, and low salinity, *N. scintillans* thrived and become the most dominant species ( $Y = 0.86$ ). S2 stood up with  $31125 \text{ ind.m}^{-3}$  among all the sample stations as shown in Fig. 3. Additionally, as a group III species (as discussed in 3.5), *N. scintillans* displayed a significant negative correlation with water temperature and salinity. A red tide of *N. scintillans* had occurred several times in the neritic areas of China, resulting in the death of mollusks such as scallops and oysters, and bringing huge economic losses to the fishery (Baliarsingh et al. 2016). In this survey, the massive propagation of *N. scintillans* was mainly distributed in near-shore and the Pearl River estuary area (with similar environmental conditions of previous *N. scintillans*-related red tides) (Mikaelyan et al. 2014). It indicates risks of occurrence of red tides caused by *N. scintillans*. In addition, low salinity zooplankton groups near the shore and estuaries such as *Acartia pacifica* and *Sinocalanus laevidactylus* were detected. In summer, the abundance of phytoplankton decreased significantly when water temperature increased and salinity decreased. Although the abundance of *N. scintillans* decreased, they remained the dominant species ( $Y=0.76$ ). *N. scintillans* is mainly distributed in the pearl river estuary sea areas such as Station S3, S11, and S12, among which S11 presented the maximum abundance of  $4650 \text{ ind.m}^{-3}$ . As salinity increased while the autumn temperature was still high, the density of phytoplankton as a food source decreased, and thus, replacement of dominant zooplankton species had taken place: *P. acirostris* and *L. penicilliger* became the dominant species, while the planktonic larvae began to multiply and became the absolute group. It can be seen from Fig. 4 that *Nauplius larvae*, belonging to group I, showed a positive correlation with salinity, while *Penaenus orientalis* and *Eriocheir sinensis* (in group II) were mainly positively correlated with temperature. The relationship between different species of planktonic larvae and environmental factors is quite different, which is consistent with previous research results (Fanjul et al. 2018). In winter, dominant species became *P. parvus*, *A. gibber*, *B. amoyensis*, and *A. danae daphnia* with both temperature and phytoplankton abundance decreasing, which were all negatively correlated with temperature.

### Other Effects

It is important to note in particular that the direct effect of the nuclear power plants on the environmental changes was due to the increase in the temperature for the temperature drainage, which became a major factor affecting the marine ecological environment (Alibek 2016, Jiang & Wang et al. 2020, Muthulakshmi et al. 2019). In this study, the differ-



ences in the abundance distribution of zooplankton between the four voyage outlets and the neighboring stations were compared. As a result, zooplankton abundance near the outlet was not much different from that at the adjacent stations in spring; What mattered was the distance from shore: zooplankton abundance was higher at near shore stations than that at the stations in the open sea, indicating significant influence from tides. In summer, zooplankton abundance around the outlet and the south sea area is lower than that in the North Sea area, which indicates that the estuary runoff may have a great influence on the distribution of zooplankton. However, zooplankton abundance around the outlet is lower than those found at non-outlet stations in autumn, which is more likely related to temperature drainage from the nuclear power plant. The situation in winter is more complex with zooplankton distributed quite randomly. In conclusion, temperature drainage seems did affect zooplankton distribution in autumn.

## CONCLUSION

In the seawater near Taishan Nuclear Power Station, a total of 48 species of zooplankton taxa belonging to 11 taxonomic groups were identified. At the taxonomic level, copepods covered the vast majority of zooplankton and they were mainly composed of low salinity groups near the shore, which is typical of subtropical flora. The differences in zooplankton density, biomass, and diversity indices were significant in different seasons. The results indicate that the abundance and biomass in spring were significantly higher than those in other seasons. However, the zooplankton diversity index was the lowest in spring and showed an upward trend till winter. According to Pearson correlation analysis and canonical correspondence analysis, pH, salinity, and temperature were the principal factors affecting the distribution of zooplankton. By comparing the results among the study stations and between different seasons, it seems that the zooplankton community in the survey area was mainly determined by different seasons, estuary runoff, and tide. This study will be helpful in the further understanding of the threat of the Taishan Nuclear Power Station on the marine life and the coastal environment, and in providing scientific guidance for the protection of the ecological environment of surrounding seas.

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