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NEARSHORE MACROBENTHIC COMMUNITIES OFF TWO NUCLEAR POWER PLANTS IN NORTHERN TAIWAN

I-Jiunn Cheng*, Pou-Chung Ko, Shin-I Hu, Chien-Peng Hu, and Trip-Ping Wei

Key words: macrobenthos, nuclear power plant, sediment characters, seasonal variation.

ABSTRACT

The nearshore macrobenthic communities outside the Nuclear Power Plants I and II were monitored on a seasonal basis from winter, 2000 to summer, 2004. The animal and sediment were sampled by scuba diving. The macrobenthic assemblages, sediment characteristics and total organic content were analyzed. The macrobenthos assemblages in terms of species richness, density and biomass was determined. The mean grain size and sorting (i.e. inclusive graphic standard deviation) of sediment were also determined.

The small-sized annelids and crustaceans were the dominant macrobenthos. A total of 96 species of macrobenthos was found in the sediment near the Nuclear Power Plant I. The sediment was composed mainly of moderately sorted coarse sand, with silt-clay content less than 2%. The total organic content ranged from less than 1% to 7%. A total of 86 species of macrobenthos was found in the sediment near the Nuclear Power Plant II. The sediment composed mainly of moderately well sorted medium sand, with silt-clay content equal or less than 4%. The total organic content ranged from 1% to 4%. The short distance between two power plants resulted in about 50% of species shared by both plants.

Statistical analyses showed that the macrobenthic communities in the relative open system outside the Power Plant I were more affected by season than by the sediment characteristics. The relative protected environment outside the Power Plant II resulted in higher habitat diversity. The sediment characters strongly influenced to the macrobenthic communities. The synoptic comparisons between two power plants showed that in spite the differences in the microhabitat, the nearshore macrobenthic communities in the Northeast Taiwan were mainly affected by the sediment characters. Seasonal variation was the secondary factor. Results of this study found that the influence of thermal effluent from the power plant to the nearshore macrobenthic community structures was rather localized. Nearshore macrobenthic communities appeared to have reached a stable condition with the constant environmental disturbances from the power plants.

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INTRODUCTION

The Nuclear Power Plants I and II in Taiwan have operated over three decades. The environmental impact assessment of these two plants to the nearshore marine ecosystem has also been carried out since then. Among the various monitoring fauna, benthic community has considered suitable for investigating the effect of power plant to the nearshore ecosystem, because of their low mobility and sedentary life styles (Bomber and Spencer, 1984; Suresh *et al*., 1993; Warwick, 1993). Due to the regularly radioactive monitoring from both Taipower Company and the other project of this assessment program, the main concern of this study is the physical disturbance from the effluent warm water.

The influence of warm water to the macrobenthic community can be divided into physical disturbance from the water current and physiological disturbance from the thermal effluent (e.g. Reid *et al*., 1991; Levinton, 2001). On the physical aspect, the strong effluent current will remove the fine-grained particles, and result in the sediment composing of coarser particles. However, the limited and infrequent flow will confine the impact close to shore. Thus, the physical disturbance may be limited. On the warm water aspect, the temperature can change the physiological status, thus the metabolism, of the animal (Bayne and Newell, 1983; Levinton, 2001; Valiela, 1984). It will have a profound effect on the fitness of population. As the result, some species will either migrate out or extinct from this area due to poor adaptation to the environmental changes. Others may flourish or immigrate by improving the habitat conditions. Together the influence of warm water and irregular discharge from the power plant, the benthic environment will be unstable. The species diversity may be low and composed mainly of the opportunistic species (Rhoads and Boyer, 1982). However, due to the shallow water, the nearshore benthic environment is subjected to high variation in both physical factors, such as tide, wind and other meteorological events, and chemical factors, such as washovers, the environment is unstable in nature. The species diversity is lower than the offshore benthic community and composed mainly of pioneer species (Aller and Stupakoff, 1996; Mathew and Govindan, 1995; Nair *et al*., 1998). Thus, the influence of warm water discharge to the nearshore macrobenthic community is subjected to debate.

The macrobenthic community structure is influenced by the sedimentary characters (Basford *et al*., 1993; Marques and Bellan-Santini, 1993; Cheng and Tsai, 1994; 1999; Hernandez-Aranta *et al*., 2003). In general, the sediment with the mixture of fine and coarse particles tends to host more species than the pure sand or silt-clay particles. This is because the mixture particles can provides higher habitat diversity. In addition, the relative higher surface area of the fine grains can also attract more organic matter, thus food available to the macrobenthos. The higher porosity and permeability among the particles allow a higher water flux, thus more oxygen exchange in the sediment (Marshall *et al*., 2001). The animal abundance will be higher in this sediment. The sand substrate existed mainly in the stronger hydrodynamic environment. The relative lower surface area results in the lower sediment organic content. The muddy sediment, on the other hand, exists mainly in the low hydrodynamic enviro-nment. Although it has a higher organic con-tent, the low permeability results in the lower oxygen availability and creates an anoxic environment. Both environments are not suitable for macrobenthos, thus have a lower species diversity and total abundance.

The monitoring of the macrobenthic communities outside the Nuclear Power Plants I and II has been conducted for over thirty years. The temporal change of the macrobenthic community since the operation is an interesting and important issue. However, due to the lack of the sampling locations and sampling techniques, the quality of the data was poor and considered invalid for the quantitative analyses. The program was reorganized in 1998. The sampling locations were determined by the portable GPS and the sampling techniques were identified. The sampling locations were moved closer to the shore in winter of 2000, because we believe that the new sites will provides a clearer picture on the influence of power plant to the macrobenthic community. Because the mobility of most macrobenthos was low, the data from 1998 to winter of 2000 were excluded from the analyses. The purpose of this study is then to determine the long-term influence of these two Power Plants to the nearshore macrobenthic community. The influential factors other than the thermal effluent were also determined.

MATERIAL AND METHODS

1. Sample collection

From winter 2000 to summer 2004, animal and sediment samples were collected from the nearshore sediment off the Nuclear Power Plants I and II to determine the biological and sediment characters. The sediment was sampled four times a year on the seasonal basis. A total of 7 stations from each power plant were chosen, including three stations outside the inflow site, three stations outside the effluent site and a background control site. Each inlet stations is about 400 m from the jetty, each effluent stations is about 500 m from the jetty, and the background station is about 1.5 km away from the inlet jetty. The sampling locations were showed in Figs. 1 and 2. Because the bottom of the nearshore waters off Nuclear Power Plants I and II was composed mainly hard rocks, the sediment layer was relative thin and sampling with the grab had not succeeded in the preliminary experiment. Thus, in this study, the sediment was sampled with scuba diving. The diver sampled the sediment by pushing a wooden grid of 35×15 cm^2 into the sediment about 2 cm at each station. Three replicates were taken from each station. The location of each station was determined by a portable GPS. The water depth of each station was also determined. The sampling location and water depth were listed in Table 1. Samples were stored in a plastic refrigerator and

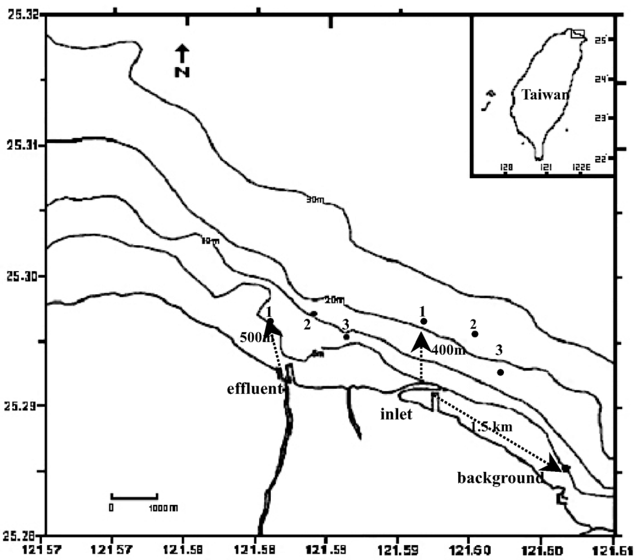

Fig. 1. Sampling stations of the macrobenthic communitiesoff the Nuclear Power Plant I from winter 2000 to summer 2004. Three stations off the inlet site were about 400 meters off the jetty. Three stations off the effluent site were about 500 meters off the jetty, and the background station was about 1.5 km off the inlet jetty.

brought back to the laboratory in the same day. A series of subsamples were taken from each station for analysis of macrobenthic assemblages, grain size distribution, and total organic content.

2. Macrobenthic assemblage analysis

Each subsample used for macrobenthic study was sieved in freshwater through a 0.5-mm metal screen. Specimens retained on the screen were fixed with 3-5% buffered formalin water solution containing Rose Bengal. The animals were sorted under a dissecting microscope. Each organism was identified to the lowest possible taxonomic level, usually to the species. The total number at each lowest taxonomic level was tallied, and the density (= abundance) was calculated as the number m^{-2}. The organic carbon content of an organism was taken to the representative of its biomass. Organic carbon content was determined by an ash-free dry weight method (Cheng and Tsai, 1994; Cheng and Chang, 1999), the result being multiplied by the total animal abundance in each taxonomic group, and expressed as mg m^{-2}. The species richness of each station was defined as number of species m^{-2}.

3. Grain size analysis

The sediment characters were presented as the graphic mean (M_z) and inclusive graphic standard deviation (σ_1). These two parameters were determined by sieving the dried sand through a series of 4.00, 2.83, 2.00, 1.00, 0.50, 0.21, 0.105 and 0.064 mm metal screens, and calculated by the following formula (Folk, 1974).

$$M_z(\dot{\phi}) = (\dot{\phi}_{16} + \dot{\phi}_{50} + \dot{\phi}_{84}) / 3$$

$$\sigma_1 = (\dot{\phi}_{95} - \dot{\phi}_5) / 6.6 + (\dot{\phi}_{84} - \dot{\phi}_{16}) / 4$$

$$\dot{\phi} = \text{-log (mean grain size, mm)}$$

$\dot{\phi}$: percentile, and $\dot{\phi}_5$, $\dot{\phi}_{16}$, $\dot{\phi}_{50}$, $\dot{\phi}_{84}$ and $\dot{\phi}_{95}$ means the phi value at 5%, 16%, 50%, 84%, and 95% of the total sand weight.

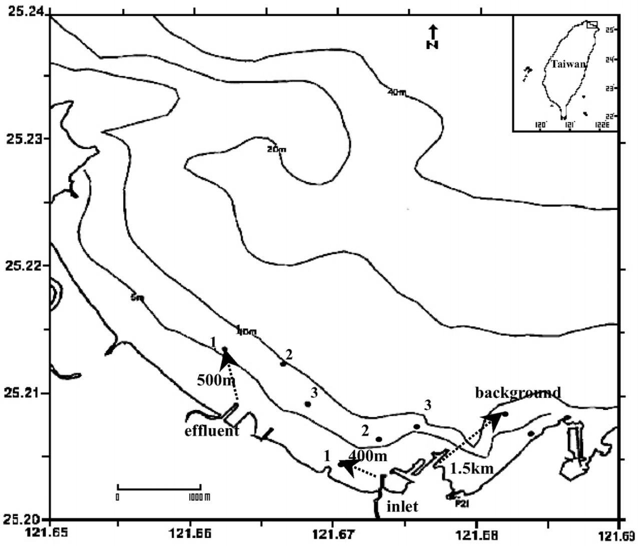

Fig. 2. The sampling stations of the macrobenthic communities off the Nuclear Power Plant II from winter 2000 to summer 2004. Three stations off the inlet site were about 400 meters off the jetty. Three stations off the effluent site were about 500 meters off the jetty, and the background station was about 1.5 km off the inlet jetty.

The unit of graphic mean is mm, and the inclusive graphic standard deviation (or sediment sorting) is unit less. The silt-clay content was also calculated. The unit is percentage of total sediment weight.

4. Total organic content analysis

The total organic content (TOM) was analyzed by an ash-free dry weight method, which measured the weight loss after ignition of dry sediment at 500°C overnight (Cheng and Tsai, 1994; Cheng and Chang, 1999).

5. Statistical analysis

The changes by season and by different stations in the same power plant in macrobenthic species richness, density and biomass, total organic content, mean grain

Table 1. The location and water depth of each sampling station off the Nuclear Power Plants I and II

Station	Latitude	Longitude	Depth (m)
Nuclear Power Plant I			
Inlet 1	25°17.597’	121°35.465’	7
Inlet 2	25°17.534’	121°35.567’	4
Inlet 3	25°17.531’	121°35.661’	7
Effluent 1	25°17.933’	121°34.536’	7
Effluent 2	25°17.751’	121°34.908’	8
Effluent 3	25°17.752’	121°34.833’	8
Background	25°17.194’	121°36.007’	12
Nuclear Power Plant II			
Inlet 1	25°12.405’	121°40.241’	11
Inlet 2	25°12.327’	121°40.295’	12
Inlet 3	25°12.411’	121°40.364’	13
Effluent 1	25°12.809’	121°39.289’	7
Effluent 2	25°12.732’	121°39.375’	6
Effluent 3	25°12.675’	121°39.601’	9
Background	25°12.691’	121°41.074’	8

size, inclusive graphic standard deviation and silt-clay content were analyzed by a two-way ANOVA (Sokal and Rholf, 1982). The changes of relevant parameters between two power plants were analyzed by a three-way ANOVA (Sokal and Rholf, 1982). Normality and equal variance tests were carried out prior to the ANOVA tests. A Spearman Rank Order Correlation Analysis method (Sokal and Rholf, 1982) was used to analyze the relationship between every paired combination of the parameters examined. A linear regression analysis was used to determine the relationship between pairs of parameter if one parameter varied linearly with the other (Sokal and Rholf, 1982). A multiple linear regression analysis was used to determine the relationship among three or more parameters if they are varied linearly with the others. A forward stepwise analysis was used to determine the major influential factors among parameters. An arcsine transform was used to translate the percentage values before analysis.

RESULTS

1. Nuclear Power Plant I

A total of 10 Phyla, 15 Classes, 42 Orders, 70 Families and 96 species of macrobenthos were identified. The small-sized annelids and crustaceans comprised 78% of total species. The dominant species of each season are listed in Table 2. The species richness varied from 0 to 11 species station^{-1}, the density varied from 0 to 430 animals m^{-2}, and the biomass varied from 0 to 403.1 mg m^{-2}. The temporal variations in the species richness, density and biomass at the inlet, effluent and background site during the study period were showed in Fig. 3.

The sediment was composed mainly of moderately sorted coarse sand, with silt-clay content less than 2%. Further divided the sampling stations into different locations showed that; the sediment near the inlet was composed mainly of moderately sorted medium to poorly sorted coarse sand with the silt-clay content about 2%. The sediment near the effluent was composed mainly of poorly sorted granule with the silt-clay content less than 2%. The sediment in the background site composed mainly of moderately sorted coarse sand with the silt-clay content also less than 2%. Thus, the sediment outside the Nuclear Power Plant I contains low quantity of fine-grained particles. The total organic matter ranged from less than 1% to 7%. The silt-clay content ranged from less than 1% to 40%. The temporal variations in total organic matter, mean grain size, phi value (graphic inclusive standard deviation), and silt-clay content at inlet, effluent and background sites during the study period were showed in Fig. 5.

Two-way ANOVA showed that (Table 3), the inlet sediment had a higher macrobenthic density than the effluent sediment ($p < 0.01$). No difference in the species richness was found between the inlet and effluent sites. Thus, the significant difference found in the table ($p = 0.035$) might due simply to the data processes in statistics. The effluent sediment had a coarser mean grain size, less homogenous in the particle size distribution, contained more fine-grained particles and higher total organic content than the inlet and background sediments ($p < 0.05$ for the silt-clay content, $p < 0.01$ for the TOM, and $p < 0.001$ for both mean grain size and sediment sorting). Spearman Rank Order Correlation Analysis showed that (Table 4) p values were less than 0.05 among species richness, density and biomass, between biomass and sediment phi value and silt-clay content, between mean grain size and phi value and between phi value and silt-clay content.

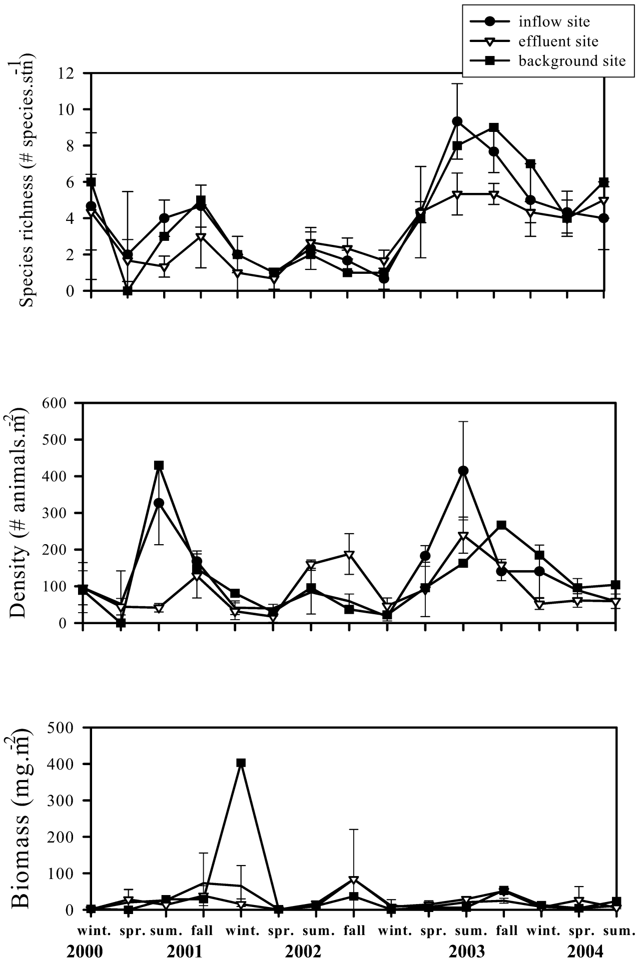

Fig. 3. Temporal changes in species richness, density and biomass of the macrobenthic community in the nearshore sediment off the Nuclear Power Plant I from winter 2000 to summer 2003. The abbreviate symbols for the seasons are denoted as follows: spr. as spring, sum. as summer, wint. as winter.

Table 2. The dominant species of each season in the sediment off the Nuclear Power Plant I and II from winter 2000 to summer 2004

Nuclear Power Plant I

Year	Season	Dominant spceies	
		Phylum	Species
1999	winter	Annelida	*Scoloplos armiger*
		Annelida	*Scaliserisus longicirrus*
2000	spring	Crustacea	*Cirolana japonica*
2000	summer	Crustacea	*Urothoe grimaldii*
2000	autumn	Crustacea	*Calcinus laevimanus*
2000	winter	Crustacea	*Liljeborgia japonica*
2001	spring	Crustacea	*Harpinia miharensis*
2001	summer	Mollusca	*Nothria conchylega*
2001	autumn	Annelida	*Notomastus latericeus*
2001	winter	Annelida	*Scoloplos armiger*
2002	spring	Crustacea	*Bablis japonicus*
		Crustacea	*Cypridina hilgendorfii*
2002	summer	Annelida	*Nothria conchylega*
		Crustacea	*Cleantis planicuda*
		Crustacea	*Cypridina hilgendorfii*
2002	autumn	Annelida	*Nothria conchylega*
		Crustacea	*Cypridina hilgendorfii*
2002	winter	Crustacea	*Bablis japonicus*
2003	spring	Annelida	*Rhabditis terricola*
		Crustacea	*Robertgurneya rostrata*
2003	summer	Annelida	*Rhabditis terricola*

Nuclear Power Plant II

Year	Season	Dominant spceies	
		Phylum	Species
1999	winter	Crustacea	*Harpinia miharensis*
2000	spring	Crustacea	*Cirolana japonica*
2000	summer	Crustacea	*Urothoe grimaldii*
2000	autumn	Crustacea	*Cypridina hilgendorfii*
2000	winter	Crustacea	*Cypridina hilgendorfii*
2001	spring	Crustacea	*Aega dofleini*
2001	summer	Annelida	*Scoloplos armiger*
2001	autumn	Annelida	*Etone longa*
2001	winter	Annelida	*Etone longa*
2002	spring	Annelida	*Etone longa*
		Annelida	*Arabella iricolor*
2002	summer	Crustacea	*Cleantis planicuda*
		Crustacea	*Cypridina hilgendorfii*
		Annelida	*Nothria conchylega*
2002	autumn	Annelida	*Scoloplos armiger*
		Annelida	*Nothria conchylega*
2002	winter	Annelida	*Scoloplos armiger*
2003	spring	Annelida	*Etone longa*
		Annelida	*Scoloplos armiger*
2003	summer	Crustacea	*Urothoe grimaldii*

Although there existed a seasonal variation in all parameters, no consistent trend was observed. A forward stepwise regression analysis showed that the interaction between the season and the site in macrobenthic density, biomass, sediment TOM and silt-clay content was caused mainly by the seasonal variation. Similar analysis showed that the interaction between the season and the site in mean grain size and sediment sorting was caused mainly by the differences among sampling sites.

2. Nuclear Power Plant II

A total of 8 Phyla, 15 Classes, 32 Orders, 59 Families and 86 species of macrobenthos were identified. Again, the small-sized annelids and crustaceans were the dominant fauna; comprised 77% of total species. The dominant species of each season are listed in Table 2. The species richness ranged from 0 to 11 species station^{-1}, the density ranged from 0 to 467 animals m^{-2},

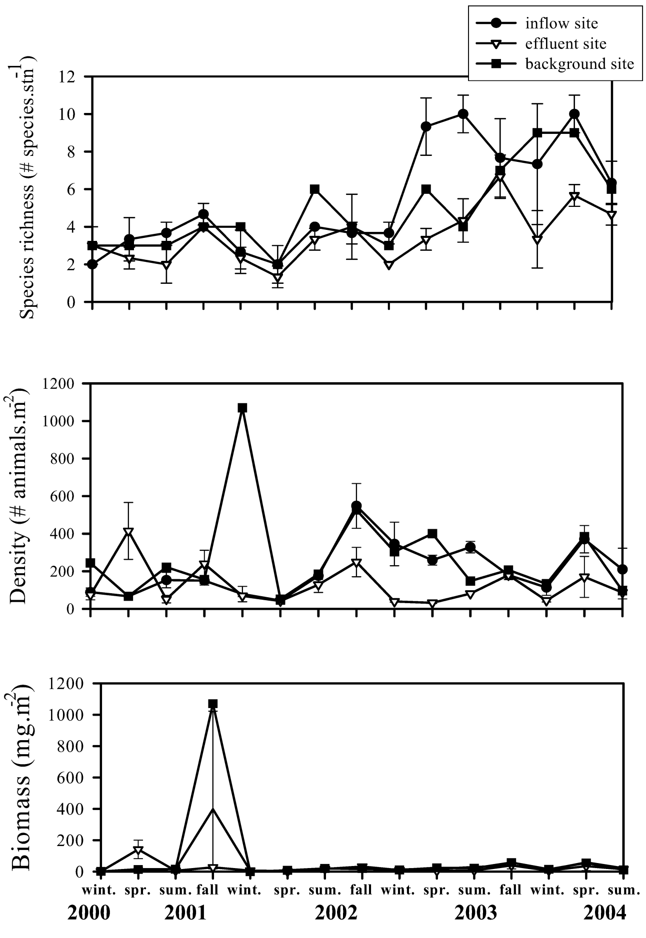

Fig. 4. Temporal changes in species richness, density and biomass of the macrobenthic community in the nearshore sediment off the Nuclear Power Plant II from winter 2000 to summer 2003. The abbreviate symbol for the seasons are explained in Fig. 3.

and the biomass ranged from 0 to 1,119.3 mg m^{-2}. The temporal variations in the species richness, density and biomass at the inlet, effluent and background sites during the study period were showed in Fig. 4.

The sediment was composed mainly of moderately well sorted medium sand, with silt-clay content equal or less than 4%. Further divided the sampling stations into different locations showed that; the sediment near the inlet composed mainly of moderately sorted medium to poorly sorted coarse sand with the silt-clay content equal or less than 4%. The sediment near the effluent composed mainly of moderately well sorted medium sand with the silt-clay content equal or less than 1%. The sediment in the background site composed mainly of the poorly sorted fine to medium sand with the silt-clay content equal or less than 4%. Thus, the sediment outside the Nuclear Power Plant II contains a relatively higher quantity of fine-grained particles. The temporal and spatial variation of total organic matter ranged from 1 to 4%. The silt-clay content ranged from less than 1% to 13%, The temporal variations in total organic matter, mean grain size, phi value (graphic inclusive standard deviation), and silt-clay content at the inlet, effluent and background site during the study period were showed in Fig. 6.

Two-way ANOVA showed that (Table 5), the effluent sediment had a finer grain size, contained a lower species richness, macrobenthic density, organic content than the inlet and background sediment ($p < 0.001$ in all cases). The sediment sorting of this site, however, was better than the other two sites ($p < 0.001$). The background sediment contained the highest percentage of fine-grained particles, followed by the inlet sediment, and the effluent sediment contained the least percentage of fine-grained particles ($p < 0.001$). Spearman Rank Order Correlation Analysis showed that (Table 6) *p*

Table 3. Two-way ANOVA on the species richness, density, biomass of macrobenthos, total organic matter (TOM), mean grain size (M_z), graphic inclusive standard deviation (σ_1) and silt-clay content in the sediment off the Nuclear Power Plant I from winter 2000 to summer 2004. The site is the inlet and effluent positions of the power plant

Parameter	Site	Season	Site x Season
Richness	*	***	ns
Density	**	***	***
Biomass	ns	***	***
TOM	**	***	***
M_z	***	***	***
σ_1	***	***	***
Silt-clay (%)	*	***	***

ns: Gnot significant; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Table 4. Results of Spearman Rank Order Correlation Analysis among parameters in the sediment off the Nuclear Power Plant I

Parameter	Density	Biomass	TOM	Mz	σ_1	Silt-clay
Richness	0.771***	0.435***	-0.067	-0.008	0.234*	0.117
Density		0.575***	-0.018	-0.185	0.151	0.239*
Biomass			-0.094	-0.0169	0.223*	0.249*
TOM				0.167	0.133	-0.106
Mz					0.253**	-0.169
σ_1						0.321***

TOM denoted as total organic matter.

Table 5. Two-way ANOVA on the species richness, density, biomass of macrobenthos, total organic matter (TOM), mean grain size (Mz), graphic inclusive standard deviation (σ_1) and silt-clay content in the sediment off the Nuclear Power Plant II from winter 2000 to summer 2004. The site is the inlet and effluent positions of the power plant

Parameter	Site	Season	Site x Season
Richness	***	***	***
Density	***	***	***
Biomass	ns	***	**
TOM	***	***	ns
M_z	***	***	***
σ_1	***	***	***
Silt-clay (%)	***	***	***

ns: not significant; *$p < 0.05$; **$p < 0.01$ ***$p < 0.00$.

values were less than 0.05 among species richness, density and biomass, between species richness and phi value and silt-clay content, between density and phi value and silt-clay content, between biomass and phi value and silt-clay content, between organic matter and mean grain size and phi value, and between phi value and silt-clay content.

DISCUSSION

Both the total and station-specific species richness of macrobenthos in the study area was not lower than those in deeper waters of Taiwan Straits (e.g. Cheng and Tsai, 1994, 1999). Two-way ANOVA showed that both species richness and density of power plants II and synoptic consideration of both plants were higher in the background and inlet sites than the outlet side, whereas the density in the power plant I was higher in the inlet site than the outlet site. No difference was observed in all comparisons of the biomass (Table 7). The background sites of both plants were closer to the inlet than the outlet (Figs. 1 and 2). The differences in both species richness and density between sites of both plants

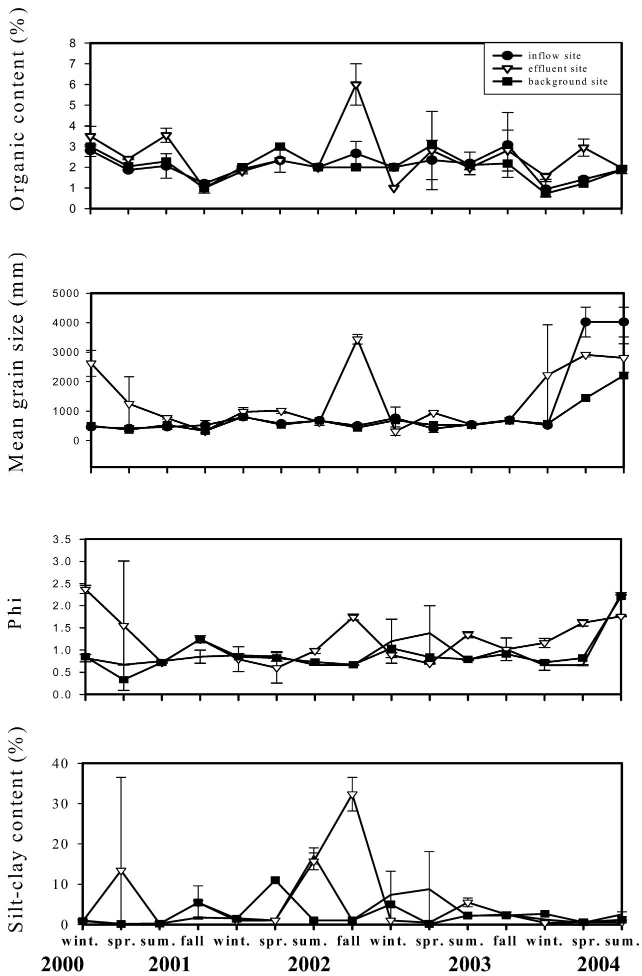

Fig. 5. Temporal changes in organic content, mean grain size, phi value and silt-clay content in the nearshore sediment off the Nuclear Power Plant I from winter 2000 to summer 2003. The abbreviate symbol for the seasons are same as in Fig. 3.

might due to the effluent of thermal waters from nuclear power plant, which cause the decrease in macrobenthos diversity near the effluent. However, due to the fact that no difference can be detected between the background and inlet sites and no difference in macrobenthos diver-

Table 6. Results of Spearman Rank Order Correlation Analysis among parameters in the sediment off the Nuclear Power Plant II

Parameter	Density	Biomass	TOM	Mz	σ_1	Silt-clay
Richness	0.552***	0.615***	0.0823	-0.17	0.361***	0.522***
Density		0.715***	0.049	0.0662	0.431***	0.409***
Biomass			-0.0702	0.111	0.242	0.249**
TOM				0.318***	0.321***	0.106
M_z					0.103	-0.106
σ_1						0.693***

Table 7. Results of statistical analyses in the species richness, density and biomass among background, inlet and effluent sites off the Nuclear Power Plant I, II, and I and II

Power plant	Species richness	Density	Biomass
No. 1	in > eff	in. > eff.	no differences
No. 2	in ≒ bkg > eff	in ≒ bkg > eff	no differences
No. 1 and 2	in ≒ bkg > eff	in ≒ bkg > eff	no differences

in: inlet site, eff: effluent site, bkg: background site.

sity off these two power plants as a whole compared to the deeper waters suggest that the influence of nuclear power plant to the macrobenthic community was only localized. Similar results were found in other studies near the coastal power plants (e.g. Holland *et al*., 2002; Gerritsen, 1989; Lardicci *et al*., 1999). Variations caused by the coastal characters, such as shallow water depth, may play a more important role in the macrobenthic community structure on the larger scale. Because the spatial distribution of macrobenthic community structure in shallow waters are related to physical and sediment characteristics (Marques and Bellan-Santini, 1993; Maurer *et al*., 1982; O'conor *et al*., 1993), the influence of nuclear power plant to the macrobenthic community structure will be discussed separately.

1. Nuclear Power Plant I

The small-sized annelids and crustaceans were the dominant macrobenthos over 3 and half years. Table 2 showed that no a single species dominant the whole period. The dominant species includes the *Scoloplos armiger*, *Cypridina hilgendorfii*, *Rhabditis terricola* of annelids and *Urothos grimaldii*, and *Northria conchylega* of crustaceans. Although Spearman Correlation Analysis found some correlations among biological parameters and between biological and environmental parameters, only a positive linear relationship existed between macrobenthic richness and density (density = 14.906 + 27.802 (richness), $n = 105$, $r = 0.67$, $p < 0.001$). This suggests that the station contains more species tends to have a higher area-specific animal abundance. Similar results were found in the other studies in Taiwan Straits (Cheng and Tsai, 1994, 1999). The analyses showed that the change in biological characters and TOM outside the Power Plant I was mainly due to the seasonal variation. It is possible that the variation in food availability may influence the macrobenthic community structure (Grant *et al*., 1991; Ingole *et al*., 2002; Nair *et al*., 1998).

The sediment near the effluent site composed mainly of coarser particles while had a higher percentage of fine-grained particles. A multiple linear regression found that total organic matter was related to the mean grain size, sediment sorting and silt-clay content (TOM = $0.13 + 0.000011M_z - 0.0048\sigma_1 + 0.0676$ (silt-clay), $n = 105$, $r = 0.403$, $p < 0.001$). A forward stepwise regression analysis showed that the total organic matter was influenced mainly by the mean grain size and silt-clay content. Thus the sediment off the effluent site had a higher organic content than the other sites. The sediment size distribution was also less homogenized. However, the differences in the sediment characters exerted little influence on the macrobenthic community structure. It is thus concluded that the major factor that influence the sediment characters was different from that of biological characters. This may related to the fact that Nuclear Power Plant I is an open system (Fig. 1). The macrobenthic community was more influenced by the season than the sediment characters. The lack of systemic changes in all parameters suggests that influence of nuclear power plant to the macrobenthic community was not significant.

2. Nuclear Power Plant II

The small-sized annelids and crustaceans were also the dominant macrobenthos over 3 and half years. Table 2 showed that the dominant species includes the *Scoloplos armiger*, *Cypridina hilgendorfii*, and *Etone longa* of annelids. A positive linear regression analysis was found between macrobenthic richness and density (density = 77.713 + 21.206 richness, n = 105, r = 0.401, p < 0.001).

Although there also existed a seasonal variation in all parameters, no consistent trend was observed. The interaction between the season and site in the species richness, density, mean grain size, sediment sorting and silt-clay content were caused mainly by the differences among sampling sites (p < 0.001 in all cases). The interaction between the season and site in the biomass,

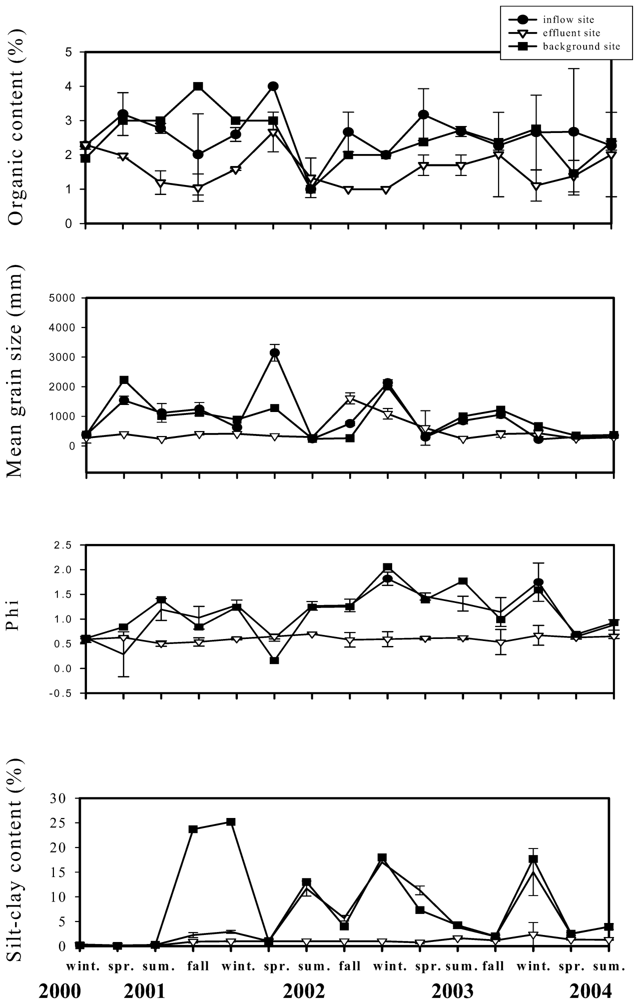

Fig. 6. Temporal changes in organic content, mean grain size, phi value and silt-clay content in the nearshore sediment off the Nuclear Power Plant II from winter 2000 to summer 2003. The abbreviate symbol for the seasons are same as in Fig. 3.

however, was caused mainly by the seasonal variation (p < 0.01). A multiple linear regression analysis found that TOM was related to the mean grain size, sediment sorting and silt-clay content (TOM = 0.120 + 0.0000136 M_z + 0.0144σ_1 - 0.0121 (silt-clay), n = 105, r = 0.371, p = 0.002). A forward stepwise regression analysis showed that the total organic matter was influenced mainly by the sediment sorting and mean grain size. Among two parameters, the mean grain size is the major influential factor. This suggests that in the more protected environment where the sediment was coarser and, secondary, the size distribution was less heterogeneity, it tends to contain more foods, thus more suitable for the macrobenthos to inhabit there (Basford *et al*., 1993; Kunitzer *et al*., 1992; Pfannkuche, 1983; Wildish *et al*., 1989).

The mean grain size of effluent sediment was finer and more homogeneous. This sediment contains less fine-grained particles and has a lower organic content. Thus, the sediment might be less suitable for the macrobenthos to inhabit. The interaction between the spatial and temporal factors for most sediment parameters was influenced mainly by the difference among sampling sites. This result might be related to the fact that the marine environment outside the Nuclear Power Plant No. 2 is a protected system (Fig. 2). Thus, the small-scale spatial variation plays a more important role in the changes of sediment characters and macrobenthic community than the season.

Biological characters were found related to the sediment characters outside the Nuclear Power Plant II. A multiple linear regression analysis found that both the species richness and the density were related to the sediment sorting and silt-clay content (richness = 2.886 + 0.940σ_1 + 5.077 (silt-clay), n = 105, r = 0.369, p < 0.001; density = 80.000 + 92.559σ_1 + 69.847 (silt-clay), n = 105, r = 0.34, p = 0.002). A forward stepwise regression analysis showed that the species richness was influenced mainly by the silt-clay content, while the density was influenced mainly by the sediment sorting. Because the total organic content was influenced by the sediment sorting, these results suggest that where the particle distribution was less homogenous, the high habitat heterogeneity and more food available allows more animals to inhabit there, thus provides a higher density site. The higher silt-clay content, on the other hand, provides a more stable environment for more species to inhabit. This result may also relate to the protected coastal environment outside the Power Plant II. In the protected environment, the hydrodynamic regime is less turbulent. The more stable sediment results in the less homogenous particle distribution. Thus, the sediment characters have a stronger influence on the macrobenthic community structure (Fresi *et al*., 1983; Yamshita *et al*., 2002). The lack of systematic changes in all parameters in this study also suggests that the influence of nuclear power plant to the macrobenthic community was not significant.

3. Synoptic discussion of Nuclear Power Plants I and II

The macrobenthos of this study is dominant by small-sized annelids and crustaceans. Similar results were found in the other shallow waters and nearshore studies (Aller and Stupakoff, 1996; Cheng and Tsai, 1999; Ingole *et al*., 2002). In spite the fact that the species diversity of the Power Plant I and II was high, it was found that about 50% of the species shared by both plants (48% from Plant I, and 55% from Plant II). The short distance between two plants (about 48 km) was the main reason for the high overlap of the species between two power plants.

In order to understand the relationship of the biological and sediment characters between two power plants, the differences in the sampling site, seasons, and power plants were analyzed by a three-way ANOVA (Table 8). The results showed that, the sediment outside the Power Plant II contained a higher species richness and density ($p < 0.001$ in both cases). Table 2, however, showed that the total species richness was higher outside the Power Plant I. It is possible that the sediment outside the Plant I was relative unstable that the species turnover rate was faster than the sediment outside the Plant II. The sediment outside the Power Plant I was coarser, less homogenous and contained less quantity of fine-grained particles than that of Power Plant II ($p < 0.001$, $p < 0.05$, and $p < 0.01$ respectively). The background sediment contained a higher organic content, higher species richness and density than the inlet and effluent sediments ($p < 0.001$ in all cases). The effluent sediment, on the other hand, contained more fine-grained particles than the inlet and background sediments ($p < 0.001$). No consistent trend in seasonal variation in all parameters was observed.

The interaction between power plant and season in species richness, density and mean grain size was due mainly to the differences between two plants ($p < 0.001$ in all cases). The interaction between these two factors in the biomass, TOM, sediment sorting and silt-clay content was caused mainly by the seasonal variation ($p < 0.001$ in all cases). The interaction between power plant and site in the species richness, density, mean grain size, and sediment sorting was caused mainly by the different between two plants ($p < 0.05$ in species richness; $p < 0.01$ in density; $p < 0.001$ in mean grain size, and sediment sorting). The interaction between these two factors in the TOM, and silt-clay content was caused mainly by the differences among sampling sites ($p < 0.001$ in both cases). The interaction between season and site in the biomass, mean grain size, sediment sorting, and silt-clay content was caused mainly by the seasonal variation ($p < 0.01$ in biomass, $p < 0.001$ in the other cases). The interaction between these two factors in species richness was equally influenced by two factors ($p < 0.001$). The interaction between these two factors in macrobenthic density was caused mainly by the difference in the sampling sites ($p < 0.001$). The interaction among three factors in all parameters except the species richness was caused mainly by the interaction between season and site ($p < 0.001$ in all cases). A multiple linear regression analysis found that the TOM was related to the mean grain size, sediment sorting and silt-clay content (TOM = $0.127 + 0.000011M_z - 0.0000223\sigma_1 + 0.0494$(silt-clay), $n = 210$, $r = 0.365$, $p < 0.001$). A forward stepwise regression analysis showed that the total organic matter was influenced mainly by the silt-clay content and mean grain size. Between the two parameters, the mean grain size is the major influential factor. This result suggests that the in this region where the grain size was coarser and the silt-clay con-

Table 8. Three-way ANOVA on the species richness, density, biomass of macrobenthos, total organic matter (TOM), mean grain size (M_z), graphic inclusive standard deviation (σ_1) and silt-clay content of the sediment between the Nuclear Power Plants I and II from winter 2000 to summer 2004

Parameter	Site	Season	Plant	Site x Season	Site x Plant	Season x Plant	Site x Season x Plant
Richness	***	***	***	**	*	***	ns
Density	***	***	***	***	**	***	***
Biomass	ns	***	ns	**	ns	***	***
TOM	**	***	ns	ns	***	***	***
M_z	ns	***	***	***	***	***	***
σ_1	ns	***	*	***	***	***	***
Silt-clay (%)	***	***	**	***	***	***	***

ns: not significant; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

tent was higher, the sediment had a higher total organic matter.

Thus, it is possible that the nearshore environment of Nuclear Power Plant II was more protected than the NPP I that the macrobenthic richness and density as well as the total organic matter were higher. The mean grain size and the sorting of sediment were lower, however. The macrobenthic species richness and density in the nearshore sediments were increased with the sediment stability (Aller and Stupakoff, 1996; Hernandez-Arana *et al*., 2003; Fresi *et al*., 1983). This study found that the spatial differences, in terms of sampling sites and power plants, were the main reason for the significant interaction between two environmental factors in most parameters. Seasonal variation is the secondary factor. This conclusion is further evident by the fact that both species richness and density were related to the sediment sorting and silt-clay content (richness = 3.063 + 0.722σ_1 + 1.606 (silt-clay), n = 210, r = 0.197, p = 0.017; density = 110.57 + 2.238σ_1 + 190.29 (silt-clay), n = 210, r = 0.208, p < 0.01; multiple linear regression analysis). A forward stepwise analysis showed that the species richness was influenced equally by both factors, and the density was influenced mainly by the silt-clay content. These results suggest that, the macrobenthic community outside these two nuclear power plants were influenced mainly by the sediment characters. The sediment where the particle was less homogenize and contained higher quantity of fine-grained particles tends to have higher habitat diversity and more foods. Thus, more macrobenthos, in term of species richness and density, will inhabit there. Even though there existed differences in the macrobenthic species richness and density between the inlet and effluent sites of both nuclear power plants (Table 7), the lack of consistent temporal change (i.e. increase of decrease) in these parameters over three and half year period suggests that the influence of thermal effluent to the nearshore macrobenthic community structures was rather localized. Macrobenthic communities appeared to have reached a stable condition with the constant environmental disturbances from the power plants.

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