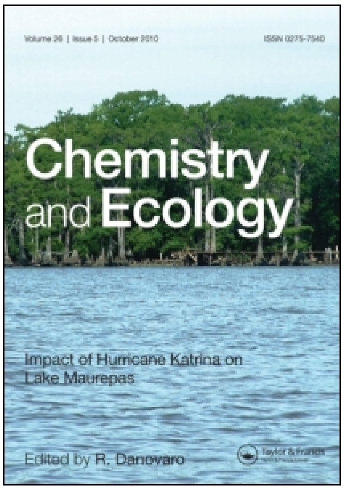

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ECOLOGICAL SURVEY OF COASTAL WATER ADJACENT TO NUCLEAR POWER PLANTS IN TAIWAN

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A total of six nuclear reactors installed in three power plants, two along the northern and one along the southern coasts of Taiwan, started their operations one after another since October 1977. Owing to the large quantities of cooling water intake into and discharge from the plants, some environmental factors such as water temperature, chlorine, environmental radioactivity and nearshore currents may be significantly changed. Variations of these abiotic environmental factors may influence the biological activities in the ecosystem, particularly doing some kinds of damage to marine biological resources. Therefore, the possible environmental impact upon the biological systems including the fishery resources along the northern and southern coasts of Taiwan should be studied before and during the plant operation.

We have started the long-term programmes of biological, chemical and hydrographical surveys of the nuclear power plant sites on both northern (since July 1974) and southern (since July 1979) coasts of Taiwan. The survey items include ocean currents, physical and chemical properties of sea water, primary productivity, specific compositions and interspecific relationships among phyto- and zooplankton, algae, invertebrates, corals, and fishes; and radionuclides in water and biological specimens, and fishery statistics. In general, except for a few events, the operations of the six units of nuclear power plants have not produced detectable effects on the marine ecosystem. Radioactivity levels and radionuclides in water and the biological specimens remained the same as background levels throughout the survey period. However, the events of coral bleaching and fish body anomalies caused by thermal discharges were observed respectively along the outlets of third and second Nuclear Power Plants. The purposes of this paper are to report and evaluate these two events during the operations of nuclear power plants in Taiwan.

Keywords: Nuclear power plants; coral bleaching; fish skeletal deformation; marine ecosystem

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INTRODUCTION

Taiwan has three nuclear power plants, the first two power plants along the northern tip and the third along the southern tip of Taiwan. Each power plant has two nuclear power reactors. The first and second reactors in the first nuclear power plant, the third and fourth reactors in the second power plant, and the fifth and sixth reactors in the third power plant were loaded with nuclear fuels in October 1977, October 1978, December 1982, March 1983, February 1984 and May 1985. Owing to the large quantities of cooling water intake into and discharge from the reactors, some physical factors (such as water temperature, nearshore and ocean currents) and chemical factors (such as chlorine, radionuclides, trace elements) may be significantly changed. Obviously, variations of these abiotic factors may influence the biological activities in the ecosystem, particularly causing some kind of damage to marine biological resources. Therefore, the possible environmental impact upon the ecosystem, including the fishery resources along the northern and southern coasts of Taiwan, should be studied before and during the plants' operation.

The National Scientific Committee on Problems of the Environment, Academia Sinica (SCOPE/AS), under the support of the Atomic Energy Council, has started the long-term programmes of biological, ecological, chemical (including chlorine, radionuclides) and hydrographical environmental monitoring along the power plant sites in the northern and southern parts of Taiwan since July 1974 and July 1979. The items monitored include non-biological factors such as near-shore and ocean currents, and physical and chemical properties of sea water, and biological factors such as primary productivity, species compositions and interspecific relationships among phyto- and zooplankton, algae, invertebrates, corals and fishes, radionuclides in sea water and biological specimens, and fishery statistics. Each part of the projects have been conducted by the best specialists available in the field and invited by SCOPE/AS. The data collected in each year were documented and discussed in annual reports. The preoperational background environmental data along the northern and southern coasts of Taiwan have been summarized, analyzed and reported (Su *et al.*, 1979, 1984). The assessments of ecological and environmental impact on the operation of the two reactors in the first nuclear power plant (Su *et al.*, 1981), four reactors in two nuclear power plants along the northern coast (Su *et al.*, 1984; Hung *et al.*, 1992), and two reactors in the third nuclear power plant along the southern coast (Su *et al.*, 1988) have been reported and discussed.

For the long-term investigation, we may conclude that, except for a few events, the operations of the six units of nuclear power plants have not produced detectable effects on the marine ecosystem. Radioactivity levels and radionuclides in the water and biological specimens remained the same as background state through the survey period. However, the events of coral bleaching and fish body anomalies caused by thermal discharges were found along the outlets of third and second nuclear power plants (Huang *et al.*, 1992; Hung *et al.*, 1994; Lin, 1995). In this paper we only discuss the events mainly caused by water temperature changes during the operation of nuclear power plants.

MATERIALS AND METHODS

The survey and monitoring projects for the northern (Fig. 1A) and southern (Fig. 1B) plant sites have been carried out since July 1974 and July 1979, respectively. The research vessels "Chiulien" and "Ocean Researcher 1", and chartered fishing boats were used in the survey cruises bimonthly. The items monitored include non-biological factors such as near-shore and ocean currents, and physical and chemical properties [such as temperature, salinity, pH, dissolved oxygen, biochemical oxygen demand, chlorine, total oils and grease, nutrients (nitrite-N, nitrate-N, phosphate-P, and silicate-Si), chlorophyll-a] of sea water, and biological factors such as primary productivity, species compositions and interspecific relationships among phyto- and zooplankton, algae, invertebrates, corals and fishes, radionuclides in sea water and biological specimens, and fishery statistics. Each part of the projects has been conducted by the best specialists available in the field invited by SCOPE/AS. The methods for analysis of these parameters were described previously (Su *et al.*, 1979). However, in this paper only some events such as coral bleaching and fish skeletal deformation along the coasts near power plants are reported and discussed.

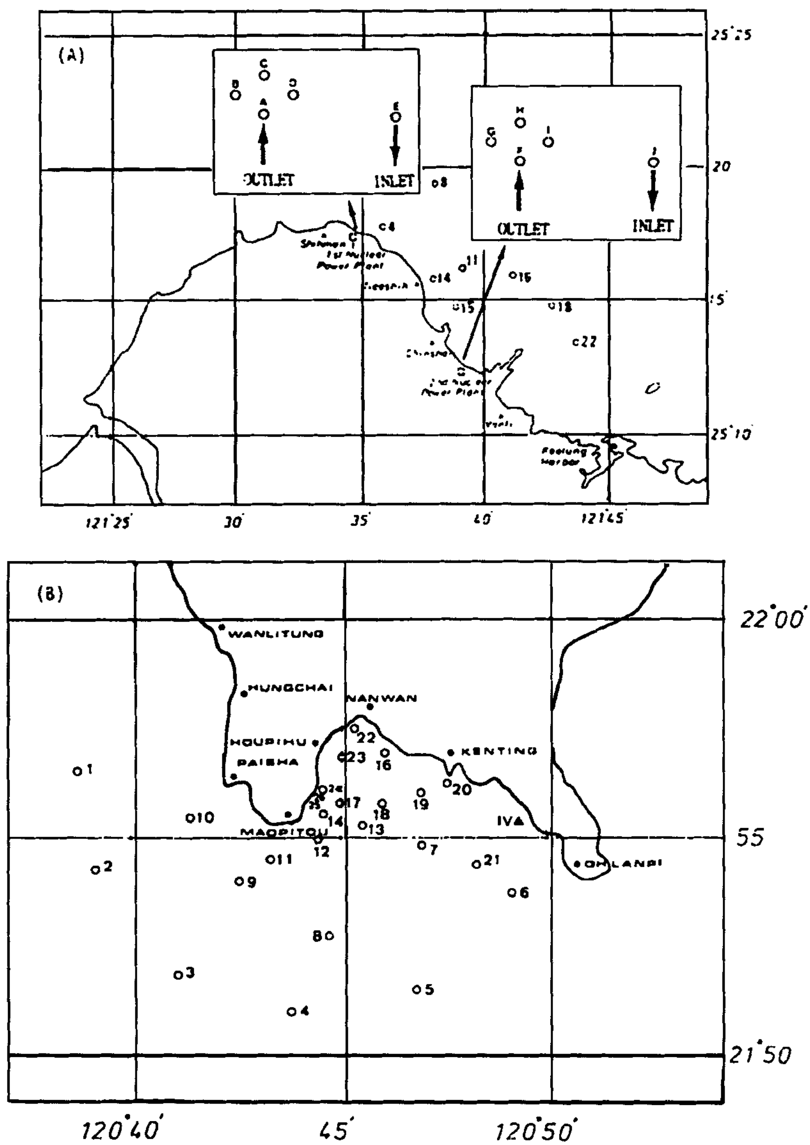

FIGURE 1 Sampling locations along the northern and southern coastal areas in Taiwan; A shows the first and second nuclear power plants in the north, and B the third nuclear power plant in the south.

RESULTS AND DISCUSSION

For the 23 and 18 years of hydrographical, chemical and biological investigations on the northern and southern coasts of Taiwan, it might be concluded that the operation of the six reactors, four in the north and two in the south, has not produced detectable effects on the marine ecosystem. Although the catch statistics of squid showed an evident decrease of this pelagic resource along the northern coast in 1982–1984, it is apparently not the consequence of the power generation operation (Su *et al.*, 1984). Chlorine in water, measured with the DPD method (APHA, 1981), indicated that the contents of chlorine (ranged from < 0.01 to 0.02 mgl^{-1}) were satisfactory, i.e., within the EPA/Taipei-water requirements (< 0.5 mgl^{-1}). Radio-activity levels and radio-nuclides in the water and biological specimens remained the same as the background state through the survey period, indicating that the operation of power plants had no adverse effects. Until now, due to the change of water temperatures around the nuclear power plants, a few events have occurred along the southern and northern coasts near the power plant sites.

Mass Coral Bleaching and Mortality Incidents

Since the two generating units of the third nuclear power plant began its full operation in January 1987, two incidents of coral bleaching were observed in July 1987 and July 1988 in a shallow bay near the west side of the plant's cooling-water outlet (Huang *et al.*, 1992). Mass coral bleaching was recorded in the first incident occurring from shore line to the depth of 3 m over an area of about $0.012\,km^2$ ($20\,m \times 600\,m$), which is approximately 0.1% of all the coral coverage in Nanwan Bay (Fig. 2). Over 90% of corals on the fringing reef were bleached in this event. For the second incident, the range of coral bleaching expanded from 5 m to 30 m in depth in the shallow bay and extended along the coast from the shallow bay to Mao-pi-tou, an area of about $0.045\,km^2$ ($30\,m \times 1{,}500\,m$), which is approximately 0.3% of the total coral cover in Nanwan Bay. About 30% of the corals living between 3–5 m depth in the shallow bay were bleached in this event, but no mass mortality of coral was found along the coast of the shallow bay

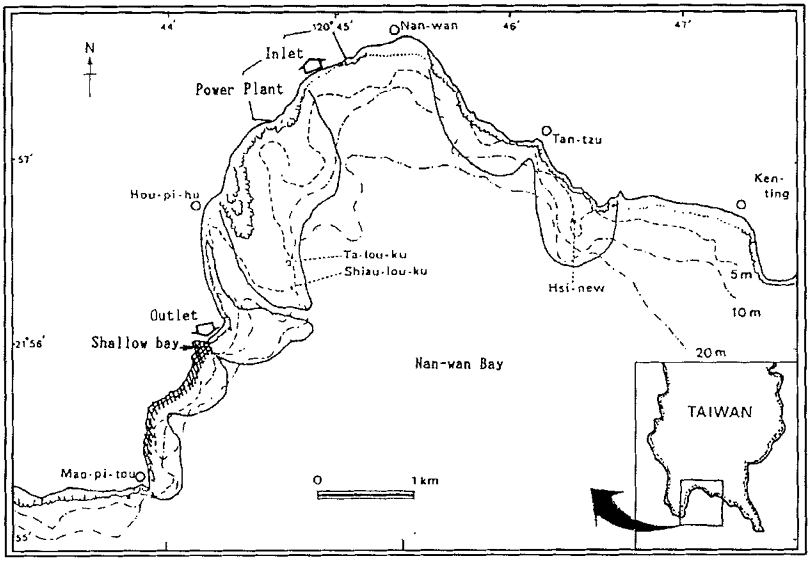

FIGURE 2 Distribution of coral reefs from Mao-Pi-Tou to Kenting and coral bleaching from Mao-Pi-Tou to Shallow Bay in summer 1987 and summer 1988 at Nanwan.

to Mao-pi-tou. The staghorn coral *Seriatopora hystrix* was recognized as the most sensitive local species. The photographic data (Tab. I) show that the percentage of coral colonies with complete decolorization (20–80% bleached) increased from 3.8% on 30 May 1988 to 52.2% on 17–19 August 1988. The percentage of normal colonies (less than 20% bleached) decreased from 82.9% to 32.1% during the same period. During the summer of 1989, the percentage of normal colonies was 85.2% on 22 June, dropping to 69.7% on 27 September but rising to 92.5% by August 1990. The percentage of coral colonies with complete decolorization was 3.3% on 22 June, increasing to 7.0% on 27 September but decreasing to 2.3% on 9 August 1990. The decrease of complete decolorization after the summer of 1989 was due to the increase of 10% of cooling water intake-discharge rate since May 1989.

Figure 3 shows some changes in the coverage of four coral colonies in the shallow bay and two colonies near the coast of Nanwan village. Conspicuous changes of coral coverage throughout the survey period were found on the three colonies numbered 1, 2 and 5, all of which

TABLE I Number of decolorization of coral colonies in the Nanwan Shallow Bay, from May 1988 to August 1990

	May 30, 1988			*June* 12, 1988			*June* 30, 1988		
	*C**	*P**	*N**	*C*	*P*	*N*	*C*	*P*	*N*
1. Acroporidae	17	39	540	9	5	106	24	75	207
2. Pocilloporidae	25	125	216	9	25	10	4	22	55
3. Poritidae	0	1	17	0	0	4	0	7	27
4. Faviidae	4	13	174	0	4	10	3	12	16
5. Alcyoniidae	1	3	129	0	0	3	0	1	24
6. Other	11	24	201	4	6	22	6	19	27
Total colonies	58	205	1277	22	40	155	37	136	356
(%)	3.8	13.3	82.9	10.1	18.5	71.4	7.0	25.7	67.3
	July 7–9, 1988			*July* 22–23, 1988			*August* 17–19, 1988		
	C	*P*	*N*	*C*	*P*	*N*	*C*	*P*	*N*
1. Acroporidae	65	159	350	294	258	182	667	165	320
2. Pocilloporidae	29	72	115	11	21	75	79	38	74
3. Poritidae	2	3	45	2	2	33	9	1	5
4. Faviidae	11	25	59	14	24	26	33	26	60
5. Alcyoniidae	2	12	46	1	9	36	12	20	39
6. Other	11	41	67	49	23	58	114	24	63
Total colonies	120	312	682	371	337	411	914	274	561
(%)	10.8	28.0	61.2	33.1	30.1	36.8	52.2	5.7	32.1
	June 22, 1989			*July* 6, 1989			*August* 6, 1989		
	C	*P*	*N*	*C*	*P*	*N*	*C*	*P*	*N*
1. Acroporidae	14	39	272	18	44	290	14	72	202
2. Pocilloporidae	9	33	31	7	23	53	5	25	48
3. Poritidae	0	0	31	0	3	25	0	0	24
4. Faviidae	0	1	109	0	2	216	0	1	185
5. Alcyoniidae	0	2	95	0	0	69	0	0	83
6. Others	1	9	82	0	4	109	2	14	75
Total colonies	24	84	620	25	76	762	21	112	617
(%)	3.3	11.5	85.2	2.9	8.8	88.3	2.8	14.9	82.3
	August 14, 1989			*September* 27, 1989			*July* 1, 1990		
	C	*P*	*N*	*C*	*P*	*N*	*C*	*P*	*N*
1. Acroporidae	14	66	214	43	103	218	0	2	199
2. Pocilloporidae	11	24	29	10	26	24	0	3	20
3. Poritidae	1	2	17	0	4	32	0	0	7
4. Faviidae	0	6	144	1	30	145	0	0	88
5. Alcyoniidae	0	1	72	0	7	78	0	0	65
6. Others	1	10	27	0	10	42	0	0	34
Total colonies	27	109	503	54	180	539	0	5	413
(%)	4.2	17.1	78.7	7.0	23.3	69.7	0	1.2	98.8
	July 10, 1990			*August* 5, 1990			*August* 9, 1990		
	C	*P*	*N*	*C*	*P*	*N*	*C*	*P*	*N*
1. Acroporidae	1	18	233	2	9	232	10	16	231
2. Pocilloporidae	1	7	32	2	8	24	4	14	28
3. Poritidae	0	0	29	0	0	18	0	0	17
4. Faviidae	0	0	145	0	0	131	0	0	170
5. Alcyoniidae	0	0	83	0	0	67	0	0	76
6. Others	0	5	62	0	1	49	0	2	50
Total colonies	2	30	584	4	18	531	14	32	572
(%)	0.3	4.9	94.8	0.7	3.2	96.0	2.3	5.2	92.5

* C: Complete decolorization colonies; P: Partial decolorization colonies; N: Normal colonies.

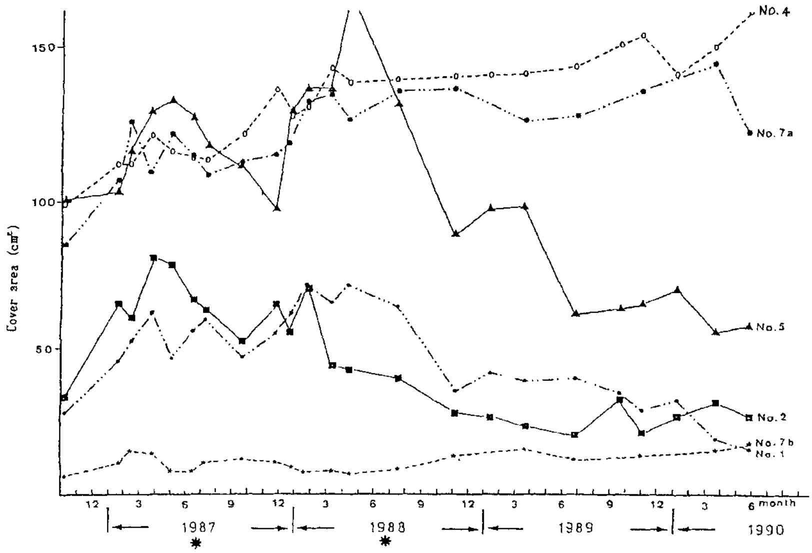

FIGURE 3 Changes in the cover of coral colonies in the shallow bay near the thermal outlet (1, 2 and 5) and near Nanwan village (4, 7a and 7b). Colony 1 is for *Sarcophyton*, colonies 2, 5, 7a and 7b are *Lobophytum*, and 4 is *Acropora*.

were in the shallow bay. The coverage of number 5 was 1677 cm^2 on 13 April 1988, but was only 891 cm^2 by 4 November 1988. All of the observed colonies of soft corals in the Shallow Bay showed a decrease in coverage after the summer of 1987 and 1988, but the decrease was less after the summer, 1988. The aggregate mortality rates of the coral colonies were 75% for those in the Shallow Bay. No significant changes of coverage were found in the observed colonies (Nos. 4, 7a and 7b) near Nanwan village during the survey period.

Immediately after the first event in July 1987, we found that thermal effluent was the major cause of coral bleaching. The temperature rise of greater than 4°C, complying with the water discharge requirement of our Environmental Protection Administration, covered an area extending for 300–400 m from the outlet to the south and west (Fig. 4). Figure 5 shows that the bottom-water temperature of the Shallow Bay varied with the outlet-water temperature of the plant. The temperature of the surface water in the Shallow Bay on the western side of the outlet exceeded 31.9°C, and in some places the temperatures exceeded 34°C, which would definitely hurt or kill corals in shallow

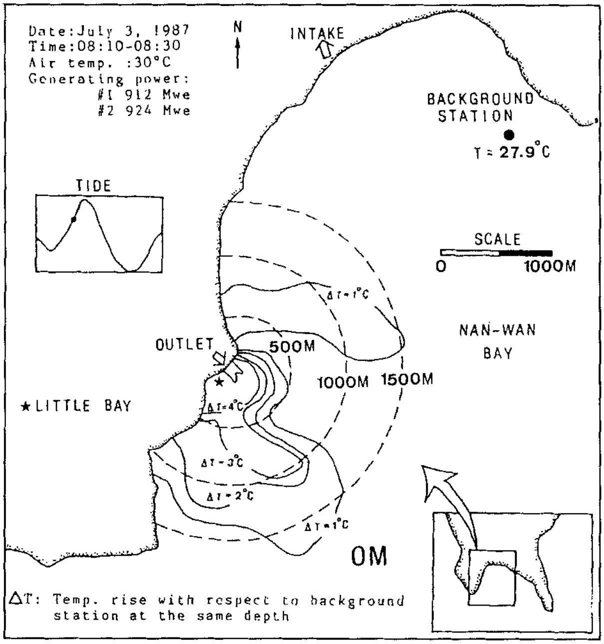

FIGURE 4 Temperature change of surface sea water in the thermal bay (Little Bay) at Nanwan, July 3, 1987. The thermal effluent discharge is indicated as T°C.

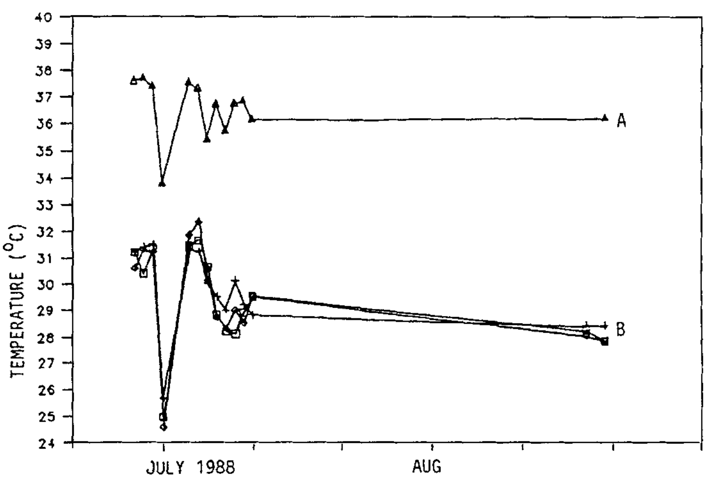

FIGURE 5 Water temperature at surface (A) and bottom (B) in the Shallow Bay at Nanwan.

water near the shore (Yang *et al.*, 1980). Except for the temperature, sea water quality, such as salinity (32.444–35.445 psu), pH (7.76–8.38), dissolved oxygen saturation (84 – 104%), biochemical oxygen demand (0.2–0.5 mgl^{-1}), chlorine (< 0.01 to 0.02 mgl^{-1}) and heavy metals (mercury, < 0.05 ugl^{-1}; chromium, 1.36–3.18 ugl^{-1}, zinc, 0.50–48 ugl^{-1}; cadmium, < 0.02 ugl^{-1}–0.98 ugl^{-1}; lead, 0.2–12.4 ugl^{-1}; and copper, 0.6–17.0 ugl^{-1}), as sampled in the Shallow Bay, met the marine-water criteria set by our Environmental Protection Administration. Nutrients (nitrite-N, 0.11–1.35 μM; nitrate-N, 0.73–8.55 μM; phosphate-P, < 0.03 μM–4.17 μM; and silicate-Si, 1.62–33.1 μM), chlorophyll-*a* (0.04–0.78 μgl^{-1}), primary productivity (0.21–1.15 $\mu gCl^{-1}h^{-1}$), and the radioactivity levels in sea water as well as the radionuclides in biological specimens were normal (Huang *et al.*, 1992).

Extensive coral bleaching caused by the synthetic stress of high temperature and high light was observed on the Great Barrier Reef (Oliver, 1985), and by sea water warming of El Nino Southern Oscillation on Java Sea (Brown and Suharsono, 1990). Kato (1987) indicated that the branchlets of poritid coral had a mortality rate of 19% under the stress of water temperature at 32°C over a period of 48 hours; the mortality increased to 57% if the temperature was 33°C for the same period. Jokiel and Coles (1974) found that the lethal temperature was 32°C for Hawaiian corals. For the Nanwan corals, estimated from laboratory experiments, indicate 31 to 32°C being the upper temperature limits for 14 coral species (Yang *et al.*, 1980). The bottom temperature in the Shallow Bay frequently reached 31 to 32°C during the summers of 1987 and 1988, confirming that the upper lethal temperature for Nanwan corals is 32°C in accordance with the limits for Hawaiian and Okinawan corals.

Fish Skeletal Deformation

The skeletal deformities of *Terapon jarbua* and *Liza macrolepis* in the outlet areas of the second nuclear power plant were observed in the summer of 1993. The following lines of evidence and preliminary results indicated that the occurrence of the malformed juveniles and/or young fishes were intimately associated with the high water temperatures of thermal discharge from power plants (Hung *et al.*, 1994); (1) The water temperatures at the stations (G, H, I; Fig. 1A), 500 m from outlet of second power plant, were generally higher than the EPA/Taipei-water discharge requirements of 4°C (Fig. 6). (2) The high temperatures above 38°C were generally observed in an area very close the outlet of the power plant where fish skeletal deformities were found. (3) No more malformed fish were collected since mid-September 1993 since the water temperature was significantly decreased after shutting down one generator and the peak recruitment of the fish was reduced. (4) Due to the decline of ambient water temperatures in the autumn and winter, the morphology of all juvenile fish occurred afterwards were all normal. (5) The laboratory data show that it takes only about two weeks to make the vertebrae of fish of the above two species curved after raising to high temperatures of 36–38°C. Their back-bone and body appearance deformities are similar to those of malformed specimens collected in the field. (6) So far all specimens of skeletal deformities were collected from the same area which is very close to the outlet of the second nuclear power plant.

For further studies, the Environmental Protection Administration has initiated a joint research group conducted by different scientists

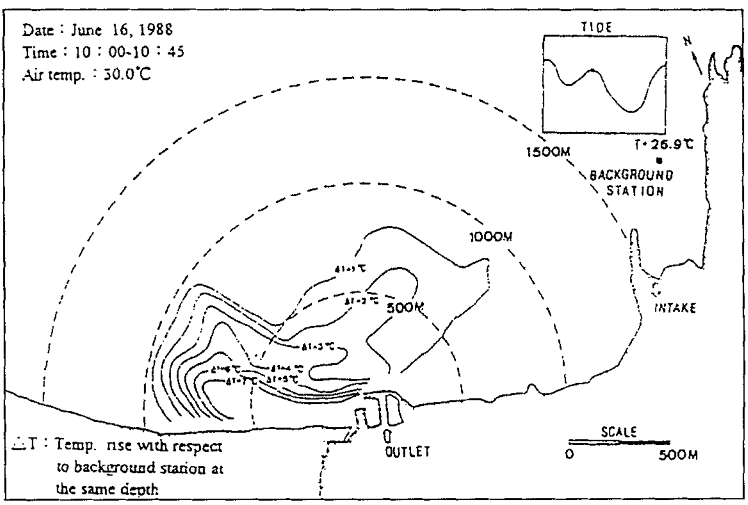

FIGURE 6 Temperature increments near the outlet of the second nuclear power plant on June 20, 1988 (after Fan, 1992); Temperature in other areas is about 28°C.

from universities and research institutes. The research items include physical (mainly water temperature), chemical [chlorine, heavy metals (such as cadmium, iron, nickel, chromium, zinc, tin and tributyltin) and radionuclides (such as Cr-51, Mn-54, Co-59, Co-60, Zn-65, Ag-110m, Cs-137 and Sr-90)], ecology (such as fertilized eggs and embryos with different temperatures), and morphology (such as analysis of structures, karyotypes and gene products). After one-year studies, the report (EPA/Taipei, 1995) indicated that water qualities except temperature, along the outlet of power plant attained the qualities of class "A" set by the EPA/Taipei. The chlorine contents (< 0.01 mgl^{-1} – 0.02 mgl^{-1}) in water were less than our EPA-water requirement ($< 0.5\,mgl^{-1}$). An early paper (Bellanca and Bailey, 1977) indicated that 10 $\mu gl^{-1}$of chlorine was harmful to some marine organisms. However, many papers (Johnson, 1977; Sugam and Helz, 1977) found that the criterion for marine organisms should be established for "oxidant species" instead of chlorine. The radionuclide contents in water, sedimental clay and sand, and fish specimens (both normal and deformed) collected from the second nuclear power plant show no indication of excess radioactivity released from the power plant. The morphological data indicated that some fish, acclimated to 36°C for four months, showed deformity; however, their karyotypes, with 48 acrocentric chromosomes, were unchanged. No deformed fish were developed after low dose (0.05 Rad) irradiation, probably concluding that the causes of deformed fish are not related to heredity. For the analysis of gene products, there is no significant difference in isozyme and allozyme patterns between normal and deformed fish collected near the power plant. However, the physical data, through several temperature control rearing experiments, proved that only one factor, temperature (above 36°C), would make the spinal cords of 1 cm normal fish fry of thornfish, or mullet, deformed (Lin, 1995). The appearances or spinal curvature of the fish are very similar to those malformed fishes caught from the outlet of the power plant. At 36°C, it will take half a year to make fish 100% malformed, but it only takes 2 weeks to reach 100% malformed in the 37°C and 38°C tanks. On the other hand, the mortality is also higher above 37°C. In the 38°C tank, all fish died after 1–2 months. The growth rate of fish in decreasing order is 34°C > 36°C > room temperature (25–30°C) > 37°C > 38°C. The ecological data confirmed that the high

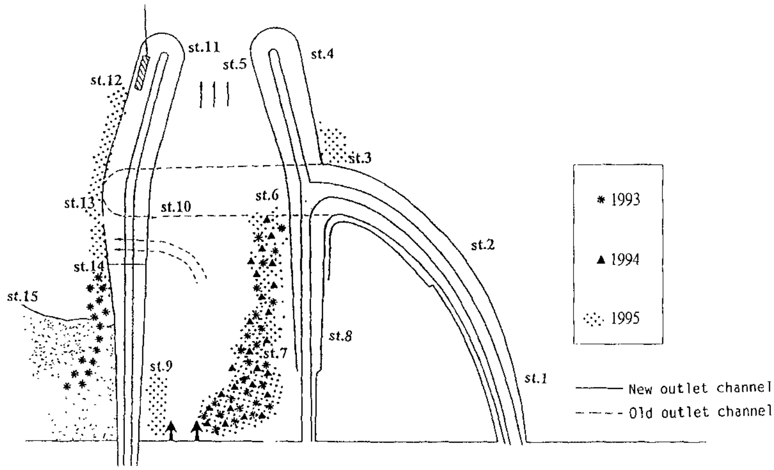

FIGURE 7 Locations of fish skeletal deformities in summer 1993; fish deformities in summer 1994; and those found in summer 1995. Location of the new effluent channel built in 1995.

temperatures (above 38°C) were the primary cause of the fish deformity. They also found that high temperatures could cause deficiency of ascorbic acid of the fish body, which might be the mechanism of causing deformity of fish.

After Taiwan Power Company reconstructed the outlet channel for changing the direction of water discharge, the water temperatures at points of approximately 500 m from the outlet of second power plant were not higher than 4°C, complying with the EPA-water discharge requirement. However, the water temperatures very close to the region where deformed fishes of *Terapon jarbua* and *Liza macrolepis* were found are still higher than 38°C (Fig. 7). Therefore, the skeletal deformities of these species were observed again during the summers of 1994 and 1995. Further action such as increasing the cooling water intake-discharge rate might be taken for eliminating these fish deformities.

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