EFFECT OF THERMAL DISCHARGES ON THE FISH ASSEMBLAGES OF A NUCLEAR POWER PLANT IN NORTHERN TAIWAN

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Key words: thermal plume, thermal pollution, coral fish, ecological monitoring.

ABSTRACT

The purpose of this paper is to study whether the thermal plume can affect the fish assemblages in the waters around the outlet area of the Second Nuclear Power Plant located at Kuosheng, a coastline between Yehliu and Chinshan village, northern coast of Taiwan. Both experimental and control stations of underwater census for reef fishes and of drift net sampling for pelagic or demersal fishes above sandy bottom were monitored four times per year from March 2001 to September 2004. The results show that no significant dif-ferences were found between the fish assemblages of the thermal waters and normal ambient waters for both coral reef fishes and pelagic or demersal fishes. It was probably due to microhabitat difference rather than water difference because the above fishes are mostly living near bottom where the water temperature are similar to each others for these two stations. On the contrary, the seasonal effect due to low water temperature in the winter had greater influence on the fish assemblages than the effect of thermal plume.

INTRODUCTION

Three Nuclear Power Plants (NPP) have been operating since 1977, 1981 and 1984 respectively in northern (1st and 2nd NPP) and southern (3rd NPP) Taiwan. The fourth Nuclear Power Plant is still constructing at Yenliao, northeastern coast of Taiwan. It is always in debate whether the thermal plume affects the fish resources in the waters around NPP. The water temperature difference (ΔT) between inlet and outlet area in Taiwan was designed up to 7-12°C, and the 2rd NPP was the highest, i.e., 10-12°C. Thermal waters could affect metabolism, growth, feeding, spawning and behavior of marine organisms as well as to their community structure and ecosystem [1, 3, 4]. In India, massive death of crabs and many macrobenthos were observed in the hot season [12, 13]. In France, seaweed assemblages encrusted on rocky shore changed when water temperature increased slightly 0.5-1.0°C [15]. In winter, thermal discharges of power plants affected the assemblage structure, recruitment, mortality, demography, spawning age, gonad development, and net production of fishes in Baltic Sea [10]. Cool shock due to shut down of power plant in winter also gave great impact to some fish species [14]. On the contrary, the assessment report from several large power plants along the coast in Italy did not detect the thermal effect on the community structures of phytoplankton, benthic organisms and fishes [1]. Nevertheless, it was pointed out that their study sites were too far away from the outlet area.

In Taiwan, it is well known that thermal plume of the 3rd NPP let the corals bleaching in the shallow waters near the outlet area [3, 11]. The thornfishes (*Therapon jurba*) and the large scale mullet (Liza macrolepis) were malformed inside the outlet bay of the 2nd NPP every summer since 1993 [7, 9]. It was because of Vitamin C deficiency which caused fish backbone to curve [5]. However, it still has no concrete evidence which proves that the thermal discharges will or will not affect the fish assemblages in Taiwan except typhoon effects at the 3rd NPP [7]. Although no thermal impacts were found at both the 1st and 2nd NPP in earlier ecological assessment before 1990. It has been pointed out that both experimental (at Yehliu) and control stations (at Kueho) chosen during that time were too far away from the outlet areas of the 1st and the 2nd NPP. [6]. The area which could be affected by thermal plume should be inside the range of 500-1,000 meters away from the outlet. Therefore, the current study moved both experimental and control stations back to the areas very close to the outlet area of the 2nd NPP. Both coral reef fish and pelagic or demersal fish assemblages were monitored and compared in order to find out the effect of thermal discharge to the local fish assemblages.

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MATERIALS AND METHODS

1. Study area and sampling design

According to the regulation for controlling thermal discharges by EPA, Taiwan, the rise of water temperature on the borderline of 500 m radius off outlet can not exceed 4°C than ambient water temperature. The hydrological simulation of thermal plume at the 2nd NPP after reconstruction of the outlet structure in 1993, the water temperature surrounded indeed decreased and met the requirement of EPA. In other words, the area about 500-1,000 m away from the outlet bay should have had no impact from warmer waters, especially in the waters below 2-3 meters because heat waters only float in the upper layer [6, 11]. Thus, several new monitoring stations located near outlet bay were chosen to replace those old stations since 2001.

For monitoring coral reef fishes, species and abundance data were recorded by two divers using a 100 m transect line (3 m each side) along the jetty of outlet bay as the experimental station (N 25° 12’ 17”, E 121° 39’ 50”), and another jetty about 1,300 m away as the control station (Fig. 1). The survey was carried four times per year during March 2001 and September 2004. The underwater topography, substratum, and water depth around 6-7 meters were very similar to each others between these two transects.

For monitoring pelagic or demersal fishes in sandy/muddy bottom, “three-layer” drift nets operated by fishermen were deployed parallel in both 300 m and 800 m away from outlet bay as the experimental and controlled station respectively (Fig. 1). The sampling frequency of drift nets was the same as underwater census. All specimens collected by drift nets were brought back to laboratory for further species identification, counting individual numbers and body weight measurement.

2. Data analysis

The Paired t test was used to analyze whether the species and individual number between experimental and control stations were significantly different seasonally. Multivariate statistical analysis was applied to analyze the community structure difference by using PRIMER V5.2 [2]. The data of fish species and individual numbers were transformed by log $(1 + x)$ using Bray-Curtis similarity coefficient to construct the dendrogram. MVDISP was used to compare the stability of communities between the two stations. One-way ANOSIM was used to check whether the thermal plume would affect fish communities ($R < 0.25$, barely separable at all; $R > 0.5$, overlapping but clearly different; $R > 0.75$, well separated).

RESULTS

1. Reef fishes

A total number of 42 families and 134 species were recorded (Table 1). Among which, 39 families and 100 species were observed from experimental station and 33 families and 112 species were obtained from control station. Only 5 species were non-reef fish species i.e., 96.3% were reef species in which 91.8% were residential and 93.3% were demersal. Most fishes observed were in young or sub-adult stages. *Diodon holocanthus*, *Abudefduf septemfasciatus*, and *A. vaigensis* were the three species recorded every time and also the most abundant. Labridae is the most dominant family with the most numerous species. At control station, more wrasse species were recorded than that at experimental station but not for the rest species. Comparing the species composition between the two stations, 21 species only occurred at experimental station and 33 species at control station. Sorensen similarity coefficient was 0.738 which indicates that their species composition were very similar to each other. Although the species number was significantly higher at control station than at experimental station ($p < 0.01$, ANOVA pair T test), no significant difference was found for total individual numbers (Table 2).

Clustering analysis showed that the community

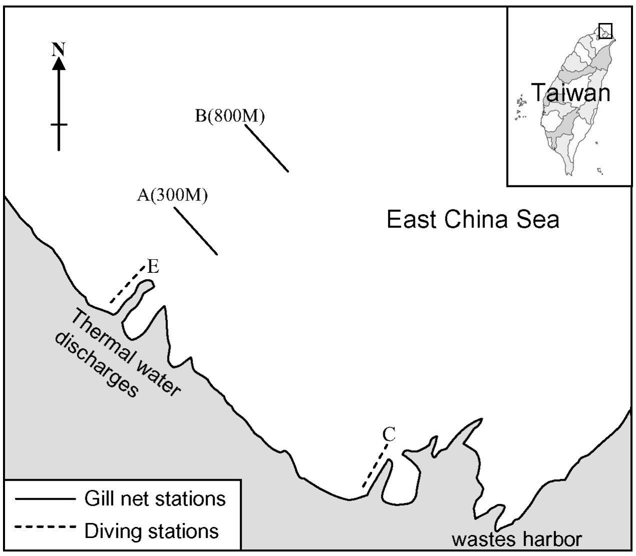

Fig. 1. The two sampling stations of underwater census by SCUBA divers, C, control station, and E, experimental staion along the jetty of outlet bay. The two three-layer drift net stations, A, experimental station about 300 m away from outlet area and B, control station located about 800 m away.

Table 1. Fish checklist and their individual numbers observed by diving at both experimental (E) and control (C) station from March 2001 to September 2004

Family	Species	Guild	E	C	Family	Species	Guild	E	C
Acanthuridae	*Acanthurus dussumieri*	R	19	21		*Thalassoma hardwickii*	R		1
	Acanthurus nigrofuscus	R		1		*Thalassoma lunare*	R	4	4
	Acanthurus xanthopterus	R	29	32		*Thalassoma lutescens*	R		2
	Naso annularis	R		2		*Xyrichtys dea*	R	1	2
	Prionurus scalprus	R	4	33	Leiognathidae	*Leiognathus nuchalis*	V	7,350	50
Apogonidae	*Apogon apogonides*	R	1		Lethrinidae	*Lethrinus atkinsoni*	R	1	8
	Apogon aureus	R	15		Lethrinidae	*Lethrinus lentjan*	R		2
	Apogon cookii	R	109	315	Lutjanidae	*Lutjanus argentimaculatus*	R	2	1
	Apogon doederleini	R	220	314		*Lutjanus fulviflamma*	R	23	10
	Apogon fleurieu	R	100			*Lutjanus fulvus*	R	1	
	Apogon nitidus	R	217	68		*Lutjanus gibbus*	R	1	21
	Apogon taeniophorus	R	26	1		*Lutjanus monostigma*	R	1	
	Archamia goni	R		275		*Lutjanus quiquelineatus*	R		1
	Archamia dispilus	R	10	216		*Lutjanus rivulatus*	R	9	
	Rhabdamia gracilis	R	304	1,000		*Lutjanus russellii*	R	3	10
Atherinidae	*Hypoatherina woodwardi*	V	4,650	3,200		*Lutjanus stellatus*	R	6	3
Belonidae	*Tylosurus* sp.	V	2			*Lutjanus vitta*	R	2	12
Blenniidae	*Ecsenius lineatus*	R	6	1		*Lutjanus kasmira*	R	3	2
	Ecsenius namiyei	R		1		*Pterocaesio diagramma*	V	3	183
	Petroscirtes breviceps	R	17	61	Microdesmidae	*Ptereleotris hanae*	R	13	
Carangidae	*Alectis indicus*	V	1		Monacanthidae	*Stephanolepis cirrhifer*	R		4
	Caranx sexfasciatus	V	8	1	Mugilidae	*Liza* sp.	V	65	11
	Seriola dumerili	V	1			*Mugil cephalus*	V		26
	Selaroides leptolepis	V	278	340	Mullidae	*Parupeneus barberinus*	R		4
Chaetodotidae	*Coradion altivelis*	R		1		*Parupeneus ciliatus*	R	4	31
	Chaetodon auriga	R	4	8		*Parupeneus chrysopleuron*	R	4	12
	Chaetodon auripes	R	14	33		*Parupeneus indicus*	R	51	74
	Chaetodon lunula	R		2		*Parupeneus multifasciatus*	R		2
	Chaetodon melannotus	R		1		*Parupeneus pleurostigma*	R		1
	Chaetodon octofasciatus	R	2			*Upeneus tragula*	R	27	27
	Chaetodon vagabundus	R		2		*Upeneus japonicus*	R	17	2
	Heniochus acuminatus	R	8	27	Nemipteridae	*Scolopsis monogramma*	R	3	1
Cheilodactylidae	*Cheilodactylus zonatus*	R	5	2		*Scolopsis vosmeri*	R	29	11
Cichlidae	*Orechromis hybrid*	R		3	Oplegnathidae	*Oplegnathus fasciatus*	R	1	11
Diodontidae	*Diodon holcanthus*	R	84	102	Ostraciidae	*Ostracion cubicus*	R	2	3
Fistulariidae	*Fistularia commersonii*	R	11	29	Pempheridae	*Pempheris oualensis*	R	5	472
Gerreidae	*Gerres oyena*	R	3	21	Pinguipedidae	*Parapercis xanthozona*	R	7	
Gobiidae	*Valenciennea muralis*	R	16		Plotosidae	*Plotosus lineatus*	R	1	60
	Istigobius campbelli	R	16	10	Pomacanthidae	*Chaetodontoplus septentrionalis*	R	1	3
Haemulidae	*Parapristipoma trilineatum*	R	2,026	52	Pomacanthidae	*Pomacanthus semicirculatus*	R		6
	Plectorhinchus cinctus	R	3		Pomacentridae	*Abudefduf septemfasciatus*	R	214	186
	Plectorhinchus flavomaculatus	R	2	1		*Abudefduf sexfasciatus*	R	16	119
	Plectorhinchus nigrus	R	3	1		*Abudefduf sordidus*	R	49	28
	Plectoorhinchus pictum	R	2	4		*Abudefduf vaigiensis*	R	1,112	1,054
	Pomadasys quadrilineatus	R	3,281	2,570		*Amphiprion clarkii*	R	4	
Kyphosidae	*Girella mezina*	R		5		*Chromis fumeus*	R	22	39
	Girella punctata	R	1	10		*Chromis notatus*	R		52
	Kyphosus cinerascens	R		10		*Neopomacentrus cyanomus*	R	36	101
	Microcanthus strigathus	R	208	74		*Pomacentrus coelestis*	R	130	152
Labridae	*Bodianus diana*	R		1		*Stegastes altus*	R	3	21
	Anampses caeruleopunctatus	R		4	Scaridae	*Chlorurus microrhinos*	R		2
	Cheilio inermis	R		1		*Scarus rubroviolaceus*	R	3	3
	Choserodon azurio	R	1	2	Scatophagidae	*Scatophagus argus*	R	1	
	Coris dorsomacula	R	42	67	Scorpaenidae	*Pterois volitans*	R	1	
	Coris gaimard	R	3	3	Serranidae	*Cephalopholis boenak*	R	6	
	Halichoeres argusr	R	1	5		*Diploprion bifasciatum*	R		6
Labridae	*Halichoeres marginatus*	R		6		*Epinephelus quoyanus*	R	1	3
	Halichoeres melanochir	R	27	18		*Grammistes sexlineatus*	R		1
	Halichoeres nebulosus	R		6	Siganidae	*Siganus fuscescens*	R	13,204	13,103
	Halichoeres nigrescens	R	35	58		*Siganus guttatus*	R		6
	Halichoeres orientalis	R		9	Sparidae	*Acanthopagrus schlegeli*	R	2	
	Halichoeres poecilopterus	R	25	35	Sphyraenidae	*Sphyraena flavicauda*	V	334	527
	Labroides dimidiatus	R	11	20	Synodontidae	*Trachinocephalus myops*	R	1	
	Pseudocoris ocellata	R	44	30	Tetraodontidae	*Arothron* sp.	R	1	
	Pseudolabrus eoethinus	R	12	74	Zancidae	*Zanclus cornutus*	R		3
	Pteragogus enneacantus	R	1		Zanclidae	*Zanclus cornutus*	R		3
	Stethojulis terina	R	74	188					
	Suezichthys gracilis	R	8	5		Total species number		100	112
	Thalassoma amblycephalum	R		1		Total individual number		34,770	25,852

In the column of habitat guild, R means residential and M, migratory or transient.

structure between the two stations could not be distinguished (Fig. 2). The separate group of three samples of E0409, E0304 and C0304 was due to very low water visibility (< 3 m) while diving which let the observation data invalid. If we took off these three samples, one-way ANOSIM analysis still could not show significant difference (R = 0.282, p = 0.001). Yearly difference among fish assemblages did not exist either (one-way ANOSIM test, E station R = 0.192 (p = 0.035), C station R = 0.186 (P = 0.04)). Nevertheless, dispersion index at control station was slightly lower than that at experimental station (MVDISP test E = 1.052 vs. C = 0.956). If we deleted those pelagic or transient species, there was still no significant difference detected between the two stations (R = 0.319, p = 0.001). No significant difference of community structure was found among different years (one-way ANOSIM test E station R = 0.192 (P = 0.035), C station R = 0.186 (P = 0.04). Dispersion index was still slightly lower at the control station than at the experimental station (MVDISP test E = 1.10 vs. C = 0.911). In other words, the stability of reef fish assemblage was lower in the thermal waters than in the ambient waters.

2. Demersal and pelagic fishes

Table 3 listed all 33 families and 64 species in total from 16 sampling times at the two stations. From the 300 m experimental station, 26 families and 43 species were recorded, and 24 families and 37 species from the control station. Among 64 species, 21 were non-reef species (32.83%), 18.8% were pelagic, the rest of 43.87% were still reef fish species. Nevertheless, the total number of individuals or biomass of fish samples belong to pelagic or migratory species, such as Carangidae was the most diverse family with 8 species, and *Arius maculates* was the highest caught in both total individual number and biomass.

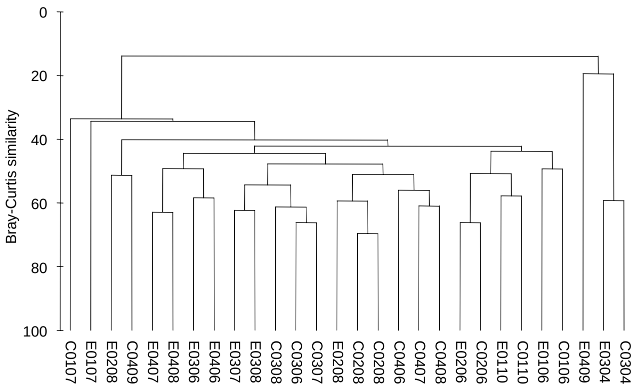

Fig. 2. UPGMA dendrogram for monitoring reef fish assemblages at both experimental (E) and control (C) station near the outlet area of the 2nd NPP during March 2001 to September 2004 (The first two digits are abbrev. of AD, the latter two digits are months).

Comparing the species composition, there were 23 species which only appearing at 300 m station and 16 species only appeared at 800 m station. The Sorensen similarity coefficient value was 0.5, even lower than the values between the two reef fish stations. Table 4 lists the total species number, individual number and body weight between the two drift-net stations which showed no significant difference.

The clustering dendrogram of Fig. 3 only showed the fish assemblage in autumn, i.e., October and November, was different from the fish assemblages in other seasons. This was due to high catches of *Platyrhina sinensis*, *Alectis indicus*, *Diodon holocanthus* and *Alectis ciliaris* etc, in these two months. Even we delete the data of these two months, no significant difference was found between the two stations (Global test R = 0, p = 0.432). This result indicates that thermal plume did not affect the community structure of either pelagic or demersal fishes.

DISCUSSION

For reef fishes, although our sampling stations of diving were moved back to the areas which are very close to the outlet bay, even along the jetty of outlet bay for monitoring reef fishes, no significant difference of fish assemblages has been found between effluent area and non-effluent area. This is because the warmer waters only existed in the surface layer, less than 1.5 m. Most of fishes observed at experimental station were reef fishes associated with reef bottom, around 5-6 meters depth, which should not be effected directly by the thermal plume. Figure 4 show that there was no temperature difference in the waters below 1.5 m but only existed in the surface layer. Indeed this warmer surface waters can attract some thermophilic species especially for those inshore migratory post-larval or juveniles, such as *Terapon jurba* and *Liza macrolepis*, the two famous malformed species caused by high water temperature at the 2nd NPP, which gathering or even living inside the outlet bay [7, 9]. However, these two

Table 2. The result of paired T test on the total number of species and individual numbers of ref fishes between experimental and control

	T value	P value	df
Species No.	-3.0783	0.0088**	13
Individual No.	1.2544	0.2318	13

*p < 0.05.
**p < 0.01.

Table 3. Checklist and their individual numbers caught by drift net at both experimental (A) and control (B) station during March 2001 to July 2004

Family	Species	Stage	Habitat	Total Wight (g)	A NO.	B NO.
Acanthuridae	*Acanthurus dussumieri*	A	R	445	1	1
	Prionurus scalprus	A	R	4,148.6		5
Ariidae	*Arius maculatus*	A	S	26,637.7	32	23
Carangidae	*Alectis ciliaris*	J	R	1,492.1	2	3
	Alectis indicus	J	R	11,192.2	9	6
	Caranx papuensis	A	R	2,090.6	6	4
	Carangoides dinema	A	S	316.8	1	
	Carangoides hedlandensis	A, J	S	50.9	1	
	Decapterus muroadsi	A	S	96.3	1	1
	Megalaspis cordyla	A	S	1,044.3		1
	Seriola dumerili	J	R	1825	2	
Cheilodactylidae	*Cheilodactylus zonatus*	A	R	1,397.6		4
	Cheilodactylus quadricornis	A	R	235.6		1
Chaetodontidae	*Chaetodon auripes*	A	R	370		2
	Coradion altivelis	A	R	566	4	2
	Chaetodon modestus	A	R	50.3	1	
	Chaetodon wiebeli	A	R	110	1	
Clupeidae	*Sardinella sindensis*	A	S	15.2		1
Dasyatidae	*Dasyatis bennetti*	A	S	898.6	2	
	Dasyatis kuhlii	A	R	680	1	
Diodontidae	*Diodon holocanthus*	A	R	4,256	5	12
Elopidae	*Elops haw aiensis*	A	S	2,048.2		3
Haemulidae	*Diagramma pictum*	A	R	8,220.3	9	9
	Hapalogenys mucronatus	A	S	2,615.7	6	13
	Parapristipoma trilineatum	A, J	R	2,074	9	4
	Plectorhinchus cinctus	A	R	1,500	2	
Holocentridae	*Sargocentron melanospilos*	A	R	1,112.3	3	1
	Sargocentron rubrum	A	R	398		2
Kyphosidae	*Girella punctata*	A	R	305	1	
	Microcanthus strigatus	A	R	275.8		2
Labridae	*Choerodon azurio*	A	R	53.3		1
Lethrinidae	*Lethrinus nebulosus*	A	R	494.5	1	
Lutjanidae	*Lutjanus fuliflamma*	A	R	376	2	
Monacanthidae	*Aluterus monoceros*	A	R	1,501.6		2
Monacanthidae	*Chaetodermis penicilligerus*	A	R	130	1	
Narcinidae	*Narcine timlei*	A	S	1,172	1	
Oplegnathidae	*Oplegnathus fasciatus*	A	R	2,299.7	1	4
	Oplegnathus punctatus	A	R	347.3	1	
Osmeridae	*Ostracion cubicus*	A	R	4,985.2	7	11
Paralichthyidae	*Paralichthys olivaceus*	A	S	267	1	
Pempheridae	*Pempheris vanicolensis*	A	R	215	1	
Pomacanthidae	*Pomacanthus semicirculatus*	A, J	R	5,130	1	
Rachycentridae	*Rachycentron canadum*	J	S	1,708.9		1
Rhinobatidae	*Platyrhina sinensis*	A	S	2,795.9	12	9
	Rhinobatos schlegeli	A	S	2,445		
Scaridae	*Scarus ghobban*	A	R	576		1
Sciaenidae	*Arygrosomus japonicus*	A	S	5,121.2	6	4
Sciaenidae	*Johnius distinctus*	A	S	124.4	1	
	Pennahia macrocophalus	A	S	617.3	4	2
Scombridae	*Scomber japonicus*	A	S	320	4	
Scorpaenidae	*Pterois volitans*	A	R	500		1
	Scorpaenopsis cirrhosa	A	R	118	1	
	Scorpaenopsis diabolus	A	R	75.2		1
	Sebastiscus marmoratus	A	R	365.6	1	2
Serranidae	*Cephalopholis boenak*	A	R	335.6	1	2
	Epinephelus chlorostigma	A	R	927.9		3
Siganidae	*Siganus fuscescens*	A, J	R	512.3	2	1
Sparidae	*Acanthopagrus schlegelii*	A	S	213.3	1	
	Rhabdosargus sarba	A	S	931.9	1	1
Triakidae	*Mustelus griseus*	J	S	1,700		1
Uranoscopidae	*Ichthyscopus lebeck*	J	S	125	1	
	Total species number				43	37
	Total individual number				149	143
	Total weight			113428		

In the column of Morphological stage: A means adult, and J, juveniles; in Habitat Column; R, rocky and S, sandy.

Table 4. The result of paired T test on the total number of species, individual numbers and biomass of pelagic or demersal fishes caught between experimental and control station

	T value	*P* value	*df*
Total species number	1.0194	0.3232	16
Total individual number	-0.3735	0.7137	16
Total weight	-1.7087	0.1068	16

*$p < 0.05$.
**$p < 0.01$.

species could not be easily observed and recorded by divers because most of them lived inside the outlet bay with sandy bottom.

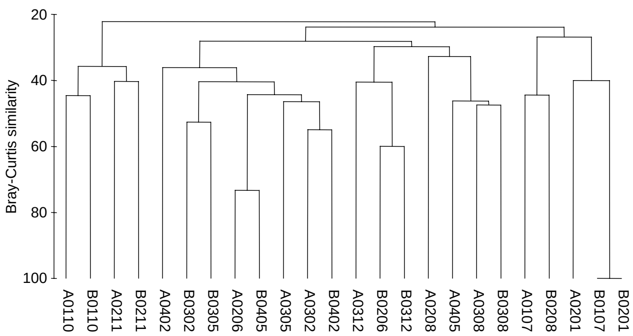

Fig. 3. UPGMA dendrogram for monitoring pelagic or demersal fish assemblages at experimental (A) and control (B) station 300 m and 800 m away respectively from the outlet area of the 2nd NPP from July 2001 to May 2004 (The first two digits are abbrev. of AD, the latter two digits are months).

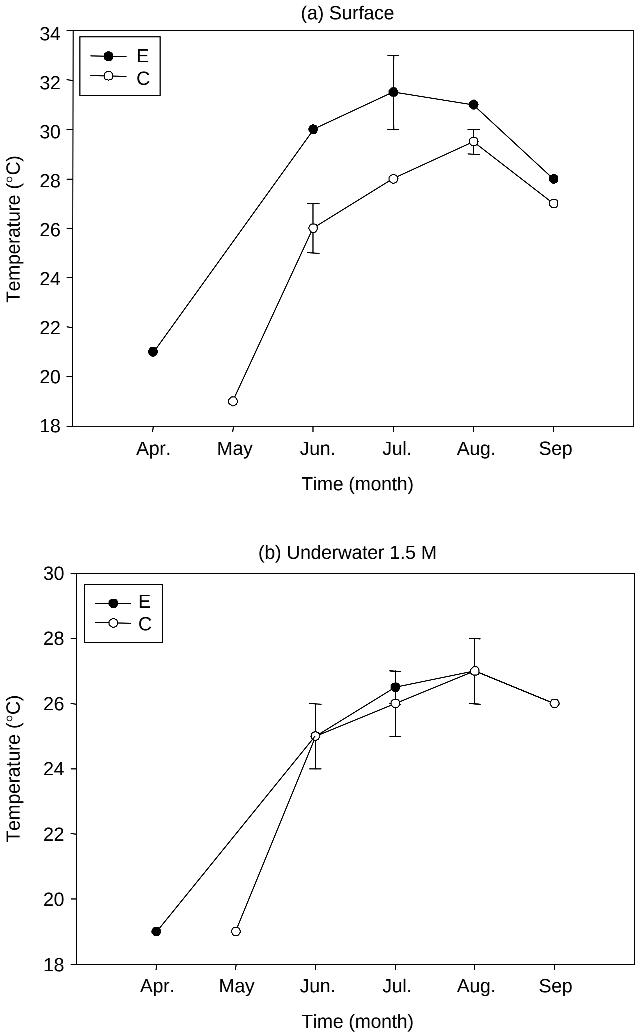

Fig. 4. Water temperature differences between the experimental and the control stations in the upper surface layer or 1.5 m below the surface.

Are there any species which could be possible related to the temperature difference? Table 5 lists some fish species which were different between the two stations. That the two herbivorous species of *Petroscirtes breviceps* and *Stegastes altus* were more abundant at the control station than at the experimental station might be because seaweed growth was better in cooler water than in warmer water [8]. As to zooplankton feeder of *Parapristipoma trilineatum* and omnivores *Microcanthus strigatus*, that they were more abundant in warmer waters which might be due to more food particles or less active zooplankton stirred up by thermal plume at experimental station. But three species of carnivores, *Apogon cookii*, *Stethojulis terina* and *Parupeneus ciliatus*, and three species of omnivores, *Prionurus scalprus*, *Pempheris oualensis* and *Abudefduf*

Table 5. The list some fish species which were quantitatively different between experimental (E) and control (C) stations (Z, zooplankton feeder; O, omnivores; C, carnivores; H, herbivores)

Species	Food guild	E	C
Parapristipoma trilineatum	Z	2026	52
Microcanthus strigatus	O	208	74
Apogon cookii	C	109	315
Stethojulis terina	C	74	188
Neopomacentrus cyanomus	Z	36	101
Petroscirtes breviceps	H	17	61
Abudefduf sexfasciatus	O	16	119
Archamia dispilus	Z	10	216
Heniochus acumnatus	Z	8	27
Pempheris oualensis	C	5	472
Prionurus scalprus	O	4	33
Parupeneus ciliatus	C	4	31
Stegastes altus	H	3	21

sexfasciatus were more abundant at the control station than at the experimental station. It was probably due to microhabitat difference rather than water difference because the above fishes are mostly living near bottom where the water temperature are similar to each others for these two stations.

For non-reef associate pelagic or demersal fishes outside the thermal effluent, no significant spatial difference between 300 m and 800 m away from outlet bay was obtained except the seasonal difference in the winter. This result probably because of that these two drift net stations were not so far away from each other and the temperature gradient (approximately less than 3°C between the two stations) was not so large enough to attract fishes and form distribution pattern, especially for the swimming ability and migratory range of non-reef and non-residential fishes that swim at the surface layer and have larger migratory range.

However, every weekend in the summer season, there are so many anglers crowded in the jetty of the outlet bay to fish those thermophilic milkfish or needlefishes. This thermal attraction phenomenon should be due to the fact that the temperature gradient here is much greater than the diffusion area outside the bay. Also, strong turbulent which probably mixed with more food particles in the plume within 100 m range probably can create stronger attraction effect than outside 100 m apart from the mouth of outlet bay.

In conclusion, based on our three and half years monitoring data on reef and non-reef fish assemblages in the waters surrounding the outlet area of the 2nd NPP, the thermal plume or higher water temperature in the surface layer did not change the fish assemblages significantly. This conclusion is the same as the results of Calanoid [16].

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