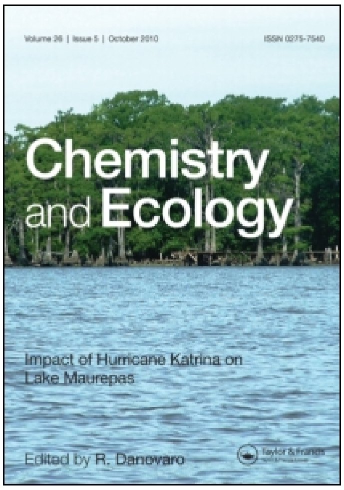

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Kuang-Lung Fan[a]
[a] Institute of Oceanography, National Taiwan University, Taipei, Taiwan

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THE THERMAL DISCHARGES FROM NUCLEAR POWER PLANTS IN TAIWAN

KUANG-LUNG FAN

Institute of Oceanography, National Taiwan University, Taipei, Taiwan, R.O.C.

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The increasing use of sea water for industrial cooling presents a real threat to the ecological environment in the ocean. In Taiwan where many electric power plants along the coast take sea water for cooling, people are concerned seriously about nuclear power plants. There are three nuclear power plants in Taiwan. Each plant has two units for generating power. The first two are located along the northern coast of Taiwan. The third is located in Kenting National Park along the coast of southernmost Taiwan. The plants take sea water for cooling, and discharge their heated effluents to the ocean surface from the coast. The thermal effluents have variable effects on the ecological environment near the plants. Fishermen living near the power plants complain that the heated water affects the inshore fishery catch. In addition, the thermal water from the second plant is easily accumulated near the coastal zone to influence the nearby swimming area in the summer-time. The thermal water from the third plant bleaches or kills some corals in shallow water near the outlet, and this conflicts with the interests of Kenting National Park.

KEY WORDS: Nuclear plants, thermal discharge, coastal zone, corals

INTRODUCTION

This paper reviews conditions along the coast of Taiwan where the nuclear power plants operating since 1977 discharge heated effluents close to coastal coral reef communities. In tropical conditions, these discharges are close to tolerance threshold of benthic communities.

GESAMP (1984) defines marine pollution as follows: "The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) which results in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities".

Ecologists consider temperature the primary control of life on earth, and fish, cold-blooded animals that are unable to regulate their body temperature, are particularly sensitive to changes in the thermal environment. Each aquatic species becomes adapted to the seasonal and daily variations in temperature of the water in which it lives, but it cannot adjust to the shock of abnormally abrupt change. For this reason there is growing concern among ecologists about the heating of aquatic habitats by man's activities. Sources of heated effluents discharged to the coastal marine or estuarine receiving waters are almost always directly or indirectly related to power generation. In Taiwan, the principal contributor of this heat is the discharge from electric power plants, and people are concerned seriously about the operation of nuclear power plants.

According to Clark (1969), the effects of increased water temperature on aquatic life can be classified as follows:

(1) it may speed up the metabolic rate –
Generally speaking the metabolic rate doubles with each increase of 10°C. Since this increases the animal's need for oxygen, the rate of respiration must rise. In contrast, the dissolved oxygen content in water decreases as temperature rises. The rate of oxygen consumption rises steadily until the lethal temperature of an animal is reached.

(2) it may stop reproduction –
Some species of fish spawn during the fall, but many more species spawn in the spring. The rising temperature in spring induces a seasonal development of the gonads and at a critical point triggers the female's deposit of her eggs in the water. Temperature also exerts a precise control over the time it takes for fish eggs to hatch. Excessive temperatures can prevent normal development of eggs.

(3) it may shorten longevity of fish –
High temperature may lead to a short but demanding spell of rapid growth, while slower rate at a lower temperature may be better for living longer.

(4) it may damage the food chain –
The optimal temperature for any water habitat depends, not only on the preferences of individual species, but also on the well-being of the system as a whole. An ecological system in dynamic balance is like a finely tuned automobile engine, and damage to any component can disable or impair the efficiency of the entire system.

In the GESAMP Report (1984), the responses of selected organisms of different classes to heat have been observed in both experimental and site studies:

(1) bacteria and phytoplankton appear to be resistant to thermal stress, even at temperatures in excess of 30°C;

(2) macrophytes are reported to be more sensitive to thermal stress and their threshold may be less than 25°C in temperate and up to 34°C in tropical waters;

(3) zooplankton is not affected by discharges to temperate European waters, where summer peaks rise to 30°C in the discharge;

(4) benthos in temperate and subtropical waters will tolerate temperatures close to discharge outfalls up to 10°C above ambient, or 35°C. If sensitive species are lost in peak summer temperatures, recolonization occurs from adjacent areas;

(5) fish – most temperate species are able to tolerate a wide temperature range but few are resident in waters with temperatures greater than 30°C. The preferred temperature varies with life stage and with season.

In general, early laboratory tests set out to test the tolerance threshold of organisms to identified stress such as an increment of temperature. The most usual response measured has been mortality. Tests on a wide variety of both tropical and temperate organisms indicate a common upper lethal temperature of about 35°C. Acclimation of test organisms at 15, 20 and 25°C, which temperatures are considerably below the upper lethal temperature, allows them to tolerate temperature increments of 8–9°C without damage. Longer-term acclimation to high or fluctuating temperatures may explain why organisms may sometimes be found living above 35°C.

GESAMP (1984) also states that temperature regimes in the tropics are such that many organisms live close to their upper thermal limits. Studies of temperature

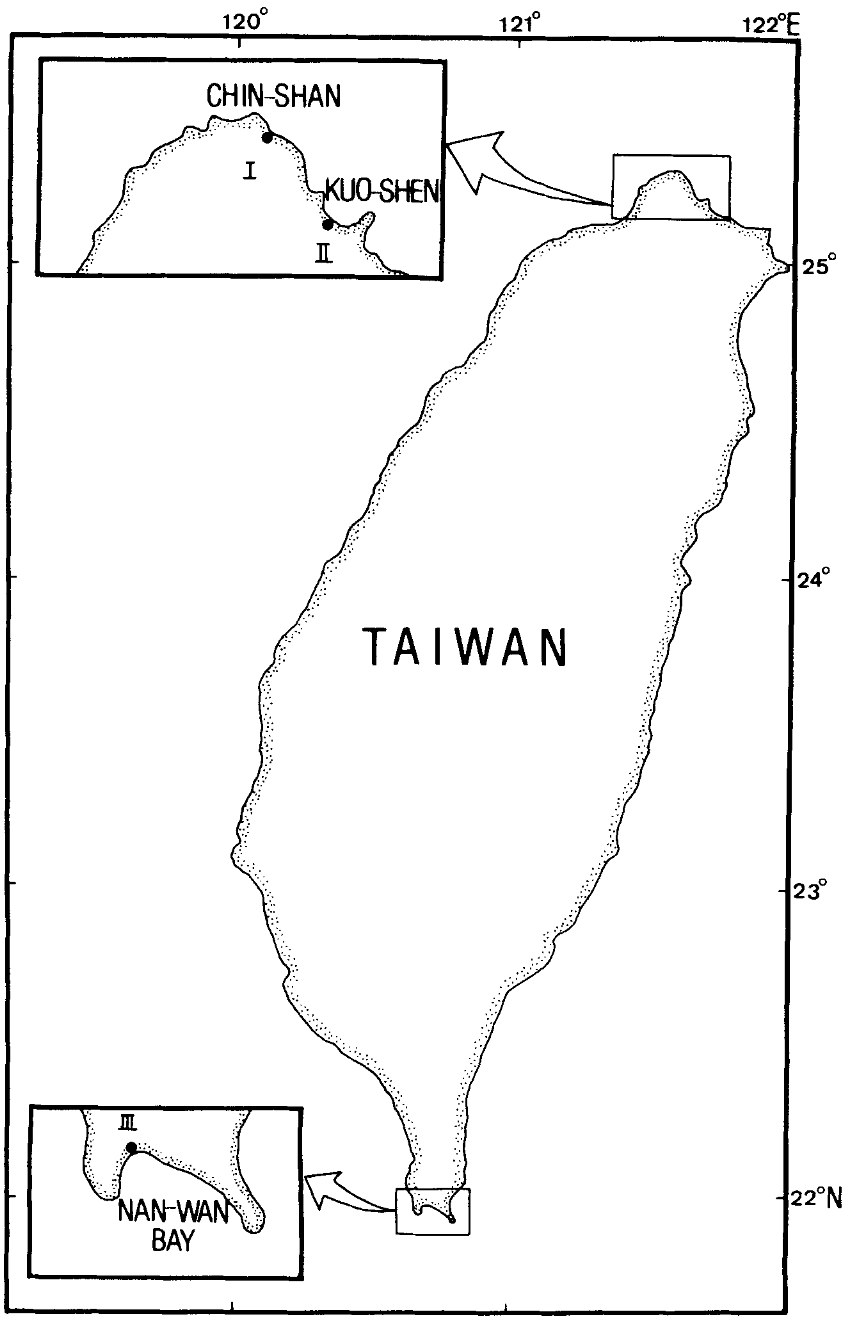

Figure 1 The locations of three nuclear power plants in Taiwan.

effects on tropical organisms, like temperate species, indicate that temperatures around 35°C are critical or lethal. Hence, temperature increments caused by thermal discharges to tropical waters need to be regulated closely to avoid adverse ecological impacts. Because of the prevailing environmental conditions and the sensitivity of many tropical species, the temperature increment, ΔT, in the plume at the point of discharge should ideally not exceed 5°C in the tropics.

Shallow-water benthic communities, whether temperate, subtropical or tropical, are the most susceptible to thermal discharges. In the tropics, caution must be exercised to avoid damage to coral reefs, seagrass and seaweed beds and mangrove communities, since these are typically in shallow water and among the most productive marine ecosystems.

Various examples demonstrate that power stations can operate with limited or no damage to the marine environment, provided that temperature increments are limited to 7°C or less in subtropical regions, and to 5°C or less in tropical waters.

CONDITIONS AND OBSERVATIONS IN TAIWAN

A total of six nuclear reactors installed in three power plants along the northern and southern coasts of Taiwan (Figure 1) began operations one after another since October 1977. Each plant has two units for generating power. Owing to the large quantities of cooling water intake and discharge from the plants, some environmental conditions such as water temperature and nearshore currents may be changed significantly. Variations of these abiotic environmental conditions may influence biological activity in the ecosystem, possibly resulting in some kinds of damage of marine biological resources. Therefore, the possible environmental impact on biological systems, including fishery resources along the northern and southern coasts of Taiwan should be studied before and after the plant operation.

The National Scientific Committee on Problems of the Environment, Academia Sinica (SCOPE/AS), with support of the Atomic Energy Council and Taiwan Power Company (TAIPOWER), has started long-term programmes of biological, ecological, chemical (including radionuclides) and hydrographic environmental monitoring in the vicinity of the power plant sites in the northern and southern parts of Taiwan since July 1974 and July 1979, respectively. The variables monitored include nonbiological factors such as ocean and nearshore currents, physical and chemical properties of sea water, and biological factors such as primary productivity, species composition and interspecific relationships among phyto- and zooplankton, algae, invertebrates, corals and fishes, radionuclides in sea water and biological specimens, and fishery statistics. The data collected in each year were documented and discussed in annual reports.

The near-shore tidal current and the ocean surface current adjacent to Taiwan affect the cooling efficiency of the nuclear power plants. The tidal currents control the distribution of thermal water plumes from the plants while surface currents bring different water masses with different water temperatures to the power plant sites. The most predominant current component along the coast of Taiwan is a tidal current of semidiurnal period. This current flows along the coastline back and forth, and reverses its direction every 6 hours or so with average current speed of about 20 cm s^{-1}. The thermal water near-shore moves parallel to the coastline about 4 km in either direction (Fan, 1987).

The surface current patterns in Taiwan Strait have been studied by Fan and Yu (1981). During winter, a branch of the Kuroshio flows into Taiwan Strait, while in summer, South China Sea water flows into Taiwan Strait (Figure 2). The surface water in Nan-wan Bay, coming either from the Kuroshio branch or South China Sea, is quite warm. It can reach about 24°C even in winter, and to 29°C or higher in summer (Su *et al.*, 1981). This warm, clear water sustains a well-developed coral community in the fringing reef in Nan-wan Bay. Along the northern coast of Taiwan, the sea surface temperature is about 26°C in summer, and about 18°C in winter (Huang, 1989). The influence of thermal effluent from the two nuclear power plants in northern Taiwan is not so obvious as that from the third in the southern tip of Taiwan.

The first nuclear power plant is located near Chin-shan in northern Taiwan. Near the first nuclear power plant the littoral zone is mostly comprised of sandstones. The No. 1 and No. 2 units began to operate in October 1977 and October 1978, respectively. During the flood tide, the current flows toward the WNW direction, parallel with the coastline, and toward the ESE direction during the ebb. Figure 3 shows the surface water temperature increment near the outlet on June 17, 1988. The data, supplied by the radioactive laboratory, TAIPOWER, were collected from 13:40 to 14:15 during ebb tide. The surface water temperature at a background station near the intake was 27.0°C. An area of temperature increment > 6°C extends from the outlet to about 500 m off-shore in the WNW direction. The surface water temperature exceeds 33°C.

The second nuclear power plant is located near Kuo-shen in northern Taiwan. Near to the plant, the littoral zone is mostly comprised of rocks with a sandy beach, on the western side of the outlet, used for swimming. The No. 1 and No. 2 units began operating in December 1982 and March 1983, respectively. During the flood tide, the current also flows toward the WNW direction, parallel with the coastline, and toward the ESE direction during the ebb. Figure 4 shows the surface water temperature increment near the outlet on June 16, 1988. The data, also supplied by the radioactive laboratory, TAIPOWER, were collected from 10:00–10:45 near the end of the flood tide. The surface water temperature at a background station near the intake is 26.9°C. An area of temperature increment > 7°C extends 700 m from the outlet to the west.

TAIPOWER prohibits fishing boats and people getting close to the plant sites. Su *et al.* (1984) summarized and discussed the data collected from July 1974 to June 1984 for assessment of ecological and environmental impact of the four units of the first and second nuclear power plants on the coastal environment of northern Taiwan. The data indicate that the thermal plumes from the power plants affect not only fishing activities near the plant sites, but also swimming activities near the second plant.

The third nuclear power plant is located on the ocean coast near Nan-wan Bay in southern Taiwan. There are 179 coral species found in Nan-wan Bay (Yang *et al.*, 1982). Corals are abundant along the coastline near the third nuclear power plant. The No. 1 and No. 2 units there began operating in July 1984 and May 1985, respectively.

The current near the outlet area flows towards the SW for most of the time during the flood. During the ebb, it flows sometimes to the SW, and sometimes to the NE, but with a predominantly SW direction (Liang *et al.*, 1978). There is also some evidence to indicate that sea water near the outlet might recirculate to the intake area

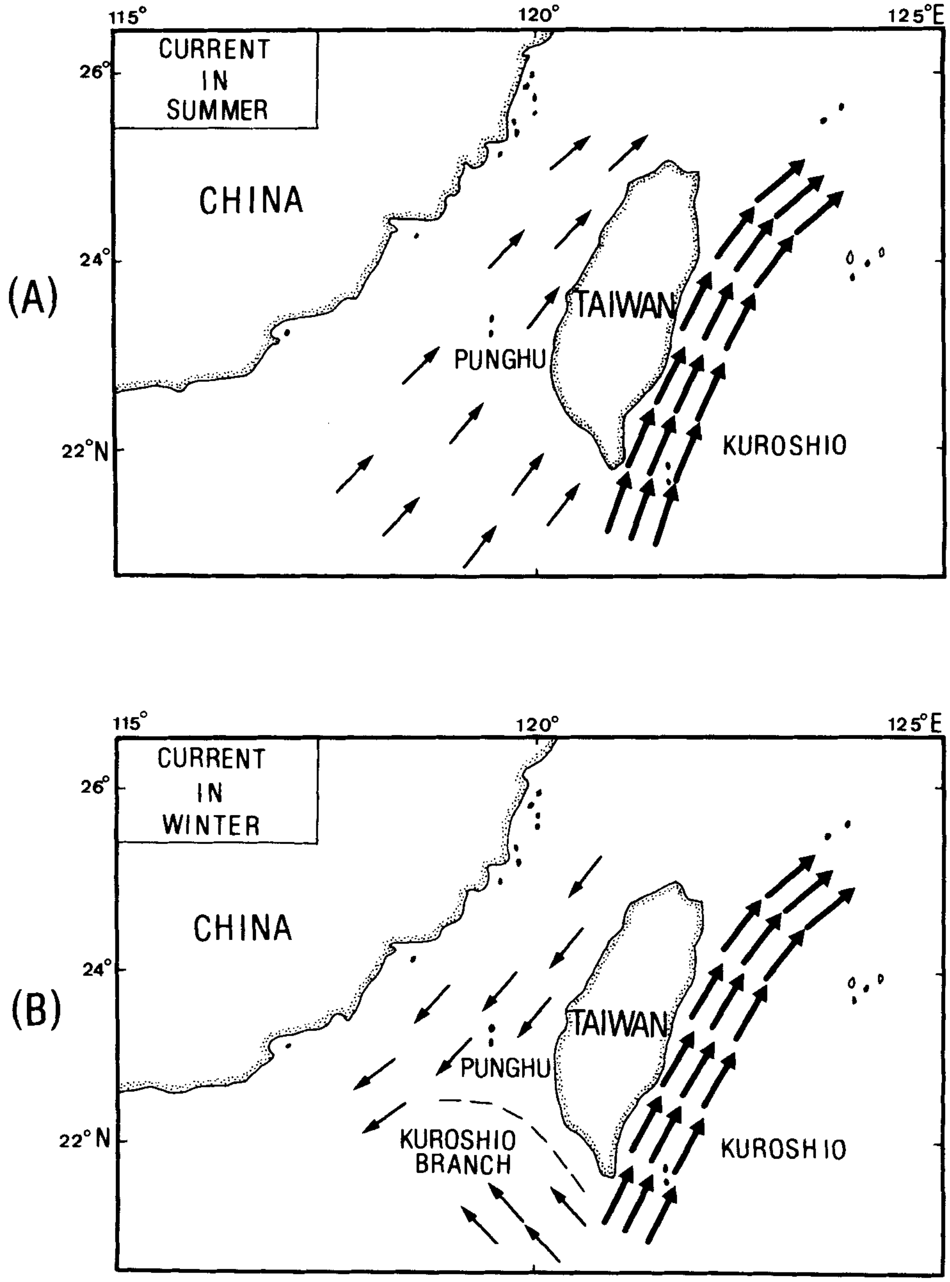

Figure 2 Surface current patterns in the vicinity of Taiwan in summer (A) and winter (B).

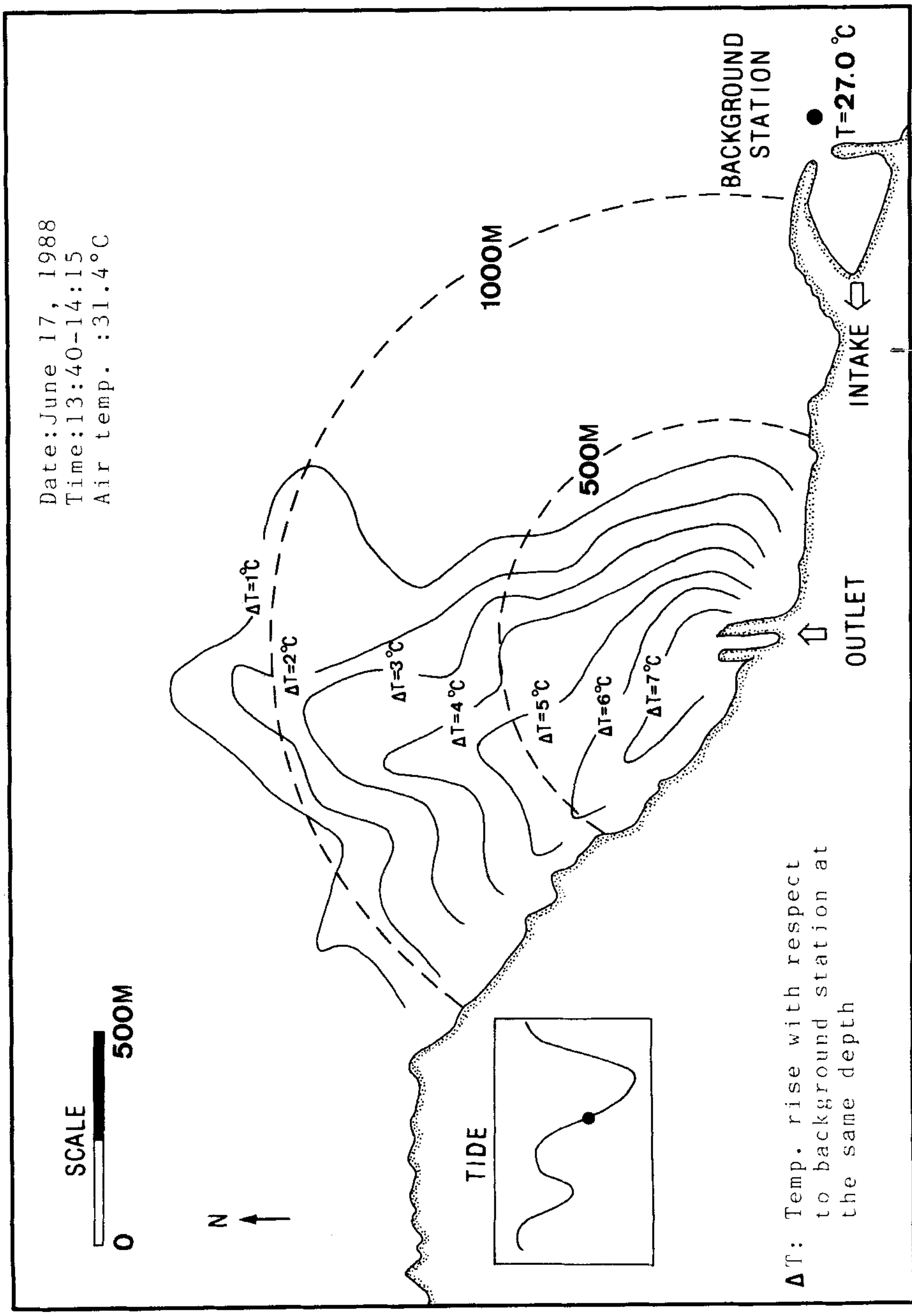

Figure 3 Surface water temperature increments near the outlet of the first nuclear power plant in the afternoon of June 17, 1988.

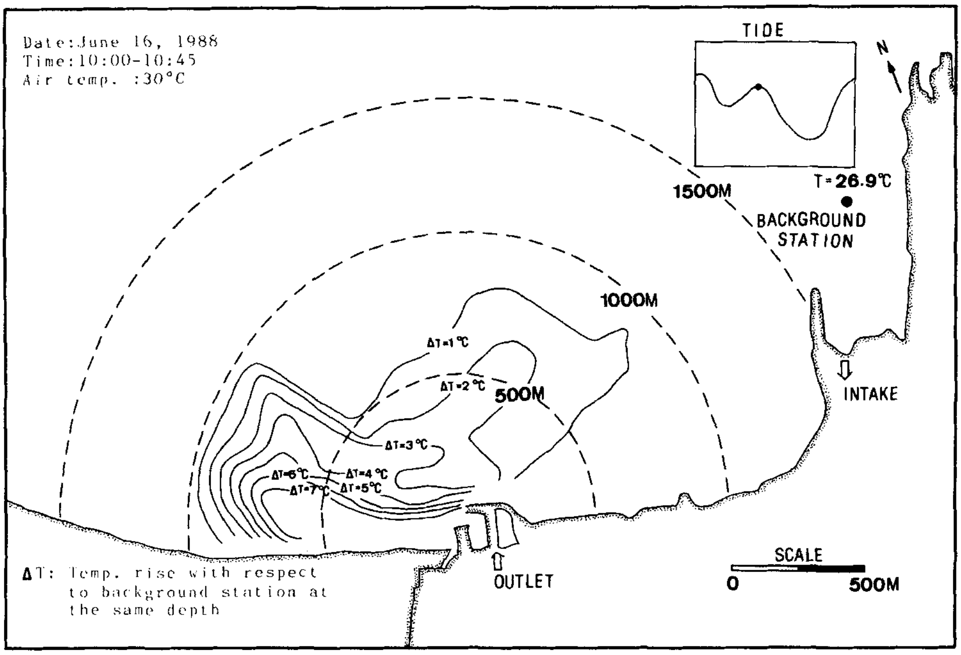

Figure 4 Surface water temperature increments near the outlet of the second nuclear power plant in the morning of June 16, 1988.

(Su *et al.*, 1980). For this reason TAIPOWER located the intake to the northeast of the outlet (Figure 5). TAIPOWER also constructed a 120 m offshore surface discharge to avoid recirculation.

The second unit of the third nuclear power plant began operating in May 1985. Unfortunately, the first unit caught fire in July 1985 and stopped operation until January 1987. Two units operated simultaneously again since January 1987. In early July 1987, almost all the coral living in a water depth less than 3 m in Little Bay was bleached. Figure 5 shows the temperature increment near the outlet of the third nuclear power plant on July 3, 1987. The data, again supplied by the radioactive laboratory, TAIPOWER, were collected from 8:10 to 8:30, during the flood tide. The surface water temperature at a background station near the intake is 27.9°C, the area of temperature increment > 4°C extends from the outlet to 300–400 m offshore in the southern and western directions. In this case, the surface water temperature in Little Bay, on the western side of the outlet, exceeds 31.9 °C. In some areas, the temperature exceeds 34°C. The thermal discharge water, for the most part, lies in the surface 3 m layer and will damage or kill corals in shallow waters near the shoreline. This first serious incident was found in early July 1987 occurred during the first summer when both nuclear reactors of the third nuclear power plant were operating simultaneously (Fan, 1988).

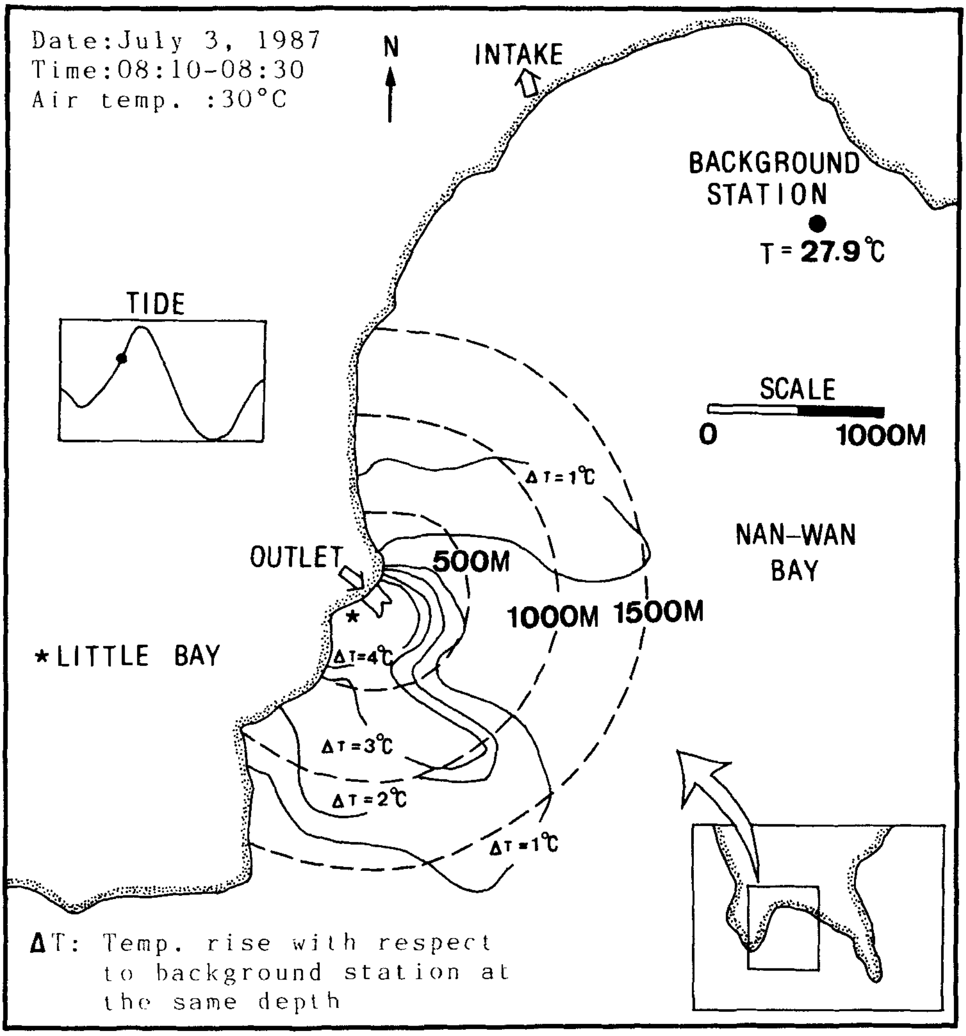

Figure 5 Surface water temperature increments near the outlet of the third nuclear power plant in the morning of July 3, 1987 (Fan, 1988).

DISCUSSION

Su *et al.* (1988) summarized and discussed the data collected from July 1979 to June 1988 for a preliminary assessment of ecological and environmental impact of the two units of the third nuclear power plant on the coastal environment of Nan-wan Bay. The data indicate that the bleaching of corals in July 1987 due to the thermal discharges was found only in the surface water layer of 0–5 m depth of a shallow bay near the cooling-water outlet. The percentage of bleached coral colonies was 90–100% at the depth of 0–3 m and 50–70% at the depth of 3–5 m. The area of bleaching extended to about 12,000 m^2 (20 × 600 m) in the Little Bay.

In the summer of 1988, the thermal plume from the third nuclear power plant damaged corals in a more extended area. The area of bleaching not only covered the Little Bay, but also extended from the Little Bay to Mao-Pi-Tou covering an area of about 45,000 m^2 (30 × 1.500 m) (Figure 6). The growth rate of corals in thirteen marked colonies in the shallow bay decreased gradually during the period July 1987 to October 1988. In May 1989, TAIPOWER installed more pumps to increase cooling water by 10% in volume. Since then, most of the bleached corals began to recover, and none of these marked colonies showed a decrease in growth rate during the period from October 1988 to September 1990 (Huang *et al.*, 1991).

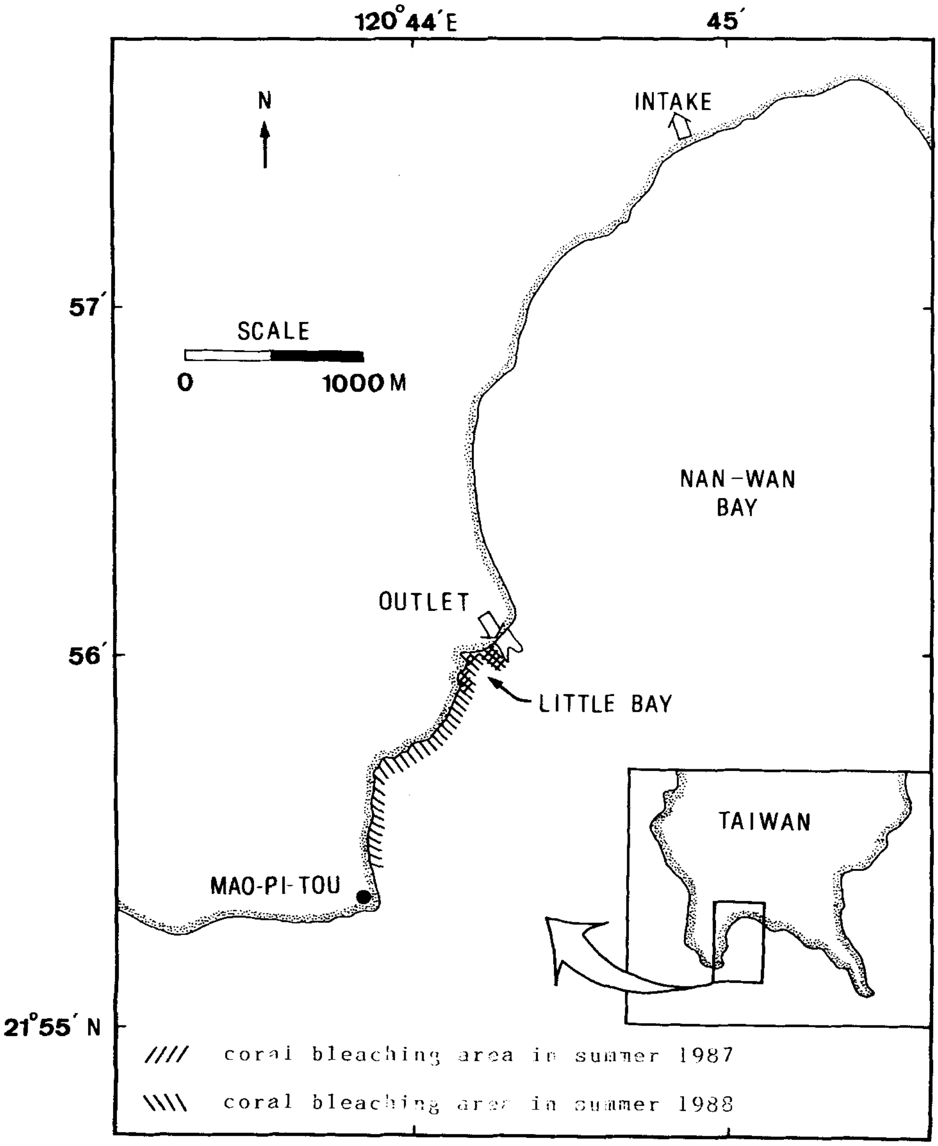

Figure 6 The coral bleaching area in Nan-wan Bay in the summer of 1987 and 1988 (Huang *et al.*, 1991).

There are two power stations located on open coastlines in tropical or subtropical areas, Tanguisson Point, Guam (Jones and Randall, 1973; Neudecker, 1976) and Kahe Point, Oahu, Hawaii (Jokiel and Coles, 1974; Coles, 1975, 1977) for which similar conditions are reported. Both stations discharged (up to 1973) through shoreline outfalls at about $\Delta T \sim 6.0°C$ resulting in coral mortality and damage over 1–2 hectares. Approximately the same areal damage occurred for 26 MW generation capacity at Tanguisson as at Kahe for 500 MW, because wave action at the former site carried the thermal plume along the reef front. These studies indicate that siting on an open coastline with ready access to open ocean water will not necessarily prevent damage, if depths in the path of the plume are insufficient to prevent the plume impacting on the bottom in shallow depths.

Extensive bleaching of corals caused by the stress of high temperature and high light levels was also observed on the Great Barrier Reef (Oliver, 1985). Extensive coral bleaching also occurred in the Java Sea during sea water warming caused by the El Niño Southern Oscillation (Brown and Suharsono, 1990). A sublethal coral bleaching response to seasonal variations in sea water temperature was also observed in Jamaica (Gates, 1990). Jokiel and Coles (1974) found that the lethal temperature was 32°C for the Hawaiian corals. For the Nan-wan Bay corals, laboratory experiments revealed that the upper temperature limits of 14 coral species were estimated at 31–32 °C. When the corals are exposed to a thermal stress of > 33°C, they die within a few days (Yang *et al.*, 1980). The bottom water temperature in the shallow bay was frequently in the range of 31 to 32 °C in the summers of 1987 and 1988. This result confirmed that the upper lethal temperature for Nan-wan Bay corals was 32 °C similar to that for Hawaiian and Okinawan corals (Huang *et al.*, 1991).

CONCLUSIONS

In the tropical coastal environment, thermal discharges from power plants can damage coral communities in 0–5 m depth where temperature exceeds 32 °C and the temperature increment in the discharge is > 6 °C. Surface currents may limit the dispersion of cooling water discharges in some tidal conditions and seasons.

So far there have been no records of direct kills of fish by thermal pollution in Taiwan waters. Some people even propose to use heated water discharged from nuclear power plants for mariculture of milk fish, which may be killed in cold weather in the winter. Until now, these proposals have not been taken up since people still worry about the effects of the residual chlorine in the discharge water on fish.

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