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Epipelagic mesozooplankton succession and community structure over a marine outfall area in the northeastern South China Sea

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Abstract: *This study analyses distribution and abundance patterns of mesozooplankton communities at 13 stations in the coastal waters over a marine outfall area in the northeastern South China Sea. Cruises were conducted in March, June and September 2002, and plankton samples were collected with a 333 μm North Pacific net. The Mesozooplankton was dominated by calanoid Copepods, Cladocera, Chaetognatha and Pteropoda. Stations located near the entrance of the harbor provided a relatively higher abundance of Noctilucales and Radiolarians. In total, 20 zooplankton groups were identified in which, Calanoida, Cladocera, Chaetognatha, Pteropoda, Poecilostomatoida and Appendicularia comprised 92.77% of the total zooplankton abundance. Copepoda dominated in all three cruises, comprising 65.32% of the total mesozooplankton abundance. Samples collected in June recorded higher mesozooplankton abundance than March and September samples. Onshore stations recorded higher BOD values, higher abundance of Noctilucales and Radiolarians and a relatively lower abundance of the overall mesozooplankton. Total mesozooplankton abundance did not correlate significantly with temperature, pH, or dissolved oxygen, but correlated negatively with BOD.*

Key words: *Mesozooplankton, Copepod, Outfalls, South China sea*
PDF of full length paper is available with author ***(*jshwang@mail.ntou.edu.tw)***

Introduction

Planktonic communities are known to be influenced by space time variations in hydrochemical parameters and physical forces (UNESCO, 1981; Cloern *et al*., 1989; Bianchi *et al*., 2003; Waniek, 2003; Sridhar *et al.,* 2006). Land-based industrial and domestic effluents further impact the abundance and composition of planktonic communities in coastal areas (Bianchi *et al*., 2003; Cornils, 2005) and to a variable extent, *via* urban runoff, industrial processes, vehicular exhaust and spillage of fossil fuel (Barbara and Nancy, 2002). Large amount of domestic and industrial wastes have historically been discharged into the Kaohsiung harbor of Taiwan and the adjacent coastal water masses of the northeastern South China Sea. Coastal waters in southwestern Taiwan in the vicinity of Kaoshiung city are influenced by the river run-off, important harbors (2), wastewater discharge (4) and marine outfall systems. Relatively higher concentration of chlorinated derivatives had been recorded from the Kaoshiung coastal waters (Lee and Fang, 1997). Furthermore in a comparative study by Lee *et al*. (2000), the Tso-Ying (T-Y) outfall area recorded higher concentration of hexachlorobutadiene (HCBD) than that recorded in other outfall fields in the Kaoshiung coast. Such effects may also mask the underlying seasonal pattern in organism's abundance, biomass and diversity.

Southern Taiwan has two important harbors, the harbor of Kaoshiung, being the largest harbor (area 18 km^2) in Taiwan and to the north of Kaoshiung harbor the T-Y harbor which is being used as a naval base. Both harbors are subjected to an accumulation of significant amount of organic wastes and petrogenic pollutants because of intensive boating activities (Chang and Fang, 2004). The ecosystems consisting of hydrodynamical and biological variables in the T-Y outfall areas are extremely complex due to interacting effects of pollution and intensity of tidal inflow and outflow (Yang, 1995; Yang *et al*., 2000; Liang *et al*., 2003). The waste waters discharged from outfall diffusers, as well as particulate pollutants may settle down to the seabed which affects the benthos (Turner, 1994; Lee *et al*., 1998; Servais *et al*., 1999). Chemical and biological properties of this area have not been elucidated thoroughly (Wang *et al*., 1990; Hwung *et al*., 1990). The presence of phenols, oil and grease were shown at higher than the limit threshold criteria in waters above the T-Y outfall area (Yang, 1995). A higher level of copper and zinc has also been reported in surface sediments in the T-Y outfall area (Lee *et al*., 1998). No study has been conducted to date on Pb or on CN. Chemical parameters considered in these studies may not be sufficient to furnish a complete picture of the health of the ecosystem. An examination of biological components, especially the plankton composition certainly provides further insight to the evaluation of environmental quality. As regards to plankton, algal composition and primary production have been described by Wang *et al.* (1990). To date, no study has been conducted aiming mesozooplankton analyses above marine outfall areas in coastal waters around Taiwan. This prompted us to examine the spatial and temporal distribution of mesozooplankton abundance over the T-Y outfall area in the northeastern margin of the South China Sea along the southwestern coast of Taiwan. We found it worthwhile to undertake a concurrent analysis of certain water quality parameters; such as dissolved oxygen (DO) and biochemical oxygen demand (BOD). In addition, we selected heavy metals which could be used as base-line data for future chemical monitoring of the area.

Materials and Methods

Study area: The T-Y marine outfall system is located in the north of Kaoshiung city off the estuarine water masses of the Dien Pao River. It discharges industrial waste waters from two industrial parks, a large petroleum refining plant and a petrochemical plant. This area is strategically important as it represents the boundary waters between the northeastern South China Sea and the southeastern Taiwan Strait. Furthermore, one of the busiest naval bases in Taiwan, the T-Y naval base is located in this area. The coastal current in this region follows mostly southeastwards at a velocity ranging from 30-40 cm/sec, while the mean tidal range is 47 cm (Yang, 1995). Thirteen sampling stations grouped in three areas were set up over the T-Y marine outfall area off the T-Y naval harbor between 22°37'51"-25°45'49"N and 120°9'5"-121°14'52"E in order to encompass the greatest range of environmental conditions (Fig. 1). Research cruises were conducted in March, June and September 2002, using a fishing vessel. Stations were numbered according to the sampling sequence and the last sampling station (St 13) was located at the mouth of the Dien Pao estuary.

Water quality analyses: Selected water parameters, for example temperature, dissolved oxygen (DO) and pH were measured on board using a Sea Bird CTD instrument prior to zooplankton collection. Water samples were collected in a metal-free Van-Dorn bottles and stored at 4°C and then brought back to the laboratory for the analysis of biochemical oxygen demand (BOD_5), lipid, mineral oils, heavy metals (Pb and Cu) and cyanide (CN) (Hung, 1986). Standard procedures as provided in standard methods for the water sampling and the examination of water quality (APHA, 2005; EPA, 1996) were followed for further analyses. Our chemical data were adopted from the Industrial Development Bureau (2002).

Mesozooplankton sampling, enumeration and identification: Zooplankton samples were collected by hauling a north pacific (NORPAC) zooplankton net (mouth diameter 45 cm; mesh size of 333 µm, and 180 cm in length) to which a hydrobios flow meter was mounted at the centre of the net mouth. Hauls were towed horizontally (at 0-10m depth) for 10 minutes at a speed of 2 knots. Zooplankton samples were preserved in seawater with 5% buffered formaldehyde immediately on board. In the laboratory, samples were split by a Folsom splitter until the subsample contained sufficient specimens. Zooplankton was identified to the lowest possible taxon using standard keys (Chen, 1992; Chen *et al.*, 1991; 1996; Chihara and Murano, 1997).

Data analysis: Spatial and temporal variations in the abundance and distribution of mesozooplankton were analyzed using two factor analysis of variance without replication, with stations and seasons as major factors. Variation in zooplankton included composition and total abundance. In order to reduce higher heteroscedasticity observed in the original species abundance data for copepods, a transformation power (λ = 0.983) was generated by regression coefficients, that were estimated simultaneously, using the method of maximizing the log likelihood function (Box and Cox, 1964). Accordingly, data were Log (X+1) transformed for statistical analyses.

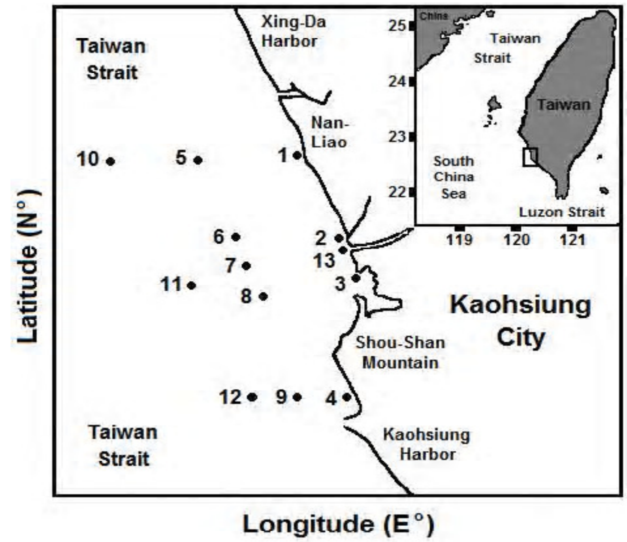

Fig. 1: Map of sampling station (1-13) in the study area

Results and Discussion

Hydrographic parameters: Water temperature recorded in the outfall the T-Y outfall area averaged 28.2°C and ranged from 25.4°C in March, to 30.4°C in September 2002 (Fig. 2a). In all three sampling cruises, the seawater was alkaline with a minimum pH of 7.9 in March and a maximum pH of 8.5 in September. Differences in the values recorded for temperature, pH, dissolved oxygen (DO), total lipid and mineral oil were significant ($p < 0.01$, one way ANOVA; Fig. 2a-d) among seasons but not for sampling stations. The averaged values of BOD recorded during three cruises ranged from 1.10 mgl^{-1} to 2.26 mgl^{-1}, but did not differ significantly among seasons. Significant seasonal variations were recorded for DO, lipid, and mineral oil, with highest values in March and lowest in September (Fig. 2b-c). The presence of cyanide in the water column was detected during all three cruises, ranging from 0.0017 to 0.0026 mgl^{-1}, whereas the detectable amount of lead was recorded only in June and September samples ranging from 0.0021 to 0.0250 mgl^{-1} (Fig. 2d). Average BOD values, lipid and mineral oil concentration in the water showed a significant spatial variation (Fig. 3a-c). The BOD value recorded at stations 5, 7, 10 and 12 (near shore stations were significantly less than at onshore stations: 3, 4 and 13 (Fisher's PLSD tests, $p<0.05$) which are coastal stations. In September, station 13 situated near the mouth of the Dien-Pao estuary recorded extremely higher BOD values (8.2 mgl^{-1}).

Mesozooplankton community structure: Throughout the study, mesozooplankton, namely Copepoda, Cladocera, Chaetognatha, Mysidacea and Euphausiacea numerically dominated the zooplankton abundance consisting >90% of the total counts (Fig. 4, Table 1). Exceptions were stations 3, 4 and 5 where heterotrophic protists, mainly Noctilucales and Radiolarians dominated the total zooplankton (Fig. 4). These stations showed consistently higher BOD levels (1.8 to 3.6 mgl^{-1}). A total of 20 zooplankton groups were identified in our samples in which Copepoda, Cladocera, Mysidacea and Chaetognatha comprised the holoplankton (Table 1). Meroplankton was mainly represented by fish eggs and their larvae, and other invertebrate larvae. Six groups formed >95% of the

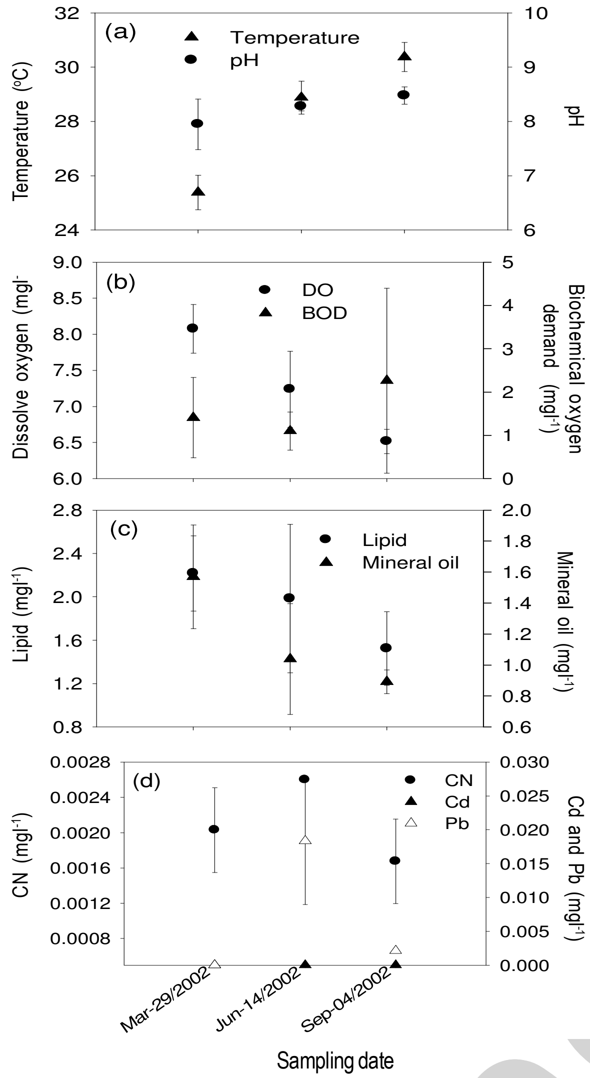

Fig. 2: Seasonal variation in water quality parameters; average temperature and pH (a), DO and BOD (b), lipid and mineral oil (c), CN, Cd and Pb (d) concentration over the Tso-Yin outfall area in the northeastern South China Sea

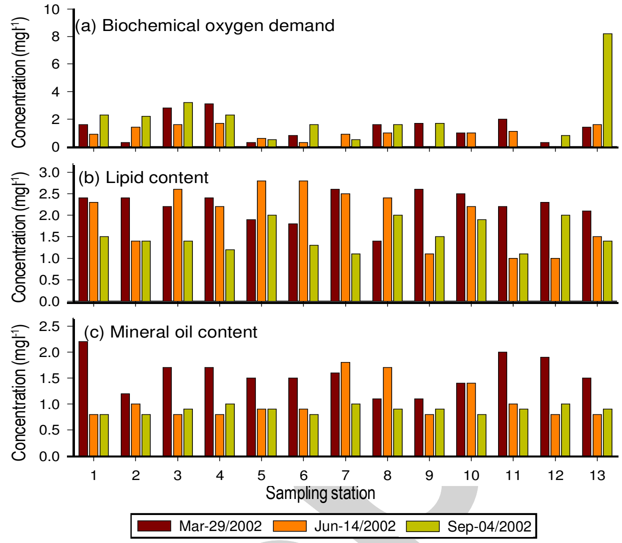

Fig. 3: Values of BOD (a), lipid (b) and mineral oil (c) recorded at each sampling station during the March, June, and September cruises

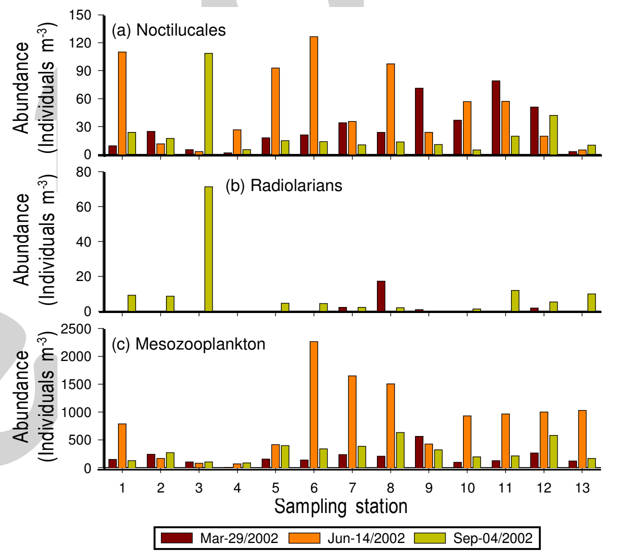

Fig. 4: Abundance of Noctilucales (a), Radiolaria (b), and mesozooplankton (c) at each sampling station

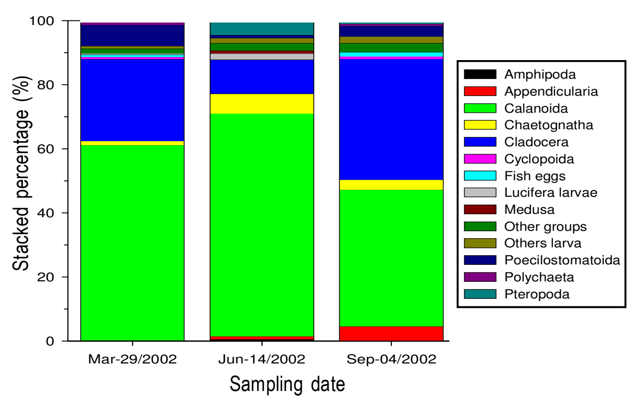

Fig. 5: The relative abundance of 10 major mesozooplankton groups recorded during three cruises over the Tso-Yin marine outfall area in the northeastern South China Sea

zooplankton community, namely Copepoda, Cladocera, Chaetognatha, Pteropoda, Appendicularia and Decapoda (Table 1). The relative abundances of 10 major mesozooplankton groups recorded during each cruise are given in Fig. 5.

Correlation between zooplankton abundance and physical parameters: Significant correlations recorded between different zooplankton groups and physical parameters are illustrated in Figs. 6 and 7. Total zooplankton abundance did not show any significant correlation with water temperature, pH or dissolved oxygen, but was negatively correlated with BOD ($r = -0.397$; $p = 0.022$; Pearson's product moment correlation, Fig.6g). Water samples collected in September recorded an extremely higher BOD value (8.2 mgl^{-1}) at station 13. This exceptionally higher BOD value in one sample was not used for the correlation analyses. Radiolarians ($r = 0.434$; $p = 0.0117$) showed a significant positive correlation with BOD, whereas Chaetognatha ($r = -0.4$; $p = 0.0231$), Calanoida ($r = .36$; $p = 0.0399$), Poecilostomatoida ($r = -0.35$; $p = 0.0435$) and Lucifera larvae (r = -

Table - 1: Average density (individuals m^{-3}), relative abundance (RA, %) and frequency of occurrence (OR, %) of various zooplankton groups recorded during three different cruises

Average zooplankton density (individuals m^{-3})	Sampling time (March, 2002) 218.12 ± 150.77	(June, 2002) 919.46 ± 680.93	(Sep., 2002) 327.44 ± 167.42	RA	OR	Mean ± SD
Dinophyta/ Dinophyceae/ *Noctiluca* sp	29.07±24.94	51.13±42.62	22.61±27.58	10.11	100.00	34.27 ± 34.1
Protozoa/ Sarcodina/ Actinopoda/ Radiolaria	1.68 ± 4.71	0.0 ± 0.0	9.99 ± 18.83	2.95	38.46	9.99 ± 18.83
Coelenterata/ Medusa	0.71 ± 0.76	7.93 ± 7.71	0.95 ± 1.08	0.28	64.10	0.95 ± 1.08
Annelida/ Polychaeta/ Polychaeta	1.57 ± 1.71	4.24 ± 5.79	1.88 ± 1.49	0.55	74.36	1.88 ± 1.49
Chaetognatha/ Sagittidea/ Sagittidae/ *Sagitta* sp	2.58 ± 2.18	53.17 ± 43.1	9.10 ± 5.98	2.68	87.18	9.10 ± 5.98
Arthropoda/ Crustacea/ Branchiopoda/ Cladocera	47.65±89.42	91.35±97.23	111.31±86.26	32.83	100.00	111.31±86.26
Arthropoda/ Crustacea Ostracoda	0.41 ± 0.53	0.33 ± 0.52	0.09 ± 0.32	0.03	28.21	0.09 ± 0.32
Arthropoda/ Crustacea/ Copepoda/ *C. nauplius*	0.14 ± 0.34	1.39 ± 3.08	0.59 ± 1.62	0.17	20.51	0.59 ± 1.62
Arthropoda/ Crustacea/ Copepoda/ Calanoida	114.51±53.08	601.89±523.78	125.71±108.36	37.07	100.00	125.71±108.36
Arthropoda/ Crustacea/ Copepoda/ Cyclopoida	1.28 ± 1.45	1.84 ± 1.88	2.34 ± 2.91	0.69	66.67	2.34 ± 2.91
Arthropoda/ Crustacea/ Copepoda/ Poecilostomatoida	12.37±10.55	7.41 ± 10.16	9.67 ± 9.04	2.85	87.18	9.67 ± 9.04
Arthropoda/ Crustacea/ Malacostraca/ Amphipoda	0.14 ± 0.35	4.28 ± 8.44	0.61 ± 1.49	0.18	25.64	0.61 ± 1.49
Arthropoda/ Crustacea/ Malacostraca/ Lucifera larvae	0.81 ± 1.82	17.06±12.25	1.44 ± 1.99	0.42	64.10	1.44 ± 1.99
Arthropoda/ Crustacea/ Malacostraca/ Decapoda Sergestidae	0.22 ± 0.44	2.39±3.62	1.52 ± 1.73	0.45	43.59	1.52±1.73
Arthropoda/ Crustacea/ Malacostraca/ Euphausiacea	0.06 ± 0.21	0.0 ± 0.0	0.43 ± 0.70	0.13	12.82	0.43 ± 0.7
Arthropoda/ Crustacea/ Malacostraca/ Mysidacea	0.0 ± 0.0	0.0 ± 0.0	0.15 ± 0.55	0.04	2.56	0.15±0.55
Mollusca/ Gastropoda/ Opisthobranchia/Thecosomata Pteropoda	1.02 ± 1.05	39.51±46.66	3.01 ± 3.40	0.89	71.79	3.01 ± 3.4
Echinodermata larva	0.0 ± 0.0	0.29 ± 0.55	0.30 ± 0.61	0.09	15.38	0.30 ± 0.61
Protochordata/ Urochordata/ Appendicularia	0.68 ± 0.92	8.3 ± 7.66	13.66±12.38	4.03	69.23	13.66±12.38
Protochordata/ Urochordata/ Thaliacea/ Thaliacea	0.07 ± 0.24	0.82 ± 2.13	0.75 ± 1.53	0.22	17.95	0.75 ± 1.53
Chordata						
Fish eggs	1.42 ± 1.42	2.76 ± 3.58	3.71 ± 2.38	1.09	79.49	3.71 ± 2.38
Fish larva	0.14 ± 0.35	3.98 ± 6.19	1.05 ± 1.54	0.31	35.90	1.05 ± 1.54
Other larva	1.46 ± 1.47	13.68 ± 11.81	6.15 ± 5.43	1.81	76.92	6.15 ± 5.43

0.35; p = 0.0472) showed a significant negative correlation (Fig. 6). Noctilucales (r = 0.372; p = 0.0195 Fig.7a) and Amphipoda (r = 0.351; p = 0.0288) showed a significant positive correlation with lipid (Fig. 7, b). Appendicularia abundance correlated negatively with the amount of lipid (r = -0.537; p = 0.01; Pearson's product moment correlation) and mineral oil (r = -0.411; p = 0.009), recorded from water samples.

The results of the present study indicates that mesozooplankton communities at the northeastern edge of the South China Sea facing the southwestern coast of Taiwan are spatially heterogeneous at multiple scales. Many of the zooplankton groups sampled are widely distributed in the surface waters of the South China Sea and the Taiwan Strait, but a combination of their relative abundance and the frequency of occurrence indicate that mesozooplankton abundance above the T-Y outfall area was perennially dominated by local species with a relatively lesser degree of seasonal variation. Compared with other oceanic and coastal ecosystems, the study area is notable for its shallow mixed layers, being less than 50 m deep (Chen, 1992; Karl and Lukas, 1996; Michaels and Knapp, 1996). At short time scales the study area is affected by strong internal waves (Liang *et al*., 2003; Liu *et al*., 1998). The zooplankton community in this region is mainly driven by alternating southwest (from May to early September) northeast monsoon and outfall discharged water (Chen, 1992; Shaw *et al*., 1996 and Liang *et al*., 2003). The mesozooplankton data derived from this study can directly be compared with previous studies conducted in northern, eastern and other parts of the South China Sea and the southern Taiwan Strait (Lo and Hwang, 2000). However, this area does not show significant temporal variation as it is reported from other parts of the South China Sea and the Taiwan Strait (Lo *et al*., 2004; Hwang *et al*., 2006). Relatively higher abundance of Dinoflagellata, Noctilucales and their positive correlation with lipids indicate that the outfall area is affected by land driven pollutants which is further supported by occasionally higher BOD. Noctilucales are distributed worldwide, being common in neritic and coastal regions, being pollution-tolerant, they are indicators of eutrophication (Paffenhofer and Flagg, 2002; Umani *et al.*, 2004), which is further supported by an insignificant correlation of the Noctilucales with BOD in our study. The abundance of Appendicularia, Ostracoda and Chaetognatha in this study area was similar to previous studies in contiguous water masses (Chen and Lin, 1993; Lo and Hwang, 2000). Chen *et al.* (1991) studied zooplankton distribution in the South China Sea and clearly demonstrated a seasonal variation in zooplankton abundance and composition in relation to monsoonal winds. The overall abundance of zooplankton in this in the South China Sea around the Nansha Islands was lower in comparison to the T-Y marine outfall area. Seasonal patterns of zooplankton abundance with low values in winter and higher values in summer are similar to results of numerous previous studies in coastal waters (Chen, 1992) around Taiwan. The summer maxima of zooplankton abundance and the assemblages of species and to some extent the relative proportion of species abundance were expected. Compared to the data obtained before the operation of these marine outfall system, Chl *a* as well as primary productivity increased when the outfall area began to receive waste waters (Wang *et al*., 1990; Bianchi *et al*., 2003). Therefore, the level of nutrients in the ocean water increased with distance from the wastewater effluent source (Hwung *et al*., 1990).

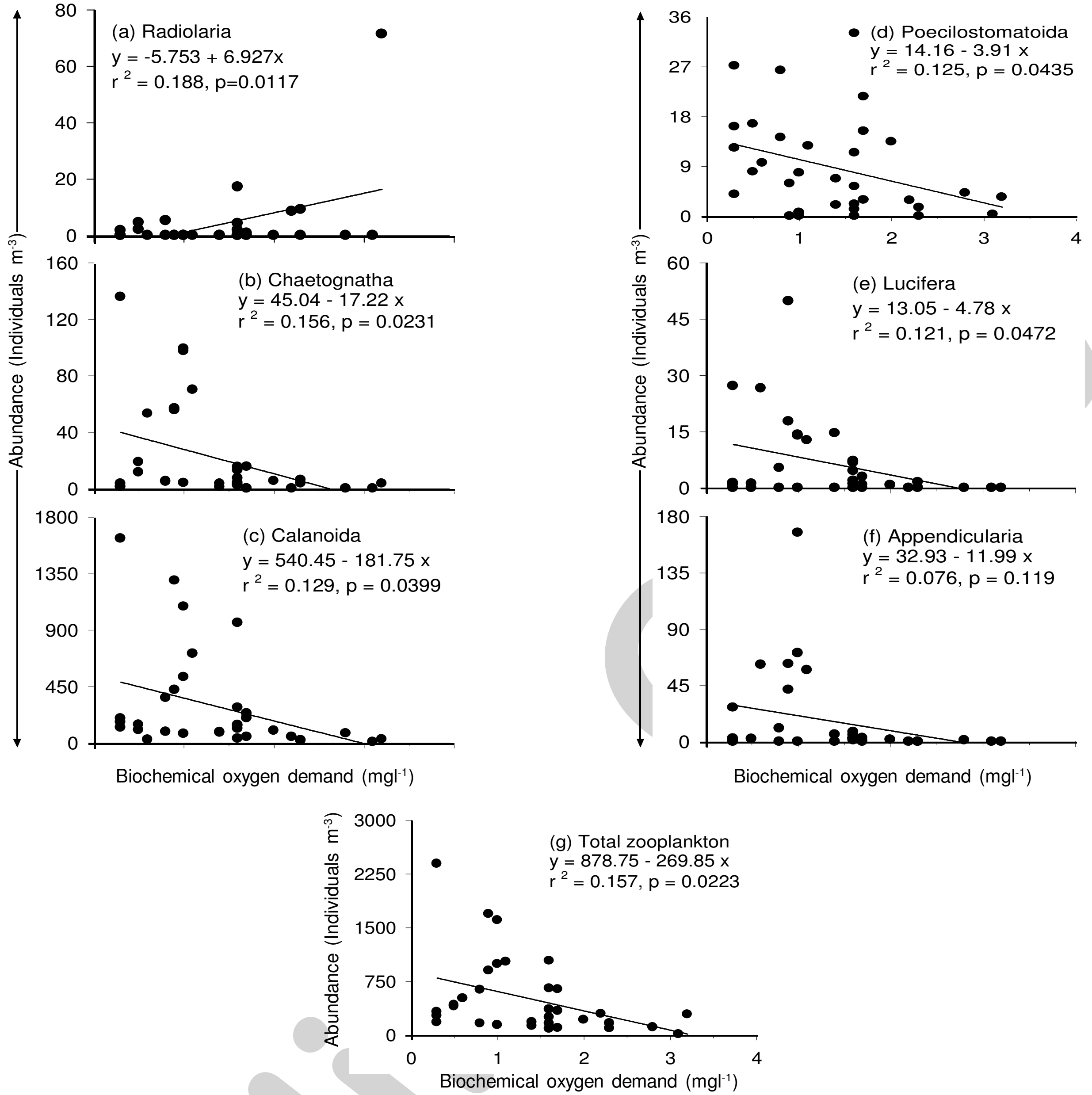

Fig. 6: Correlation between biochemical oxygen demand and the major zooplankton groups showing a significant correlation

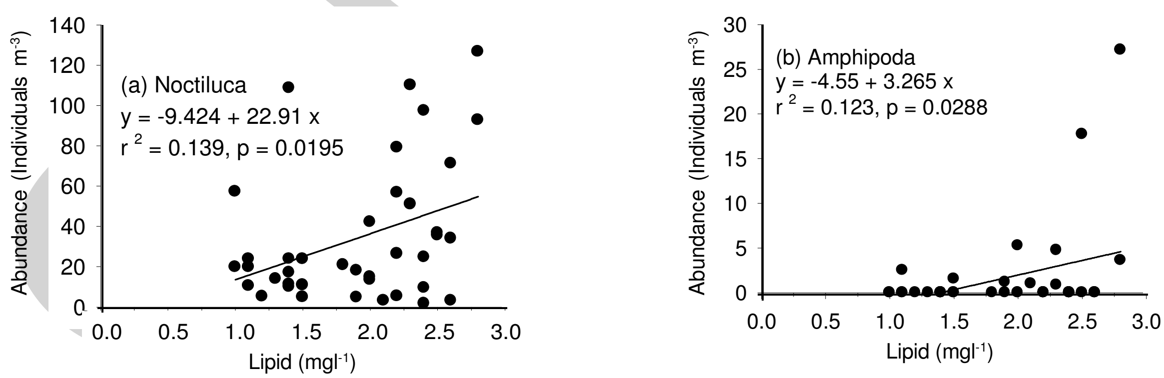

Fig. 7: Correlation of lipid concentration in the water column with Noctilucales (a) and with Amphipoda (b)

Information about mesozooplankton abundance in the area will not only provide background information for future monitoring, but will give a measure for the effectiveness of pollution control measures. Finally, questions raised by these results suggest numerous areas where an interaction between pollutants, nutrients, phytoplankton and zooplankton requires extensive additional studies and long term monitoring.

Acknowledgments

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