Short-term variation in zooplankton community from Daya Bay with outbreaks of *Penilia avirostris* *

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Abstract

The zooplankton community structure in bays fluctuates as a result of anthropogenic activities in such waters. We focused on the short-term variability of a zooplankton community and compared its differences at the outflow of a nuclear power plant (ONPP), in a marine cage-culture area (MCCA) and in unpolluted waters (UW) in the south-west part of Daya Bay from 28 April to 1 June 2001. Environmental factors and zooplankton abundance differed significantly among stations at ONPP, MCCA and UW: high temperatures and a high zooplankton abundance occurred at ONPP, while a high chlorophyll *a* concentration and a low zooplankton abundance prevailed in MCCA. Statistical analysis revealed that the zooplankton diversity and abundance could be reduced by the activity of the marine cage-culture in a short time. *Penilia avirostris* made up an important component of the zooplankton in the study area, its abundance ranging widely from 16 to 7267 indiv. m^{-3} from April to June and peaking at the ONPP outflow. The outbreak of *P. avirostris* probably resulted from the combined effects of favourable water temperature, food concentration and its parthenogenetic behaviour.

1. Introduction

Bays are subject to various kinds of human pressure, such as domestic sewage, industrial waste, harbours, aquaculture and the activities of electric power plants. Increased anthropogenic input to embayments has resulted in their severe eutrophication. Primary production in such enriched environments has increased and phytoplankton communities have changed (Oviatt et al. 1989, Spatharis et al. 2007, Wang et al. 2009). The composition and structure of zooplankton are also significantly different, with the proportion of small zooplankton increasing in heavily eutrophic bays (Uye 1994, Uye et al. 1998, Park & Marshall 2000, Chang et al. 2009).

Daya Bay is a semi-enclosed bay on the northern continental shelf of the South China Sea (Figure 1a, see p. 585). In the last 30 years, the nutrient structure has become eutrophic mainly as a result of marine aquaculture and waste drainage from land (Wang et al. 2006, 2009, Wu & Wang 2007). The Daya Bay Nuclear Power Plant (DNPP) has been operative in the south-west part of Daya Bay since 1993. These changes have affected the bay's ecological environment. The growth of small diatoms has accelerated and become predominant in the aquaculture areas (Wang et al. 2009). The rise in temperature caused by thermal discharge from the power plant has favoured dinoflagellates over diatoms (Li et al. 2011). The zooplankton in Daya Bay has been investigated since the 1980s (Xu 1989). However, little is known about the influence of these human activities on the zooplankton at the scale of short- and long-term changes. The objective of this study was to attempt to understand the short-term variations of the zooplankton community and the influence of environmental factors on their distribution pattern. We hypothesised that the zooplankton community differed among the three areas (the outflow of nuclear power plant ONPP, the marine cage-culture area MCCA and the adjacent unpolluted waters UW). To test this hypothesis, we analysed the zooplankton species composition, its spatial and temporal variations, and environmental factors by the use of a high-frequency sampling strategy during a short period in Dapeng Cove (located in the south-west of Daya Bay). It was also expected that the study would provide insight into the long-term variation of zooplankton in Daya Bay.

2. Material and methods

2.1. Study area and station location

Dapeng Cove (Figure 1a), was selected as the survey area because it is greatly affected by human activities. The DNPP is on the north shore of the cove. Fish, shrimp and shellfish aquaculture have been well developed there since 1985, and a cage-cultured fishery is situated in its inner waters, which results in highly eutrophic conditions. Six sampling stations were located in Dapeng Cove (Figure 1b). Stations 1 and 2 (S1 and S2) were at the water intake and outflow of the DNPP respectively. S6 was in the cage culture area, and S5 in outer Dapeng Cove, where the water quality was much better (Wu & Wang 2007, Wang et al. 2012). Detailed information on the sampling stations is given in Table 1. Ten cruises were conducted in

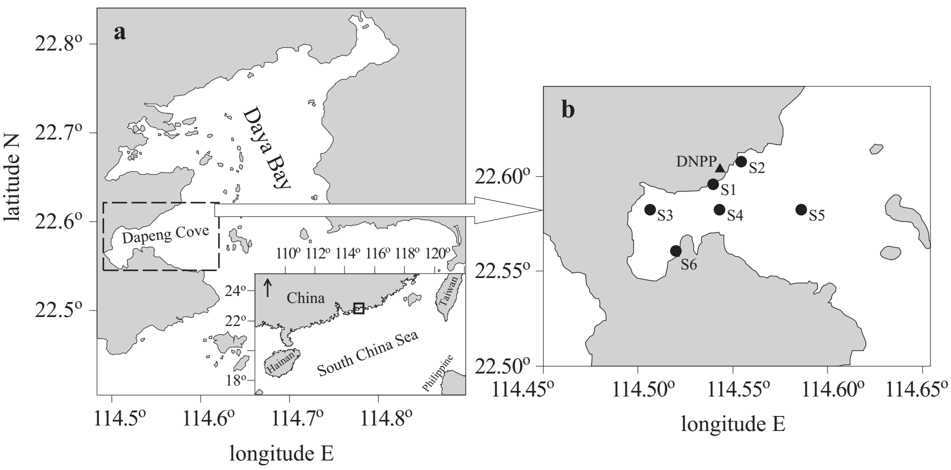

Figure 1. The location of Daya Bay (a) and the six sampling stations in Dapeng Cove (b)

Table 1. Information on the stations in Dapeng Cove sampled from 28 April to 1 June 2001. DNPP, Dapeng Nuclear Power Plant

Station	Longitude E	Latitude N	Depth [m]	Site
S1	114°32.4′	22°35.8′	8	water intake of DNPP
S2	114°33.3′	22°36.5′	10	water outflow of DNPP
S3	114°30.4′	22°35.0′	7	outfall of polluted rivers
S4	114°32.6′	22°35.0′	12	central area of Dapeng Cove
S5	114°35.2′	22°35.0′	15	external area of Dapeng Cove
S6	114°31.2′	22°33.7′	5	marine cage-culture area

the morning every 3–4 days from 28 April to 1 June, except from 4 to 14 May.

2.2. Sampling and measurement

Zooplankton collections were made by vertical hauls of a plankton net (mouth diameter: 0.5 m, mesh size: 505 μm) from 1 m above the bottom to the surface. The base of the net was weighted with a 15-kg hammer. The filtered water volume was determined by the rope length multiplied by the mouth size (unit: m^3). After collection, the zooplankton was immediately preserved in 5% formaldehyde. Organisms were identified to species level under a stereomicroscope (Chen & Zhang 1965, Zheng et al. 1984).

Temperature and salinity were measured in situ using a YSI 6600 multi-parameter water quality monitor. For the determination of surface chlorophyll *a* (Chl *a*) concentration, a 200-mL water sample was gently passed through a 0.45 μm cellulose filter and extracted with acetone (90%v/v) for 24 h at 4°C in darkness. The surface layer Chl *a* concentration (unit: mg m^{-3}) was then determined with a Turner design 10 AU fluorometer before and after acidification (Parsons et al. 1984).

2.3. Data analysis

One-way ANOVA (least significant difference or LSD) was used to test for differences among stations for physical and biological parameters from the DNPP outflow water area (S2), the aquaculture area (S6) and the external area of Dapeng Cove (S5). A species was defined as dominant when Y, the dominance indicator, was ≥ 0.02 (Xu & Chen 1989). Y was calculated as follows: $Y = (n_i/N)\, f_i$, where i is the sample number, n_i is the ith species abundance, f_i is the frequency of occurrence of species i, and N is the total abundance of all zooplankton species. The hierarchical cluster and multidimensional scaling (MDS) analyses of similarity among the sampling stations were computed on the basis of the Bray-Curtis similarity index and $\log_{10}(x+1)$-transformed data from the dominant species (Clarke & Gorley 2006). Pearson's correlation analysis was used to examine possible relationships between sea surface temperature, salinity and Chl a with zooplankton abundance. The tests were deemed significant when $P < 0.05$.

3. Results

3.1. Environmental parameters

The surface water temperature of Dapeng Cove rose from 28 April to 1 June and then maintained a high level of nearly 30°C after 20 May. Salinity

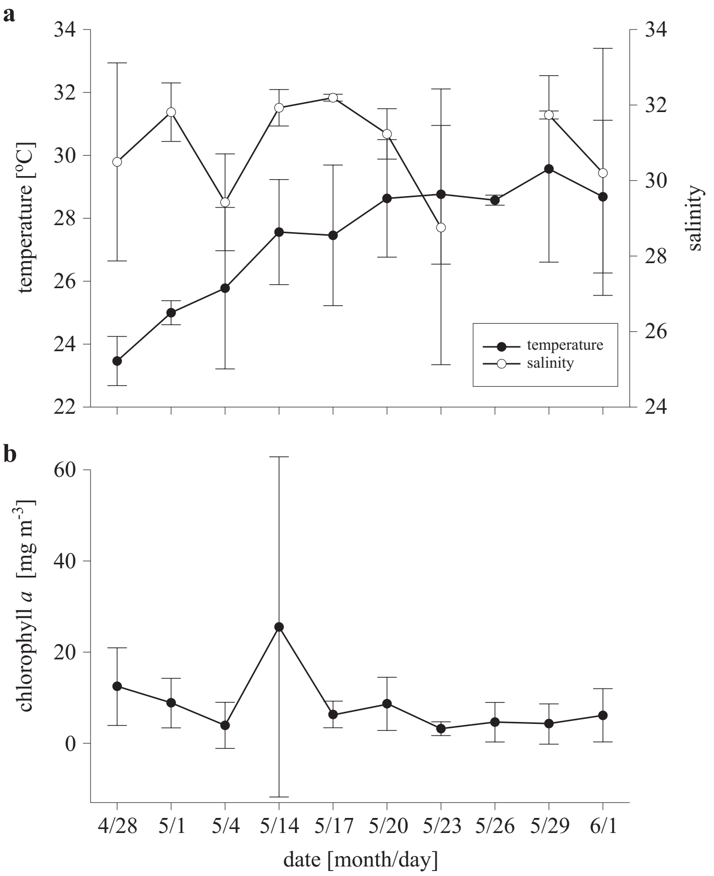

Figure 2. Temporal variations of temperature and salinity (a), and chlorophyll a (b) from 28 April to 1 June in Dapeng Cove

ranged from 28.78 to 32.19 owing to the frequent rains during the survey period (Figure 2a). The Chl *a* concentration fluctuated widely from 3.22 to 25.57 mg m^{-3} with an irregular temporal distribution (Figure 2b).

There were marked increases in surface water temperature at the water outflow of the DNPP (S2) and in Chl *a* concentration at S4 and S6 (Table 2). The regional distributions of salinity did not differ significantly among S2, S5 and S6 ($P > 0.05$); however, temperature at S2 was significantly higher than that at S5 and S6 ($F = 8.581$, $P < 0.01$). Chl *a* concentration at S6 was higher than that at S2 and S5 ($F = 15.208$, $P < 0.001$).

Table 2. Variations of environmental parameters (means ± standard errors) for surface temperature, salinity and chlorophyll *a* at six sampling stations (S1–S6) in Dapeng Cove from 28 April to 1 June

Variables	S1	S2	S3
temperature [°C]	26.56 ± 1.82	**30.91 ± 3.67**	26.62 ± 1.78
salinity	31.58 ± 0.75	31.53 ± 1.71	31.48 ± 1.12
Chl *a* [mg m^{-3}]	6.54 ± 5.12	2.18 ± 1.47	8.16 ± 4.09

Variables	S4	S5	S6
temperature [°C]	26.49 ± 1.85	26.76 ± 1.94	26.55 ± 1.80
salinity	30.75 ± 1.65	30.24 ± 2.61	29.49 ± 3.50
Chl *a* [mg m^{-3}]	17.35 ± 30.15	4.07 ± 3.10	12.19 ± 6.64

3.2. Zooplankton community

3.2.1. Species composition

A total of 72 taxa of zooplankton (including 14 groups of planktonic larvae) were identified during the survey period (Table 3). Copepods represented the most diverse group with 35 species, accounting for 48.61% of the total species richness. Planktonic larvae formed an important group, including mainly macruran, brachyuran and polychaete larvae, which represented more than 20% of all taxa. The richness of other groups was generally < 5 species (Table 3). For example, two species of cladocerans (*Penilia avirostris* and *Pseudevadne tergestina*) were observed. The species number varied among stations, with the maximum at S5 (55 species) and the minimum at

Table 3. The list of species and occurrence of different zooplankton groups in Dapeng Cove from 28 April to 1 June

Group	Station					
	S1	S2	S3	S4	S5	S6
Medusae						
Obelia spp.	+	+	+	+	+	+
Phialidium hemisphaericum	+	+	+	+	+	+
Phialucium carolinae	–	+	–	+	–	–
Solmundella bitentaculata	+	–	–	–	–	–
Ctenophora						
Pleurobrachia globosa	–	–	–	–	+	–
Cladocera						
Penilia avirostris	+	+	+	+	+	+
Pseudevadne tergestina	+	+	+	+	+	+
Ostracoda						
Ecuconchoecia aculeata	–	+	–	–	+	–
Copepoda						
Acartia erythraea	+	+	+	+	+	+
Acartia pacifica	–	+	–	–	+	–
Acartia sp.	–	–	+	–	+	–
Acartia spinicauda	+	+	–	+	+	–
Acrocalanus gibber	+	+	+	+	+	+
Acrocalanus gracilis	–	–	–	+	+	–
Calanopia elliptica	–	–	–	–	+	–
Calanopia thompsoni	–	–	–	–	+	–
Candacia bradyi	+	–	–	–	–	–
Canthocalanus pauper	+	+	–	+	+	–
Centropages furcatus	–	–	–	+	–	–
Centropages abdominalis	–	–	–	–	+	–
Centropages tenuiremis	+	+	+	+	+	+
Copepodites	+	+	+	+	+	+
Corycaeus affinis	+	+	–	–	–	–
Corycaeus specious	–	–	–	+	–	+
Corycaeus sp.	+	–	–	–	+	–
Euchaeta concinna	+	+	–	–	+	–
Labidocera bipinnata	–	+	+	–	+	–
Labidocera minuta	–	–	+	–	–	–
Macrosetella norvegica	–	–	–	–	+	–
Macrosetella gracilis	–	+	–	–	–	–
Oithona plumifera	–	+	–	–	–	–
Oithona rigida	+	–	–	–	–	–
Oithona spp.	–	–	+	–	+	–

Table 3. (*continued*)

Group	Station					
	S1	S2	S3	S4	S5	S6
Oncaea spp.	–	–	+	–	–	–
Paracalanus aculeatus	–	–	–	–	+	–
Paracalanus crassirostris	+	+	+	–	+	–
Pontella fera	–	+	+	+	+	+
Pontellopsis tenuicanda	+	+	–	+	+	+
Subeucalanus subcrassus	–	–	–	–	+	–
Tomera discaudata	–	–	+	+	+	+
Tortanus forcipatus	–	–	–	–	+	–
Tortanus gracilis	–	–	–	–	+	–
Undinula vulgaris	–	–	–	–	+	–
Mollusca						
Atlanta sp.	–	+	+	–	+	–
Decapoda						
Lucifer hanseni	+	+	+	+	+	+
Lucifer intermedius	+	+	–	–	+	–
Lucifer penicillifer	–	–	+	–	–	–
Chaetognatha						
Sagitta bedoti	–	+	+	+	+	–
Sagitta delicata	+	+	+	+	+	+
Sagitta enflata	+	+	+	+	+	+
Sagitta johorensis	+	–	–	–	–	–
Sagitta neglecta	–	+	+	–	–	–
Tunicata						
Dolioletta gegenbauri	–	+	+	+	+	–
Doliolum denticulatum	–	+	–	–	–	–
Oikopleura dioica	+	+	+	+	+	+
Oikopleura longicauda	+	+	+	+	+	+
Oikopleura intermedia	–	–	–	–	+	–
Larvae						
Anomura larvae	–	+	+	–	+	–
Bipinnaria larvae	–	+	–	–	–	–
Brachyura zoea	+	+	+	+	+	+
Cirripedia larvae	+	+	+	+	+	+
Echinoplutenus larvae	–	–	–	+	+	–
Fish eggs	+	+	+	+	+	+
Fish larvae	+	+	+	+	+	+
Leptasynapta larvae	–	+	+	–	+	–
Macrura larvae	+	+	+	+	+	+

Table 3. (*continued*)

Group	Station					
	S1	S2	S3	S4	S5	S6
Ophiopluteus larvae	+	+	+	+	+	–
Phoronida larvae	–	+	–	+	–	–
Polychaeta larvae	+	+	+	+	+	+
Porcellana larvae	+	+	+	+	+	+
Stomatopa larvae	+	+	+	+	+	–

Note: + presence, – absence

S6 (24). There were ca 35 species at S1, S2, S3 and S4 during the sampling period.

3.2.2. Abundance

The abundance of zooplankton fluctuated irregularly, being low in the beginning and middle of the sampling period, and with two peaks on 14 and 23 May (Figure 3a). The temporal variation of cladoceran abundance determined the total zooplankton abundance (Figure 3b). Cladocerans constituted from 41% (28 April) to 90% (14 May) of the total zooplankton abundance, with an average of 74%. Although copepods had the highest species diversity, their abundance was lower than those of cladocerans and planktonic larvae. The proportion of planktonic larvae generally decreased from the beginning to the end of the survey, whereas copepods increased (Figure 3b).

The abundance of zooplankton varied among sampling stations, with the highest at S2 (3772.96 ± 2019.97 indiv. m^{-3}) and the lowest at S6 (854.83 ± 743.88 indiv. m^{-3}). There is a significant difference among S2, S5 and S6, the zooplankton abundance at S2 being higher than at S5 and S6 ($F = 9.666$, $P < 0.01$). Table 4 showed that the variation of cladoceran abundance was consistent with total abundance and was dominant at each sampling station. Pearson correlation analysis indicated that the total zooplankton abundance was positively correlated with temperature ($r = 0.399$, $P < 0.01$), but was not correlated significantly with salinity or Chl *a* concentration in Dapeng Cove during the survey period.

3.2.3. Dominant species

The dominant species consisted mainly of *Penilia avirostris*, *Acartia erythraea*, *Sagitta enflata*, brachyuran larvae and macruran larvae.

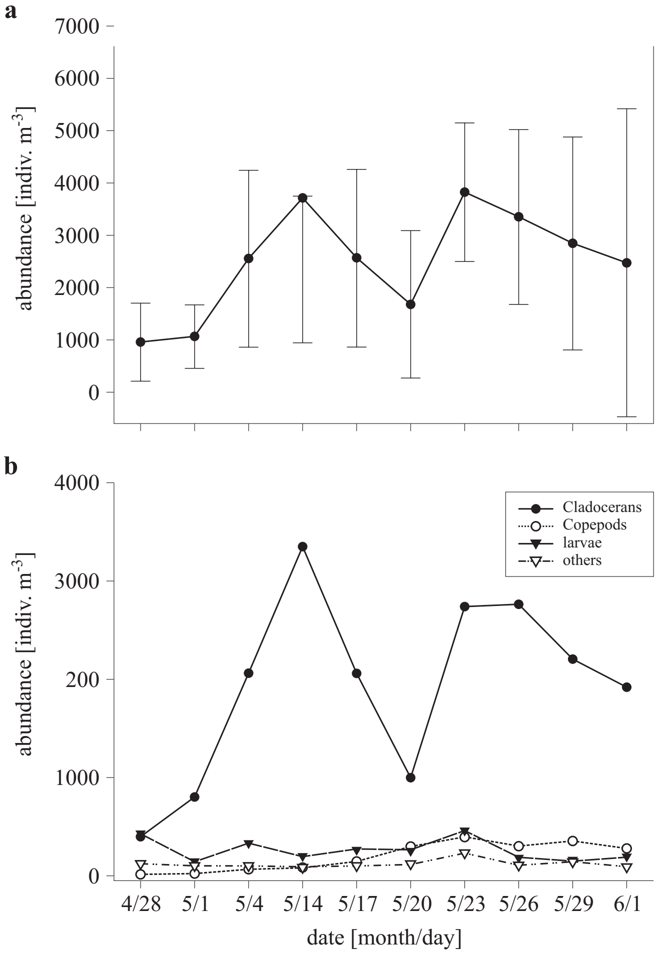

Figure 3. Temporal variations in total zooplankton abundance and the main groups from 28 April to 1 June in Dapeng Cove

Pseudevadne tergestina, *Oikopleura dioica*, cirripedia larvae and fish eggs dominated sporadically during the survey. *P. avirostris* was the predominant species during the survey period and determined the variation of total zooplankton abundance. It occurred at each station with high abundance during each survey period (Figure 4). The peak period of *P. avirostris* abundance was not consistent among stations. For example, on 1 June there were 7266 indiv. m^{-3} at S2, but only 38 indiv. m^{-3} at S6. The abundance of *P. avirostris* was significantly higher at S2 than at S5 and S6 ($F = 11.897$, $P < 0.001$).

The abundance of *A. erythraea* was < 100 indiv. m^{-3} before 17 May and then increased to about 300 indiv. m^{-3} at the end of the survey period

Table 4. Abundances of zooplankton groups [indiv. m^{-3}] at six sampling stations (means ± standard errors) in Dapeng Cove from 28 April to 1 June

Group	S1	S2	S3	S4	S5	S6
Cladocera	1708.86 ± 1948.81	3008.99 ± 1768.52	2371.30 ± 1733.74	2431.80 ± 1830.76	1483.77 ± 1199.73	569.43 ± 704.06
Copepoda	118.22 ± 100.48	372.60 ± 379.70	194.04 ± 210.49	327.19 ± 392.71	106.70 ± 179.97	44.9 ± 59.90
Larvae	189.90 ± 155.33	236.75 ± 200.74	473.30 ± 579.38	252.15 ± 146.33	261.62 ± 203.52	149.36 ± 69.95
Medusae	9.42 ± 13.77	0.72 ± 1.76	3.18 ± 4.14	6.04 ± 15.58	10.38 ± 24.11	1.50 ± 4.74
Mollusca	0.00 ± 0.00	0.42 ± 0.83	1.79 ± 3.57	0.00 ± 0.00	2.62 ± 3.40	0.00 ± 0.00
Ostracoda	0.00 ± 0.00	4.39 ± 5.57	0.00 ± 0.00	0.00 ± 0.00	0.54 ± 0.25	0.00 ± 0.00
Decapoda	18.15 ± 51.84	9.09 ± 14.25	5.66 ± 10.78	10.20 ± 16.82	17.71 ± 34.57	1.39 ± 4.17
Chaetognatha	57.41 ± 56.10	133.67 ± 150.35	55.92 ± 27.33	108.71 ± 85.81	58.69 ± 47.06	27.11 ± 42.33
Tunicata	16.52 ± 22.32	11.01 ± 9.29	59.95 ± 54.63	31.44 ± 31.12	11.96 ± 13.95	61.25 ± 107.89

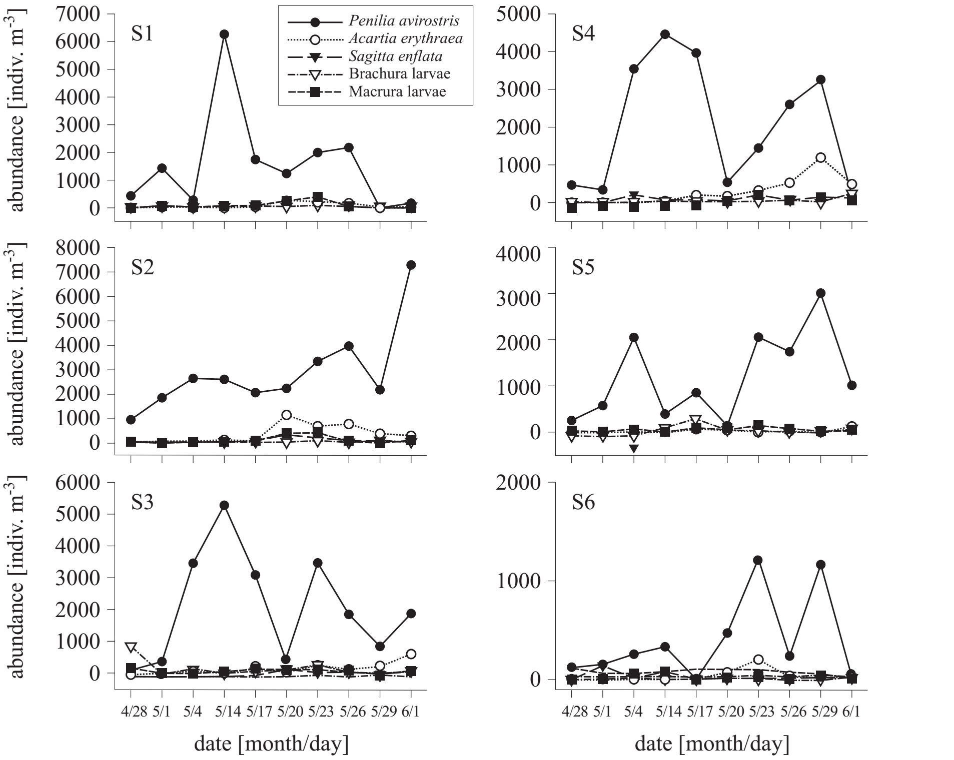

Figure 4. Temporal variations of dominant zooplankton abundances (*Penilia avirostris*, *Acartia erythraea*, *Sagitta enflata*, brachyuran larvae and macruran larvae) at six stations (S1, S2, S3, S4, S5 and S6) in Dapeng Cove from 28 April 28 to 1 June

(Figure 4). The *A. erythraea* abundance was significantly higher at S2 than at S5 and S6 ($F = 6.169$, $P < 0.01$), but the difference between S5 and S6 was not significant ($P > 0.05$). By contrast, abundances of brachyuran larvae and macruran larvae were higher early at the beginning and decreased by the end. The abundance of brachyuran larvae was significantly higher at S5 than at S6 ($P < 0.05$), and that of macruran larvae was higher at S2 than at S6 ($P < 0.05$). Although *S. enflata* occurred commonly in the study area, its abundance was often < 50 indiv. m^{-3}. The abundance of *S. enflata* was obviously and significantly higher at S2 than at S5 and S6 ($P < 0.05$). There is a significantly positive correlation between temperature and the abundances of *P. avirostris* ($r = 0.347$, $P < 0.01$), *A. erythraea* ($r = 0.479$, $P < 0.01$) and *S. enflata* ($r = 0.382$, $P < 0.01$).

The results of the hierarchical cluster analyses revealed the presence of two groups among the sampling stations at the similarity level of 80% (Figures 5c and 5d). The difference of the zooplankton community

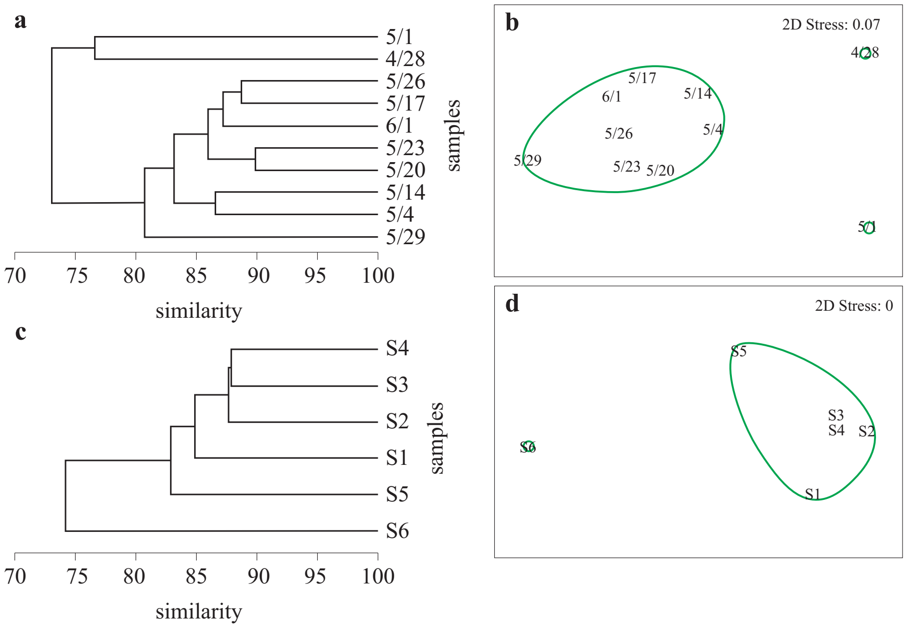

Figure 5. Results of the cluster and multidimensional scaling analyses of the zooplankton community for the surveyed date (a and b) and sampling stations (c and d) in Dapeng Cove

at S6 differed significantly from that at the other five sampling stations (stress = 0). According to the analysis result based on different sampling dates, the zooplankton community structure at the beginning of the survey is distinguished from that during the remainder of the survey (Figure 5a and 5b).

4. Discussion

4.1. Characteristics of the zooplankton community

A total number of 72 species of zooplankton were collected, which was less than that of a previous study in the study area: Shen et al. (1999) reported 145 species occurring in Dapeng Cove based on 12-month data. 265 species of zooplankton from Daya Bay have been reported since 1982. These species could be divided into four ecological forms: estuarine, inner bay, coastal and pelagic species (Lian et al. 1990, Wang et al. 2012). In our study, the first two forms accounted for most of the species, which was due to the investigated area and period. Dapeng Cove is located in the southwest inner waters of Daya Bay and has only a minimal water exchange with coastal and pelagic waters (Wang et al. 1996). The climate of Daya Bay is controlled by the East Asia Monsoon, with the north-east (NE) monsoon blowing from October to April and the south-west (SW) monsoon from May to September (Xu 1989). Our survey period was in the transition period from the NE to the SW monsoon (from 28 April to 1 June) and some temperate coastal and tropical pelagic species did not enter into the study area, with the former transported by the NE monsoon and the latter by the SW monsoon (Lian et al. 1990, Yin et al. 2011, Li et al. 2012).

The average zooplankton abundance was higher than that in a previous study in Dapeng Cove using the same-sized plankton net (505-μm mesh) (Shen et al. 1999). These authors reported that the zooplankton abundance varied seasonally with high values in autumn (795 indiv. m^{-3}) and summer (685 indiv. m^{-3}), and low ones in winter (390 indiv. m^{-3}) and spring (123 indiv. m^{-3}). The distribution of zooplankton showed lower abundances at the location of the DNPP than that at the expanding cage-culture area of Dapeng Cove (Shen et al. 1999). Our results revealed the opposite zooplankton distribution pattern. The zooplankton abundance was significantly higher at the ONPP than at the MCCA (Table 4). The average percentage of cladocerans in the total zooplankton abundance was 74% in this study, which was higher than that from the 1990s spring (4.1%) and summer (21.2%). Conversely, the percentages of copepods, chaetognaths and tunicates were lower than previously (Shen et al. 1999). Cai (1990) reported that the abundance of *Penilia avirostris* peaked in October (1000 indiv. m^{-3}), but that there were < 50 indiv. m^{-3} in Daya Bay from April to June. In contrast, we found that the abundance of *P. avirostris* reached 7267 indiv. m^{-3} at S2 on 1 June (Figure 4). These results suggest that the zooplankton abundance in Dapeng Cove has changed in comparison with historical data.

Anthropogenic activities are known to significantly affect water quality and biological resources in bays (Cornel & Whoriskey 1993, Wang et al. 2006, 2009, Wu & Wang 2007, Wu et al. 2010). The rapid expansion of mariculture was thought to be the most important source of increasing nutrients in Dapeng Cove (Huang et al. 2005). The average N/P ratio in Daya Bay increased from 1.38 in 1985 to 49.09 in 2004 (Wang et al. 2008). These nutrients are taken up by phytoplankton, and consequently, the main effect of eutrophication on phytoplankton is to increase primary production (Spatharis et al. 2007). The enriched environments accelerated the growth of small diatoms, and the predominant species shifted from large diatoms *Rhizosolenia* spp. to chain-forming diatoms (Wang et al. 2009). The proportions of small zooplankton species and gelatinous zooplankton have increased with eutrophication in Tokyo Bay and Osaka Bay (Uye 1994), in the Black Sea (Zaitsev 1992) and in Chesapeake Bay (Park & Marshall 2000). In our study, the results of cluster and MDS analysis showed that the zooplankton community at MCCA was significantly different from other sampling stations with a stress level of 0 (Figure 5). Moreover, large copepods, such as *Euchaeta concinna*, *Subeucalanus subcrassus* and *Centropages tenuiremis*, did not predominate in the zooplankton community; it was the relatively small *Penilia avirostris* that determined the zooplankton abundance (Figures 3, 4). Although zooplankton was more abundant in the MCCA relative to the 1990s data, there was no significant correlation with Chl *a* concentration, even though Chl *a* at S2 had higher values than at other stations, which might suggest that the rich primary production in the eutrophic cage-culture area may not transfer efficiently to higher trophic levels.

A 1–3°C temperature increase was associated with the discharge of cooling water from the ONPP in Dapeng Cove (Tang et al. 2003). In the surface layer of S2, the contribution of micro-phytoplankton was lower than that at S6 (Song et al. 2004). Rising temperatures from the power plant's thermal discharge have strongly influenced the phytoplankton community, favouring dinoflagellates over diatoms (Li et al. 2011). We found that the abundance of *Penilia avirostris* increased significantly with temperature and even reached its highest abundance at S2 (Figure 4). The zooplankton abundance at the ONPP differed significantly from MCCA. S2 was characterised by a high temperature and zooplankton abundance, but S6 had a high Chl *a* concentration and a low zooplankton abundance (Table 2, 4). Statistical analysis revealed that temperature was the major environmental factor determining the temporal variation of zooplankton abundance, which was in accord with other results (Wang et al. 2012). Whether the peak of *P. avirostris* was due to higher temperature or favourable food resources needs to be studied further.

4.2. The possible causes and consequences of *Penilia avirostris* outbreaks

The cladoceran *Penilia avirostris* is one of the more abundant and widespread species of crustacean zooplankton in near-shore tropical and subtropical waters (Rose et al. 2004). Periodic abrupt population increases and high densities of *P. avirostris* were observed in Guanabara Bay (Marazzo & Valentin 2001, 2004). *P. avirostris* plays an important role in the microbial loop (Grahame 1976, Kim et al. 1989, Lipej et al. 1997, Katechakis & Stibor 2004). The zooplankton community in Dapeng Cove was characterised by the predominance of *P. avirostris* in the study period (Figure 3–4). The numerical dominance of *P. avirostris* may result from competitive abilities that are superior to those of other, similarly-sized zooplankton, because they can filter smaller particles (Gore 1980, Rose et al. 2004). The rapid appearance of *P. avirostris* coincided with exceptionally warm sea surface temperatures. Warm conditions have contributed to the success of *P. avirostris* in the North Sea by favouring their resting eggs and aiding colonisation (Johns et al. 2005). The abundance of *P. avirostris* and temperature are positively correlated, which can be attributed to the increasing abundance of *P. avirostris* reported in this study.

The gut pigment content of *P. avirostris* and Chl *a* concentration were correlated significantly (Wong et al. 1992, Lipej et al. 1997), but its abundance did not increase with Chl *a* concentration in our study. *P. avirostris* feeds on particles in a wide size range, mostly on nanoplankton (2 to 20 μm), and also larger prey such as small diatoms, dinoflagellates and ciliates (Kim et al. 1989, Marazzo & Valentin 2001, Katechakis & Stibor 2004, Atienza et al. 2006). Micro-phytoplankton dominated the phytoplankton biomass, with 85.7% at S6 and 37.6% at S2 (Song et al. 2004). The difference in phytoplankton size structure between S2 and S6 might be one reason for the higher numbers of *P. avirostris* at S2 (Figure 4, Table 4).

Cladocerans reproduce in two different ways: parthenogenesis and gametogenesis. The explosive increase in their densities is the result of the high reproductive potential in the parthenogenetic generation (Rose et al. 2004, Miyashita et al. 2010). High abundances were achieved rapidly because of rapid embryonic development combined with parthenogenetic reproduction, which was favoured by temperatures between 23 and 30°C (Marazzo & Valentin 2004). High abundances of *P. avirostris* were achieved rapidly at S2 because of the influence of favourable temperatures and its parthenogenetic reproduction. Surprisingly, marine cladocerans have been little studied, compared to the many studies on other planktonic crustaceans in Daya Bay. The importance of *P. avirostris* in Daya Bay seems to be under-appreciated, given its high densities and important trophodynamic role.

The use of plankton nets of different mesh-size can affect the resulting size-frequency distributions of mesozooplankton. Generally, smaller mesozooplankton can be collected abundantly in nets of finer mesh (Tseng et al. 2011). In this study, plankton nets of 505 μm mesh size were used to sample zooplankton, which would result in the escape of some smaller zooplankton and the incorrect assessment of the zooplankton community. Some species were neglected, namely, the ones whose body length < 0.2 mm, such as *Pavocalanus*, *Oithona* and *Corycaeus*, which also occur with high abundances in the study area (Lian et al. 1990). Although there were a few defects in the sampling methodology, the average abundance of cladocerans was as high as 1360 indiv. m^{-3} and accounted for 21.8% of the total zooplankton abundance before the Nuclear Power Plant came into operation (Cai 1990). The question whether *Penilia avirostris* from the Dapeng Cove area was accidentally or factually dominant in this short period of time will be addressed in the future on the basis of long-term monitoring.

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