in "Resources and Environment in Asia's Marine Sector", ed. .J.B. Marsh,
Taylor and Francis New York, 361-380pp, 1992

Chapter 17

Trace Metals, Radionuclides, and Thermal Diffusion in Taiwan's Coastal Waters

Chen-Tung Chen, Kun-Hsiung Chang, Lee-Shing Fang, Yung-Chi Chen, Tsu-Chang Hung, Ho-Shong Hou, and James Barney Marsh

---

Abstract *This chapter resulted from the integration of three studies of marine pollution in the coastal waters surround Taiwan. Although the papers are scientific in nature, their relevance for this volume lies in their economic implications. Economic development, which is of the greatest importance for the continued support of human welfare, also utilizes the environment as an input for the disposal of wastes. This chapter documents the extent to which certain kinds of disposed residues may be found in Taiwan's offshore area. Because the demand for a clean and safe environment increases with income, it can be expected that there will be popular support for efforts to monitor and control these and other residues. Solutions also involve significant trade-offs, which will require tact and bargaining.*

INTRODUCTION

In economic development, the economy experiences an increase in the quantities of both inputs and outputs. The quantity and quality of labor and capital rise, causing an increase in the quantity and quality of goods and services produced. Productivity growth allows for a more than proportionate increase in outputs, although the usage or employment of inputs must also grow.

One such input is the environment itself. The actual services performed by the environment, which are productive in economic pursuits, are documented throughout this book. One unfortunate service, which is absolutely necessary, is in storing and breaking down our wastes. However careful we may be, the environment ultimately gets our wastes. If they are treated and well packaged before we dump them, the environment has less to do—less, but never nothing to do.

Unfortunately, the environment cannot grow along with the other inputs so as to absorb a continuously increasing flow of waste. For this reason, the impact of the flow must be continuously monitored, using the relevant scientific methods. We must also continuously develop better means of packaging and treating our waste so as to reduce the impact.

In spite of this general opening, the present chapter is rather technical. It pools the expertise of both economics and several specializations in the physical oceanographic sciences, from both the Republic of China on Taiwan and the United States. The objective is to present actual data on how Taiwan is doing in its offshore area and to discuss the potential costs of environmental deterioration.

The chapter is divided into four main parts. The first discusses the extent to which Taiwan has grown dependent on a clean ocean environment. This is followed by three case studies of pollution in particular offshore areas. A summary and the conclusions are reserved for the final section.

ECONOMIC GROWTH AND THE ENVIRONMENT

Taiwan's success with economic growth is well known. In real terms, the average annual percentage growth rate in GNP from 1952 to 1986 was 8.6% (CEPD, 24). This resulted in a 17.5-fold increase in real income during this period (CEPD, 26). In the meantime, real per capita GNP rose by a factor of 7.5 with an average annual rate of 6.1% (CEPD, 29, 30). The growth curve of real GNP is depicted by Figure 17.1.

Taiwan is also known to be a major fishing nation. The fisheries, highly dependent on a clean ocean environment, have been the top growth area in the primary sectors. As agriculture barely doubled its output between 1952 and 1986, fisheries' output rose by a factor of more than 10 (CEPD, 67). Furthermore, in the decade from 1953 to 1962, as agriculture grew at 3.7% annually, the fisheries grew at 8.6%. In the following decade, as agricultural growth slowed to 2.8%, fisheries' growth accelerated to 9.5%. Finally, after 1973, agriculture declined slightly at 0.1% per year, while the fisheries continued a robust rate of 4.6% (CEPD, 68).

A breakdown of the fisheries' sector also reveals continued growth. Catch in the deepsea fisheries, represented by Figure 17.2*a*, grew by a factor of 26.9 in the 35 years from 1952 to 1986. The curve depicting the inshore fisheries' catch (Figure 17.2*b*) shows an increase that is 9.3-fold. The cultured or aquaculture output, shown in Figure 17.2*d*, rose by a factor of 9. Only the coastal fisheries stagnated, with a total increase of only 24% in that period (CEPD, 79). However, as Figure 17.2*c* shows, even this subsector has been recovering in the last decade. Hence, as Taiwan's dependence on the land decreased, dependence on the ocean for her food has increased.

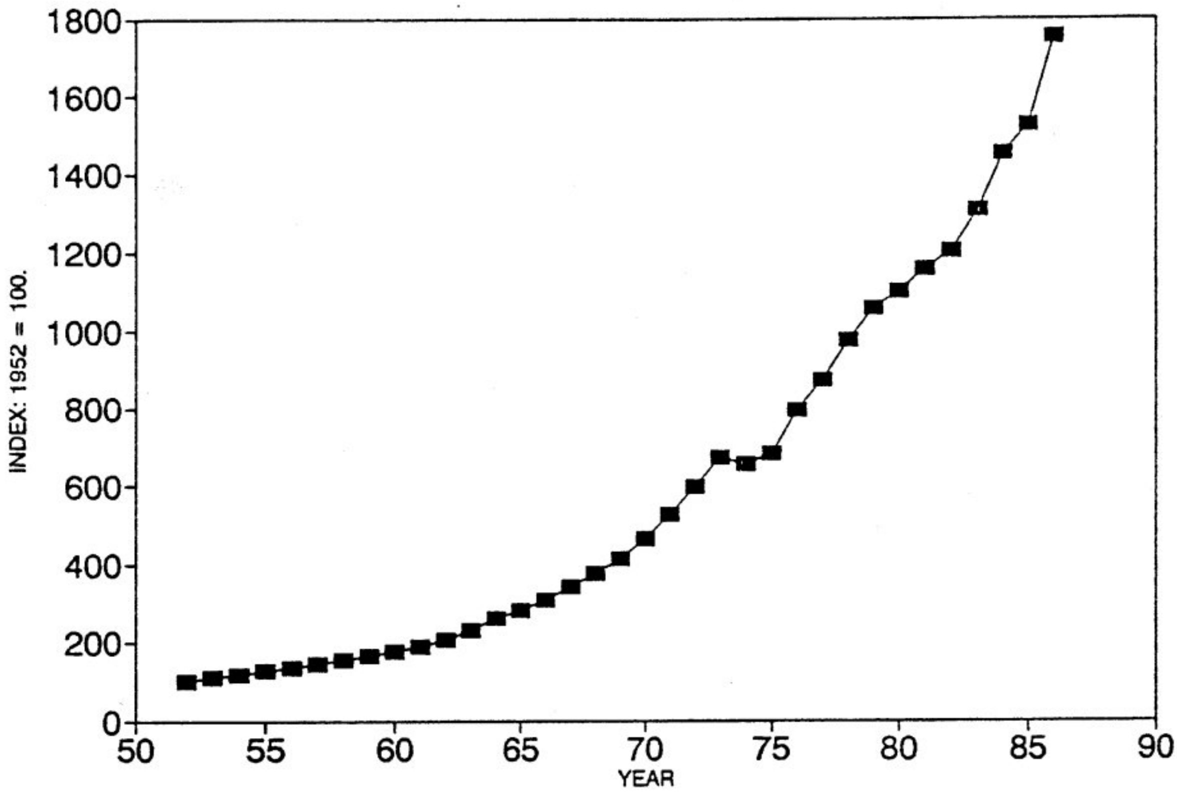
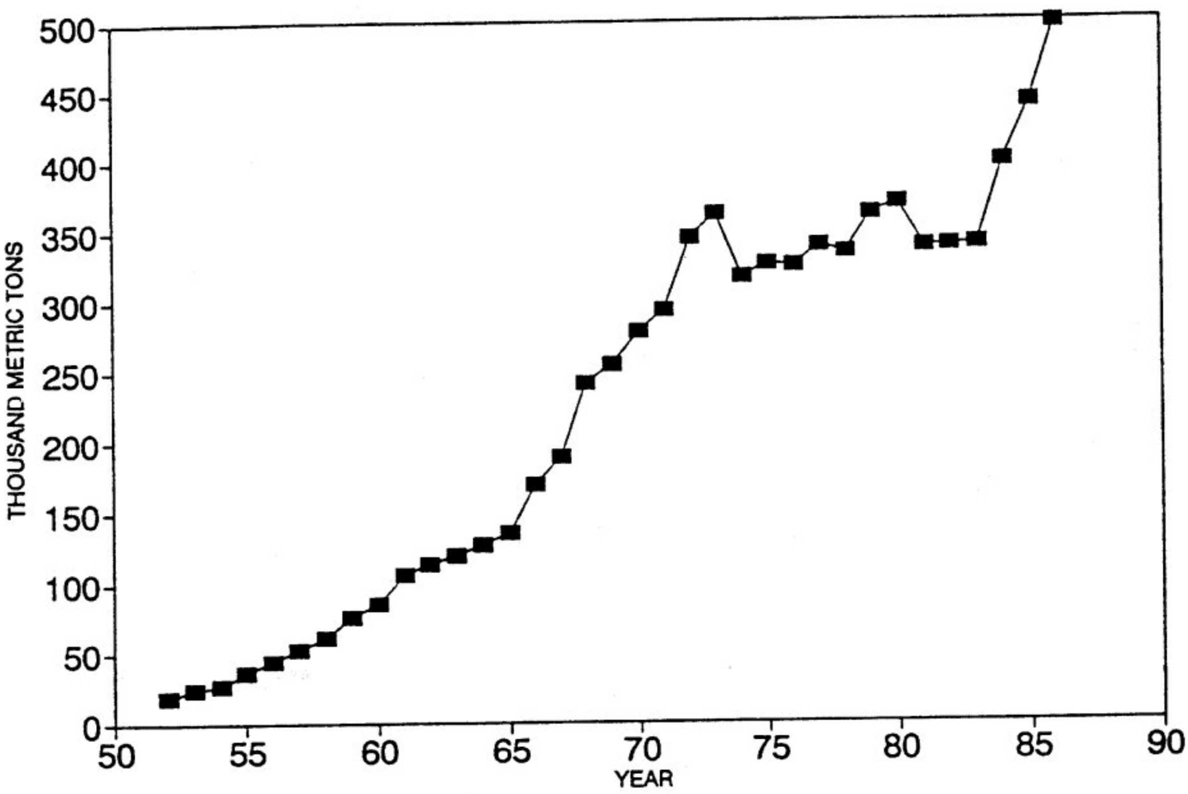


Figure 17.1 Taiwan's real GDP.

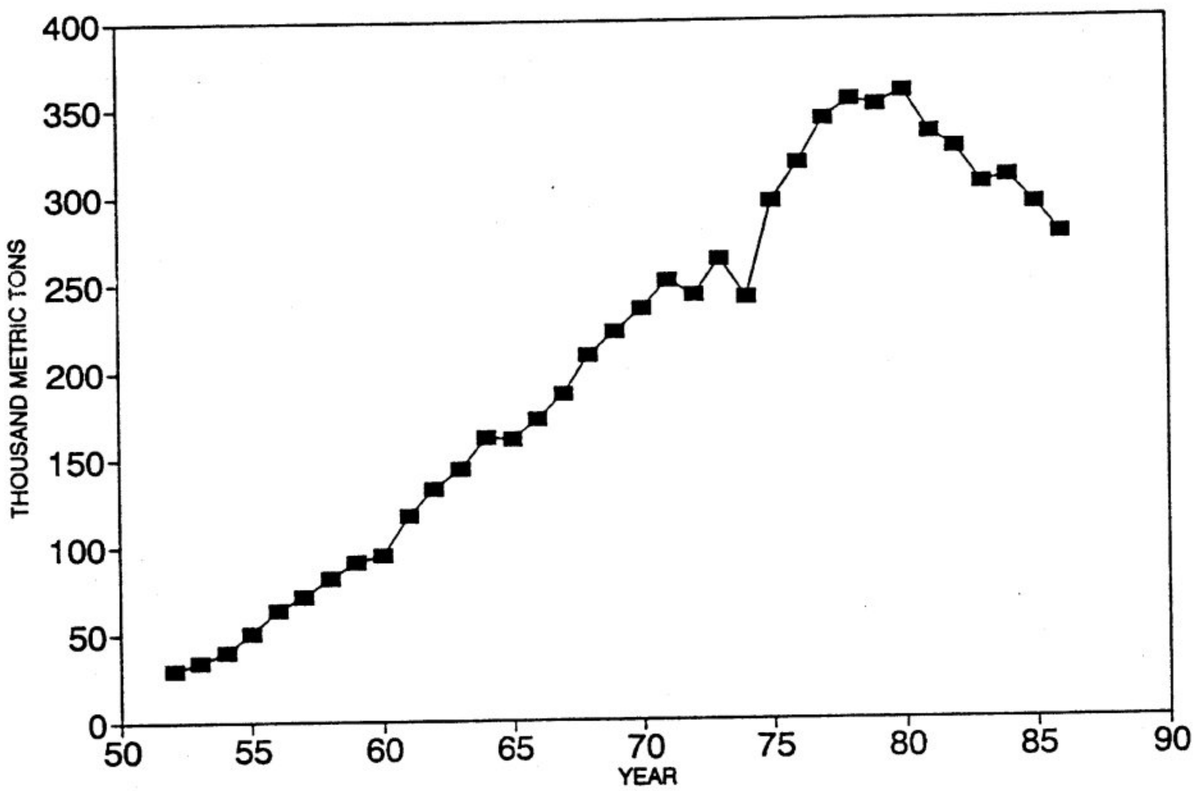
Furthermore, family income became increasingly dependent on the fisheries and the ocean. The number of fishing boats, many of which represent small businesses and families, rose from 554 in 1952 to 9922 in 1986, a 17.9-fold increase (CEPD, 133). Gross tonnage rose by a factor of 44.7, indicating a more than doubling of average boat size. These time series are depicted by Figures 17.3*a* and 17.3*b*. All of these data indicate a rapid growth rate in the number of working people who are engaged in the fisheries. By extension, it also indicates a growing dependence on a clean ocean environment.

Another important ocean industry, one which is less directly dependent on a clean environment, is shipping. In Taiwan's two major ports, Kaohsiung and Keelung, shipping volume rose by a factor of 94.1 and 40.7, respectively. These data are shown in Figures 17.4*a* and 17.4*b*. Clearly, these important ocean industries have grown up alongside Taiwan's GNP. Their contributions to GNP growth, although not measured here, are significant. That one of their important factor inputs (without which output would be difficult or impossible) is a clean ocean determines the importance of careful water-quality monitoring and surveillance.

Finally, as discussed in greater detail below, Taiwan, like other countries, has grown very dependent on the ocean for water that is cool enough to keep its power plants from overheating. But in so doing, the cool sea water becomes hot and a pollutant of a different sort. In an ironic twist, the case study below is of a

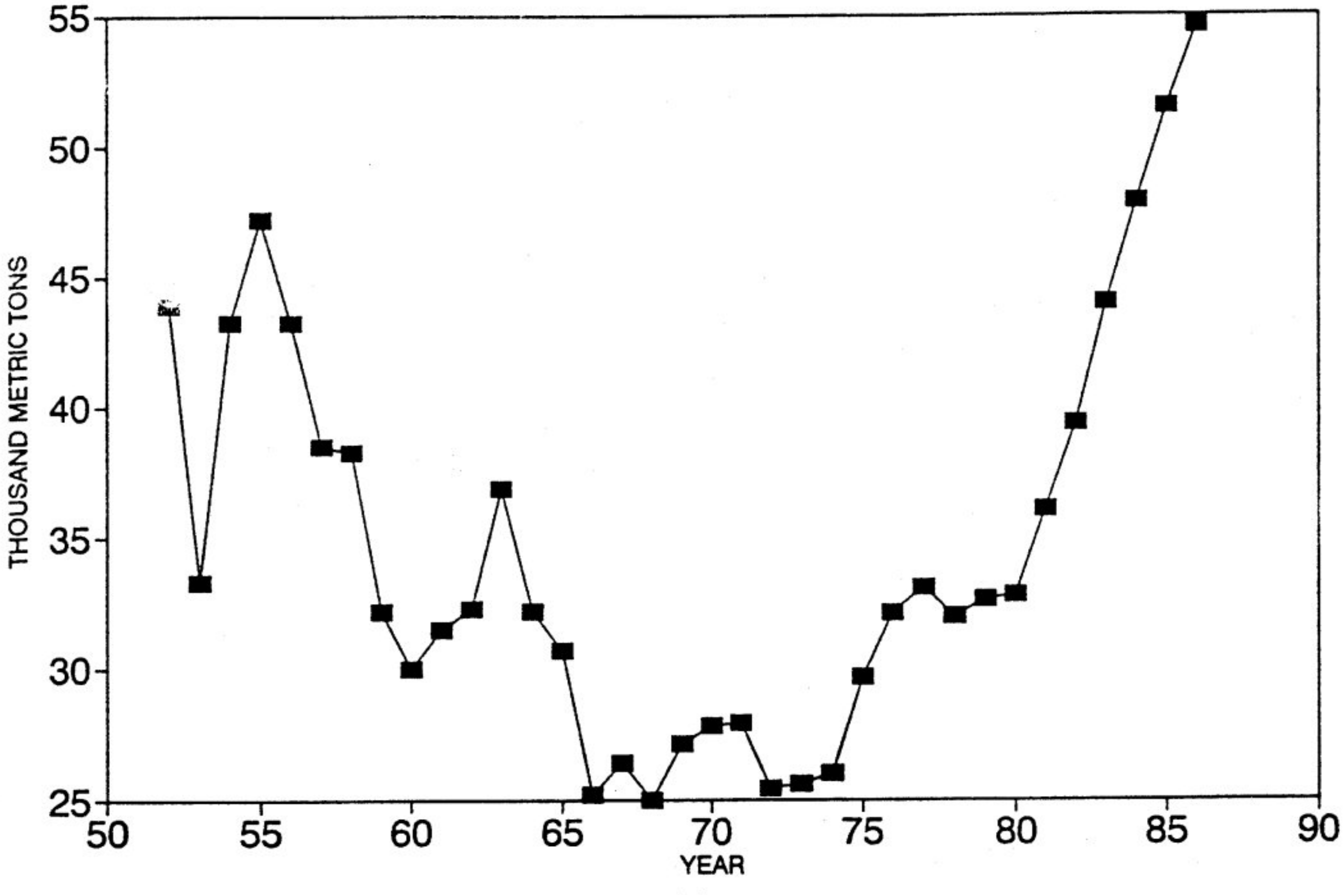


(a)

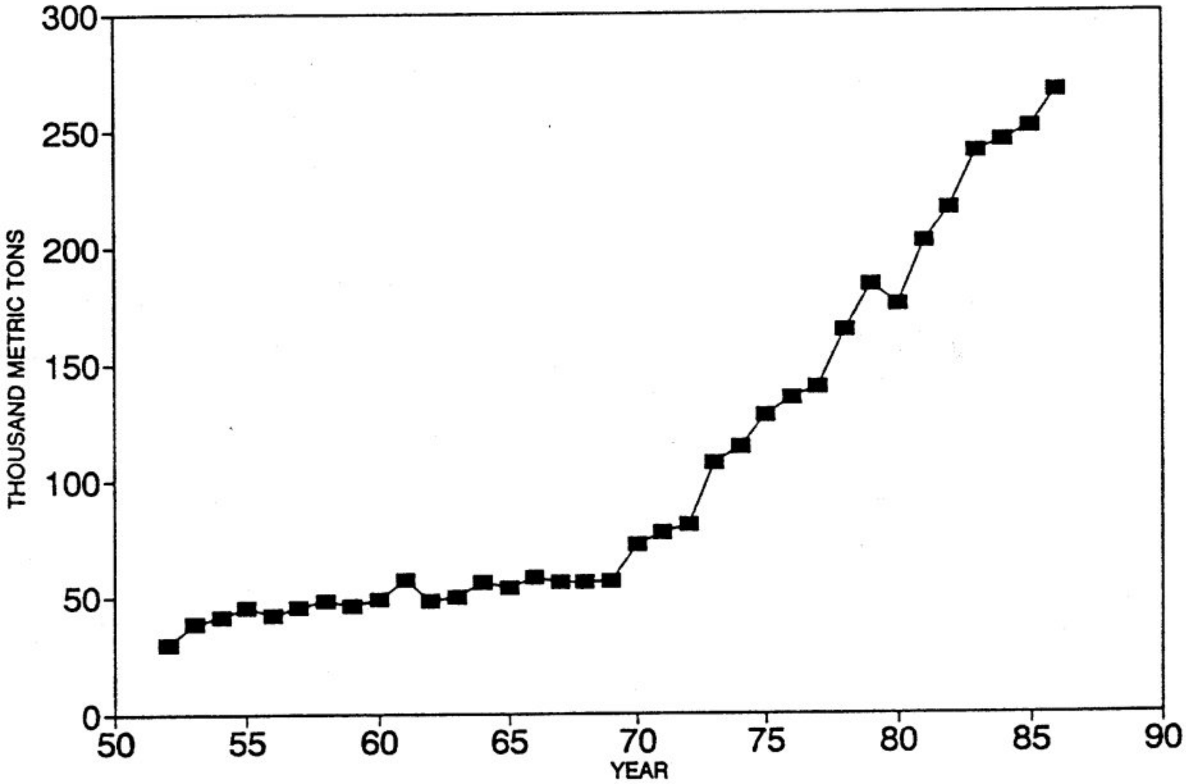


(b)

Figure 17.2 (*a*) Deepsea fisheries' catch. (*b*) Inshore fisheries' catch.

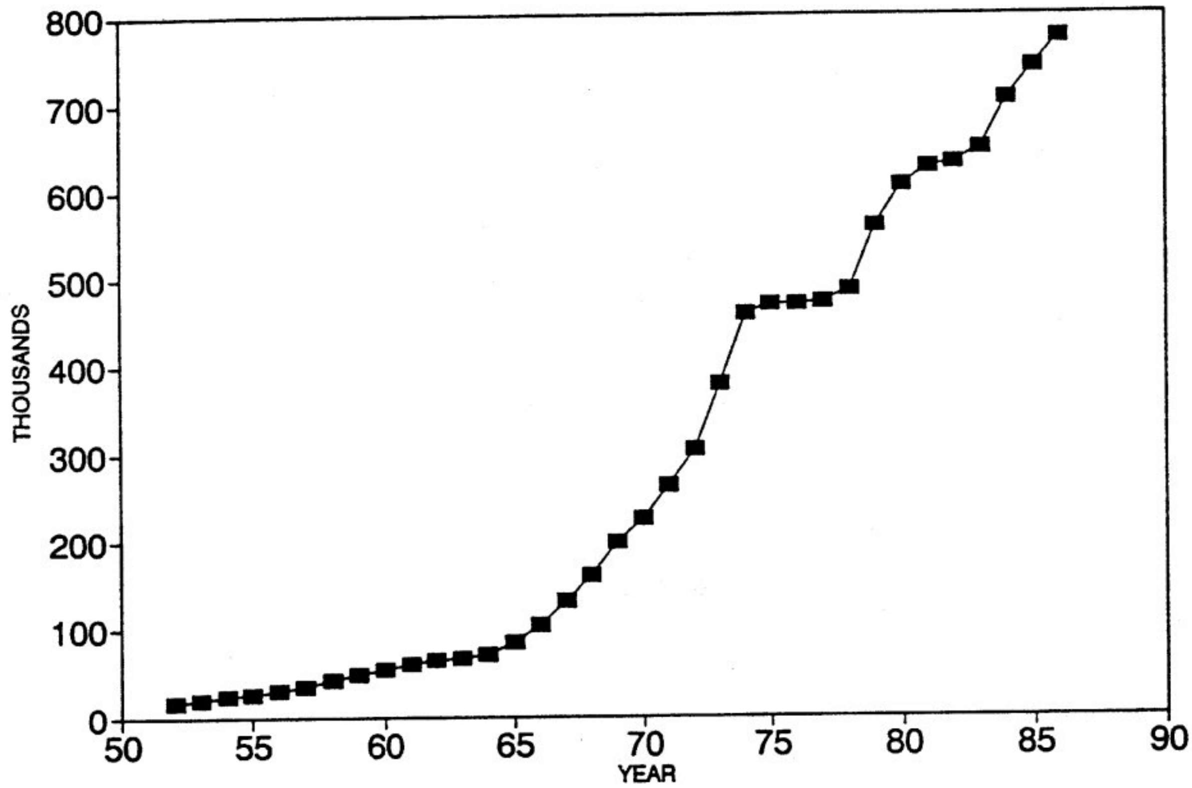


(c)

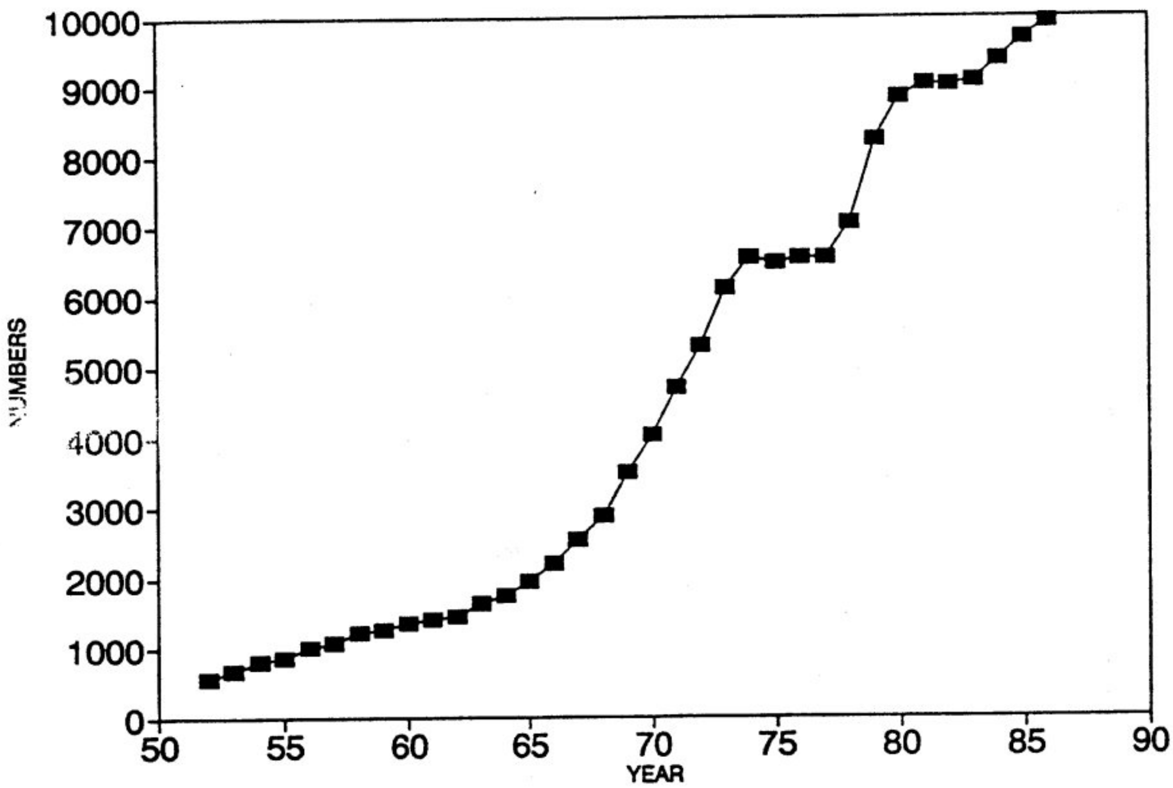


(d)

Figure 17.2 (*Continued*) (*c*) Coastal fisheries' catch. (*d*) Cultured fish production.

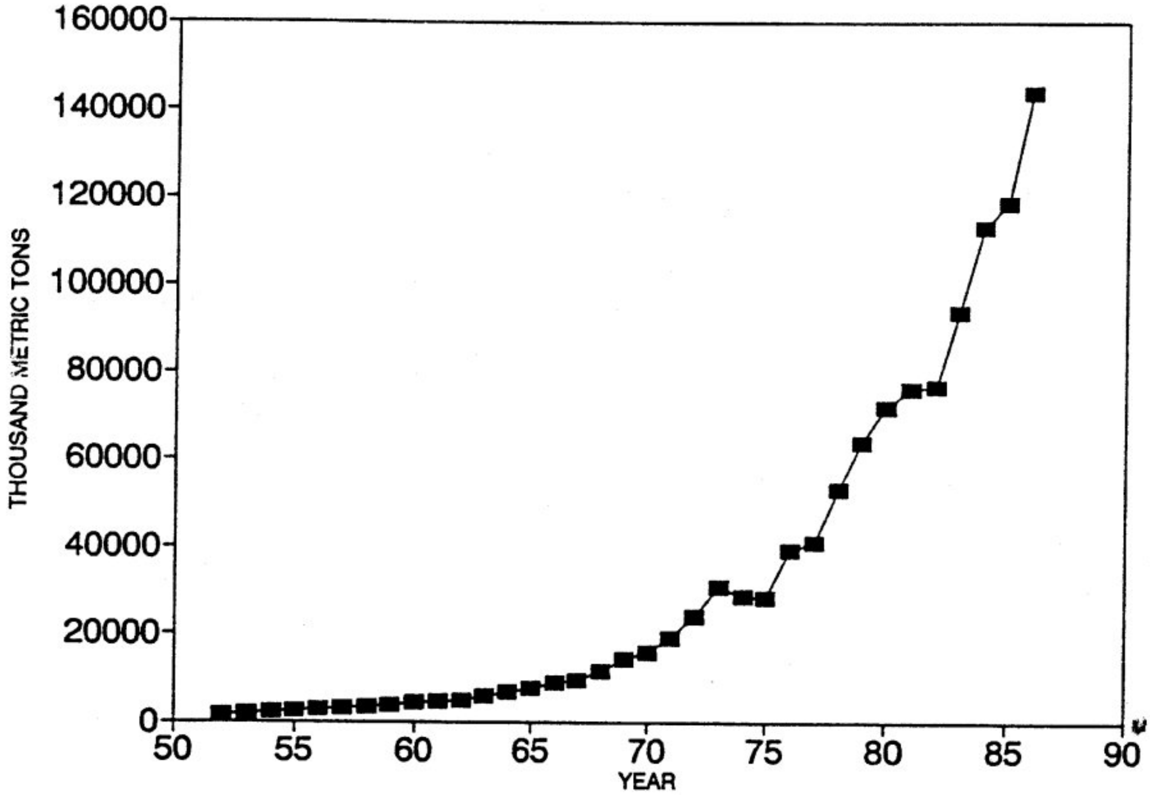


(a)

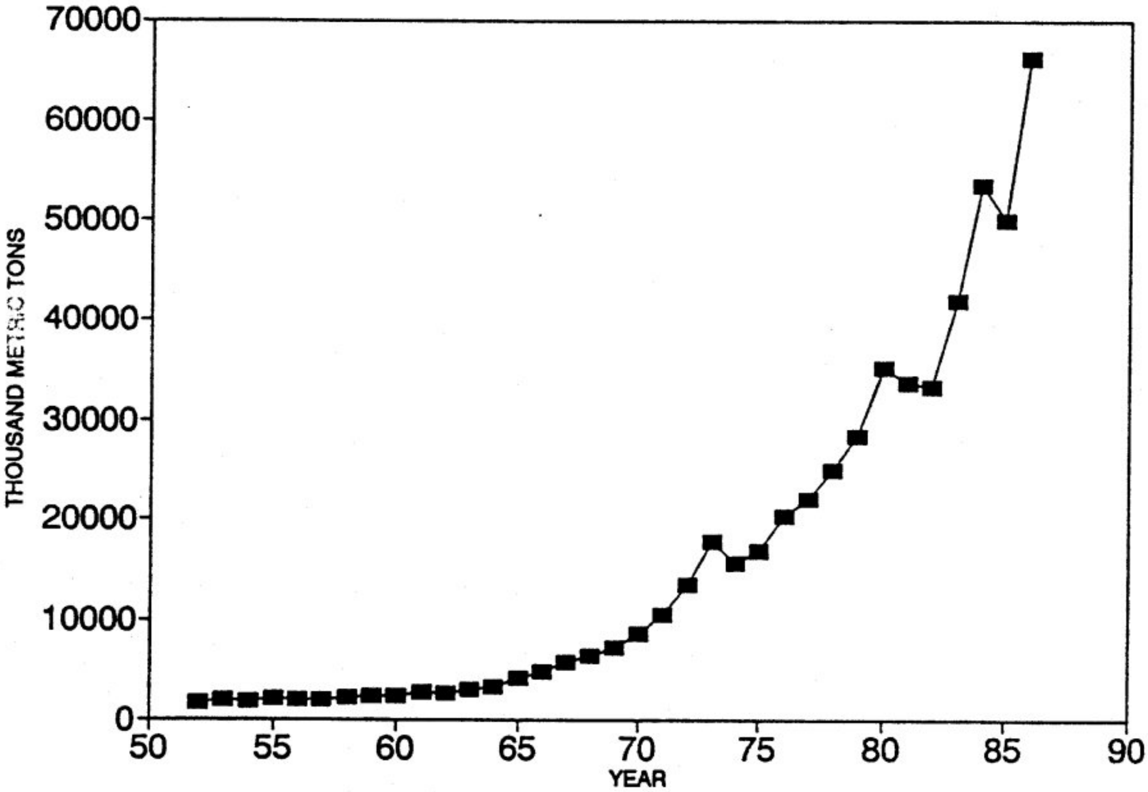


(b)

Figure 17.3 (*a*) Fishing vessel tonnage. (*b*) Fishing vessel count.



(*a*)



(*b*)

Figure 17.4 (*a*) Kaohsiung harbor cargo volume. (*b*) Keelung harbor cargo volume.

power plant that suffered from its own thermal pollution. The situation is rarely that direct, nor is it usually so easily solved.

TRACE METALS AND RADIONUCLIDES IN BANDED CORALS

The order *Scleractinia,* more commonly known as corals, is a group in the subclass *Zoantharia.* That portion of the coral that secretes the calcium carbonate skeleton is within the ectoderm of the coral polyp. Bands of varying density form within the carbonate skeleton of reef-building corals. These band pairs have been described and confirmed to be annual (Knutson et al. 1972, Patzold 1984, C. H. Wang pers. com., 1986, and others).

The annual timing of the narrow high-density band and a wide low-density band has provided a valuable tool for determining rates of growth and calcification (Buddemeir 1974; Highsmith 1979) and assists demographic analyses of coral populations (Dodge and Vaisnys 1977). Banding has also been used an environmental indicator in both contemporary and paleo-communities. For example, patterns of annual banding have been used to assess the impact of long-term changes or perturbations involving sedimentation, temperature, and nutrients. Several investigators have also attempted, with varying degrees of success, to use banded coral skeletons to document the chronology of coastal pollution. With this objective in mind, in this section, we survey our analyses of trace metals and radioisotopes in corals collected in southern Taiwan.

Materials and Methods

Coral samples were collected from five sites, all between 10 and 15 m deep: outside the cooling water outlet of the Third Nuclear Power Plant; Wan-Li-Tong; the port of Hsiao-Liu-Chiu Island; Wu-Quai-Dong on Hsiao-Liu-Chiu Island; and the port of the Low Level Radwaste Storage Site on Lan-Yu Island. Unbanded *Acropora wardi* and *Acropora mutiacuta* were collected on Lan-Yu Island. Banded porites and favia were collected at other sites. Hsiao-Liu-Chiu Island is near the heavily polluted Kaohsiung-Tainan area. The other sites are pristine. The locations are shown on the map, Figure 17.5.

The collected coral skeletons were chemically treated and cleaned, sliced with a diamond-headed rock saw, X-rayed, and ultrasonically cleaned in distilled water. The samples were then ground in an agate mortar, dissolved in acid, and, finally, analyzed for trace metals and radio-isotopes.

The data are probably unreliable below 0.13 ppm for zinc (Zn), 0.3 ppb for cadmium (Cd), 1 ppb for copper (Cu), 12 ppb for nickel (Ni), 11 ppb for cobalt (Co) and 40 ppb for lead (Pb), due to problems concerning the blank and interference corrections. For further details, see C. T. Chen et al. (1988). A Ge(Li) detector and a multichannel analyzer were used to make α-spectrum and

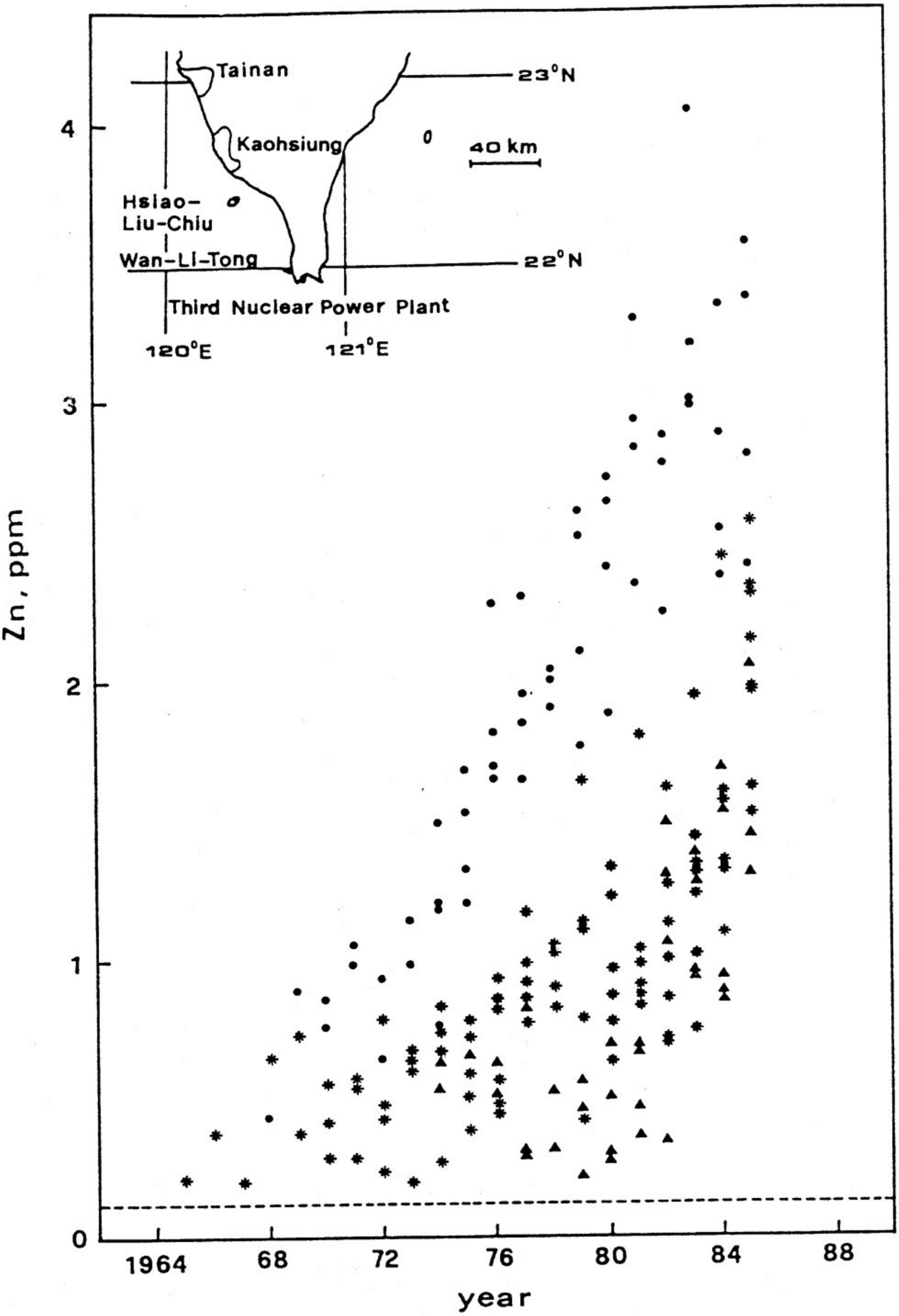


Figure 17.5 Annual variation of Zn concentration in corals collected at Hsiao-Liu-Chiu (•), Wan-Li-Tong (*), and the Third Nuclear Power Plant (▲). Values below 0.13 ppm are probably unreliable. Sampling sites are shown in the insert.

to measure α-emitting isotopes. Each sample was counted for 80,000 s. Sr-90 was measured after extraction with HCl and conversion to Y-90. In addition, low-level Cs-137 was also measured by β-counting after extraction with HCl.

Results

The results are shown in Figure 17.5. Porites and Favia show clear density bands (Figure 17.6). Each band was analyzed for trace metals. Cadmium is below our detection limit for all samples. Lead is at or below the detection limit. Copper concentrations are below 0.25 ppm, nickel is below 0.2 ppm, and cobalt is below 10 ppb. Most metals do not show clear year-to-year variations.

Figure 17.6 The X-ray picture shows the density bands in a coral sample (*Porites lobata*).

Zinc, however, shows a clear trend, as can be seen in Figure 17.5, especially for samples collected on Hsiao-Liu-Chiu Island. There was a rather steady increase since 1965. We suspect the heavy industrial pollution in the Tainan/Kaohsiung area contributed to the zinc pollution in waters around Hsiao-Liu-Chiu Island.

Although the Black Stream (the *Kuroshio)* primarily flows northward, the coastal current and eddies frequently move water southward. Semi-diurnal tidal currents in the Taiwan Strait move water northward during flood tide but southward during ebb tide. These currents may have carried the polluted water as far south as the Third Nuclear Power Plant, where the degree of contamination was lower because of the longer distance involved. Airborne particles from coal-burning power plants and heavy industry and construction of the nuclear power plant may also have partially contributed to the increased zinc concentration in the local corals.

The unbanded corals collected at Lan-Yu Island were about three years old. Whole sample analyses indicate that the trace metal concentrations were slightly lower than what was found at the Third Nuclear Power Plant.

The only man-made radio-nuclides that we were able to detect in any of our samples were strontium-90 (Sr-90) and cesium-137 (Cs-137). The activities were all lower than 60 and 8 pCi/kg, respectively. Cs-137 shows much scatter. Sr-90 data also show some scatter, but the worldwide decreasing trend seems to continue. No clear trend exists for natural radio-nuclides, potassium-40 (K-40), thallium-208 (Tl-208), and bismuth-214 (Bi-214).

Discussion

Traditionally, scientists have compared recent data with data collected in early years in order to illustrate a secular change in pollutant concentrations. There are, however, few early data available for comparison. The available data are sometimes also inaccurate. As a result, the secular trend thus obtained is often unreliable. Sediments have also been used to obtain the secular change of pollutant concentrations by analyzing these concentrations at various depths and by dating each layer. Sediments, however, are often reworked by physical turbulence and by bioturbation. Consequently, the signal is often blurred. Banded corals may provide an alternative in recording pollutant concentrations from the past.

Literature on trace metals in whole corals is widely scattered and the results vary. Perhaps the most comprehensive studies were those of Livingston and Thompson (1971) and St. John (1974). Livingston and Thompson's results for coastal coral are generally higher than ours by an order of magnitude. Those of St. John are also generally slightly higher than ours, except for Zn where the agreement is good. Samples of St. John were collected in the open ocean and may reflect a cleaner environment . Recently, K. K. Chen (1985) also measured

Zn in whole corals in Taiwan. His values are generally higher than ours by a factor of 2. Such agreement should be considered as good in view of the wide scatter of the data.

To our knowledge, the only attempts to detect trace metal chronology from banded corals are those of Dodge and Gilbert (1984) and Gallo (unpublished, 1985), Shen and Boyle (1987, 1988) and Shen et al. (1987). Dodge and Gilbert, Shen and Boyle, and Shen et al. demonstrated a significant increase in Cd and Pb concentration towards the present based on corals collected from the North Atlantic, Pacific, and Indian oceans. We do not have quality Cd and Pb data to compare with theirs. Gallo claimed to have detected Zn and Cu increases in corals collected off Fort Lauderdale, Florida. The claim, however, was based on widely scattered data (Figure 17.7) and may be subject to debate. Our Cu data also show much scatter, but the Zn data show a steady increase in concentration since 1965 (Figure 17.6). Shen and Boyle (1988) measured Ba, Cd, Mn, and V in a banded coral collected at Bermuda. They did not expect these metals to change concentration over time and did not detect any change. They did, however, expect Zn concentration to increase but did not detect the increase.

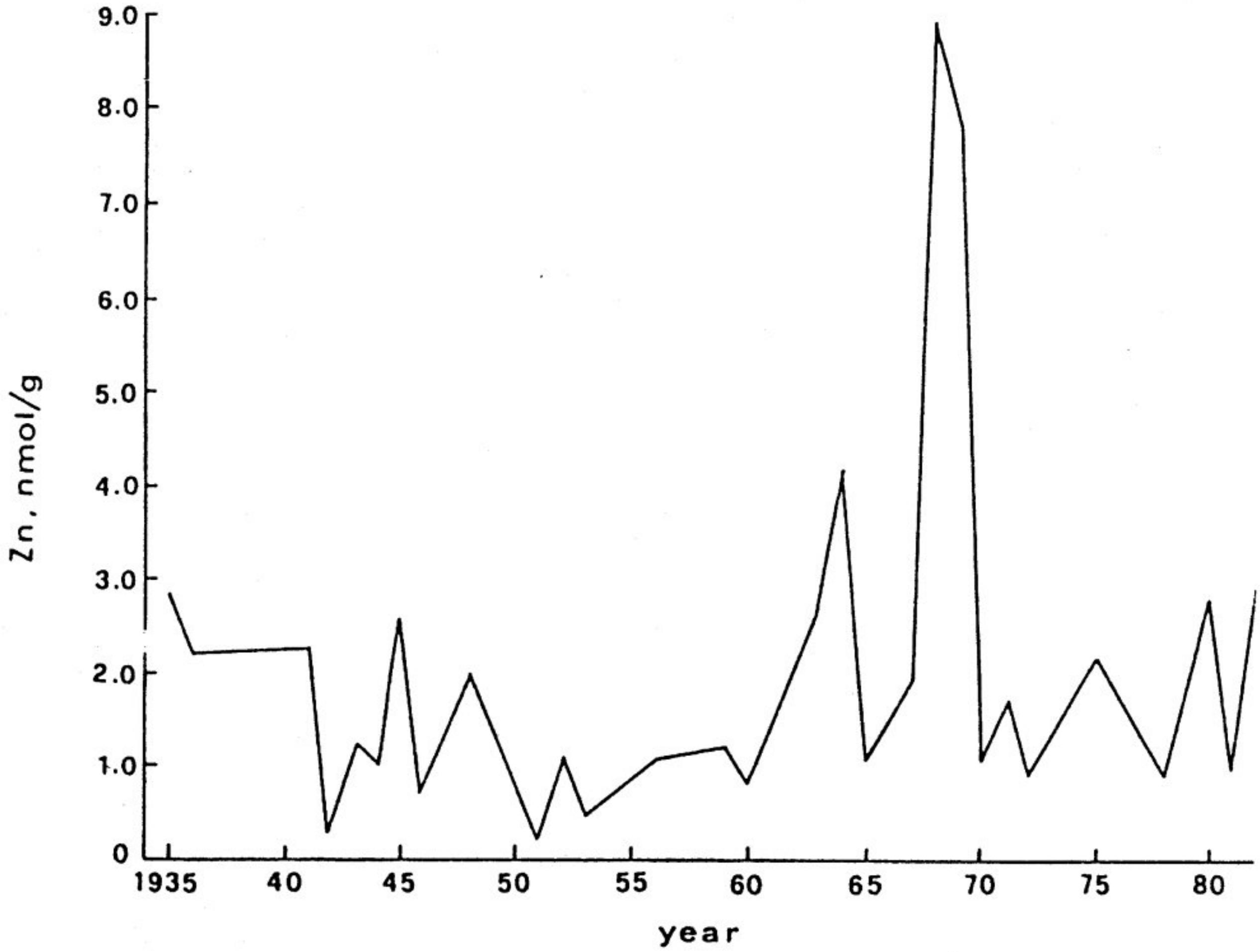


Figure 17.7 Annual variations of Zn concentration in corals collected in Fort Lauderdale, Florida. *Source:* Gallo (1985).

Zinc is one of the most commonly used metals in the industrial world, and the observed increase no doubt reflects the recent industrial activities in Taiwan. Such activities include scrapping of ships, acid cleaning of imported scrapped metal, burning of waste cable, combustion of lubricating oil, emissions from rubber tire wear and smelters, and dumping of slags in heavily polluted coastal waters in the Tainan/Kaohsiung area (Bureau of Environmental Protection of Taiwan 1986; Wang 1987).

The latest Zn concentration in corals collected in Hsiao-Liu-Chiu is approximately 2.9 ± 0.5 ppm. Taking an aragonite/seawater partition coefficient of 5.5, we estimated a local seawater Zn concentration of 0.6 ppb. The estimated local seawater concentration two decades ago was about 0.04 ppb. These values are much higher than the open-ocean surface water Zn concentration of 0.004 ppb, but lower than the polluted coastal waters of Tainan/Kaohsiung area, where levels measure as high as 40 ppb. Such discrepancies may indicate that much of the zinc we measured is not lattice-bound. Accumulation of non-skeletal zinc cannot be ruled out. The rather low Zn levels for samples collected at the Third Nuclear Power Station indicates that the total contamination is probably not severe. It should also be kept in mind, however, sampling and analysis of zinc at low concentrations (ppb level) are prone to contamination.

Differences in coral morphology and, hence, Zn uptake capacities further complicate the intercomparison of sites. Porites are characterized by very fine-grained morphologies phases and are more susceptible to accumulation of non-skeletal metal phases. As a result, direct comparison of the porites records at the Hsiao-Liu-Chiu Island with the Favia records at the Third Nuclear Power Plant may be less meaningful. Porites at the Hsiao-Liu-Chiu Island, however, do have a higher degree of contamination than the porites at the Third Nuclear Power Plant. The secular trends are also clear at both sites.

Sr-90 is a fission product of the atmospheric bomb tests conducted during the late 1950s and early 1960s. It has a half life of 28 years and has no natural sources. Toggweiler and Trunbore's (1985) data and our results at the Third Nuclear Power Plant are plotted in Figure 17.8. These data mainly reflect the atmospheric fallout with a peak between 1958 and 1962. The values have been falling since the atmospheric test ban. Our measured values for samples collected at Lan-Yu Island, Wan-Li-Tong, and the Third Nuclear Power Plant are all lower than those measured by Toggweiler.

The first reactor of the Third Nuclear Power Plant was fueled in February 1984 and was in commercial operation in July of the same year. The second reactor was fueled in December 1984 and was in commercial operation in May 1985. The Sr-90 activity recorded in the corals collected at the outflow of the cooling water does not seem to be effected by the power plant. Since other artificial nuclides commonly discharged by a nuclear power plant, such as manganese-54 (Mn-54), cobalt-60 (Co-60), zinc-65 (Zn-65), antimony-125 (Sb-125) and iodine-131 (I-131) are undetectable in our samples, we believe that the Sr-90 comes mainly from the atmospheric fallout and the level is decreasing.

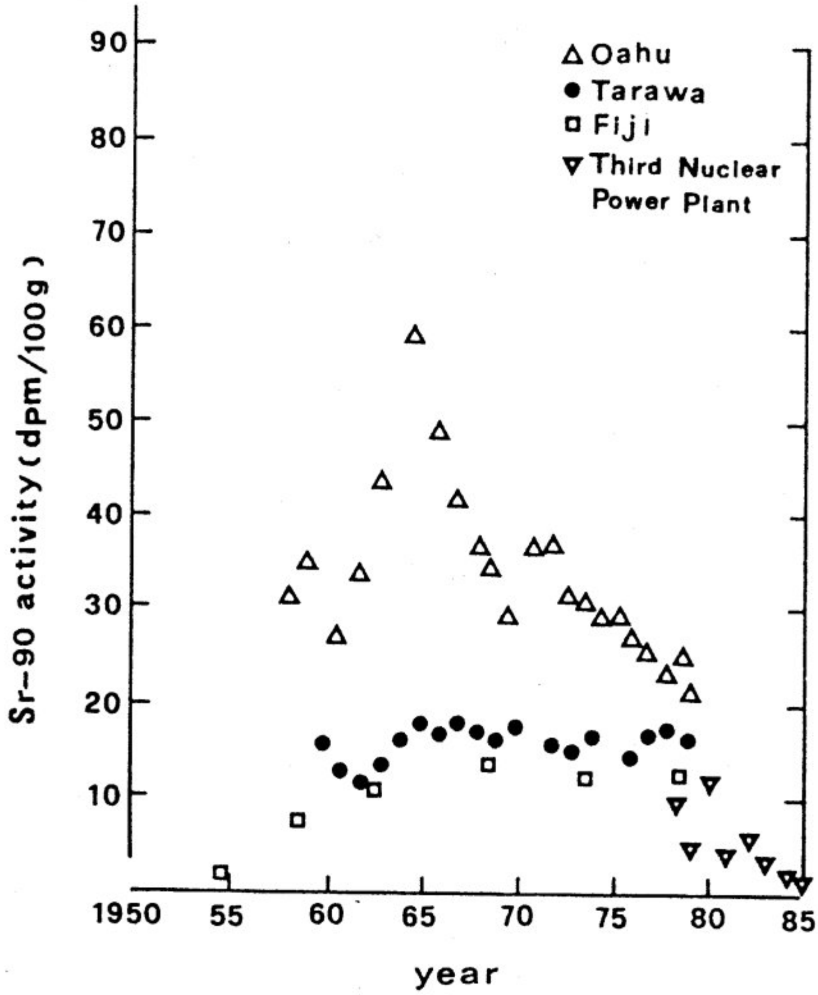


Figure 17.8 Annual variations of Sr-90 concentration in corals collected from Oahu, Tarawa, Fiji, and the Third Nuclear Power Plant in Taiwan. Data at Oahu, Tarawa, and Fiji are from Toggweiler and Trumbore (1985).

BEHAVIOR OF TRACE ELEMENTS IN THE TANSHUI RIVER

The Tanshiu River, located near Keelung in the north of Taiwan, is heavily polluted by organic materials from industrial and domestic wastes, including garbage dumps along the river. Heavy metals such as zinc, mercury, and copper in sediments in polluted river and estuarine areas have high concentrations in midstream, gradually decreasing as water flows to the estuarine areas. In this section, we discuss how the riverine processes and water paramenters influence the distribution, behavior, and mobilization of trace metals in the polluted Tanshui River.

Salinity is a good indicator for studying the process of mixing due to the properties of low salinity in river water and high salinity in sea water. The behavior of elements in estuarine water is conservative if the element concentration and salinity have a linear relationship. A nonlinear relationship indicates the addition or removal of elements from other water sources into rivers.

The results show that dissolved and particulate trace metals in the Tanshui River water are a function of salinity. In other words, salinity determines in what phase (dissolved or particulate) the trace metals are transported at various places along the river. In general, in the estuary, nickel is predominantly transported in the dissolved and iron in the particulate phase. Zinc and copper are transported in the particulate phase in river water but in the dissolved phase in high-salinity water. In contrast to zinc and copper, manganese is predominantly in the dissolved phase in river water and the particulate phase in sea water. Dissolved and particulate trace metals, other than dissolved copper, have high concentrations in the upper stream, gradually decreasing toward the river mouth.

As seawater mixes with river water, particulate trace metals are removed by sedimentation that occurs easily in the vicinity of the fresh water and seawater interphases. Trace metals are absorbed into organic matter that enters the estuary from river water and flows into the ocean. Because the sea water is full of oxygen, dissolved trace metals are released from particulate organic matter and oxidized.

Mobilization of Trace Metals in the Estuary

Dissolved oxygen and pH play an important role in the chemistry of trace elements in the natural environment. For instance, the variation of dissolved oxygen concentrations causes the different oxidizing and reducing states of the trace elements, and variations of pH influences the desorption-sorption processes of trace metals in natural water. In general, the high values of dissolved oxygen and pH of the Tanshui River are observed to be a function of salinity. In particular, high values of dissolved oxygen and pH are observed in higher salinity water (downstream) compared with values in low-salinity water (upstream). The dissolved Fe, Mn, and Zn concentrations are maximum in the deficient oxygen water of the upper estuary and gradually decrease, downstream, with the increase of salinity.

In general, dissolved copper displays no relationship to dissolved oxygen. However, dissolved Zn, Ni, and Mn decrease as dissolved oxygen increases. The concentration of dissolved Fe is very low in the deficient oxygen of river water because dissolved Fe is removed easily from oxygenated water with pH larger than 6. Dissolved Fe may oxidize to iron oxide in the oxygenated water and then absorb Mn, Zn, and Ni in the estuary.

Particulate manganese concentration is very low in the Tanshui River. J. C. Chen (1975) indicates that the trace metals in waters of western Taiwan come from ferro-magnesium clay minerals. Therefore, dissolved Mn and Zn are released from ferro-magnesium clay materials, which are associated with Mn and Zn in the waters of deficient oxygen content of the upper river.

In general, dissolved Mn, Fe, and Ni decrease as pH increases, and Cu increases as pH increases. Dissolved Zn increases with pH values. When pH values are greater than 7, the concentration of dissolved Zn decreases. The particulates and pH play an important role in the transport of trace metals in river water flowing to the ocean. The trace metals associated with ferromagnesium clay minerals and iron oxyhydroxide are transported from the Tanshui River to Taiwan Strait. The particulate Ni and Mn concentrations increase as pH increases. Particulate Zn also increases as pH increases, if pH is greater than 7. The particulate trace metal concentration increases as pH increases, demonstrating that the dissolved Mn, Ni, and Zn are absorbed into iron oxyhydroxide and ferromagnesium clay minerals during transport from the river to the ocean. The Cu associated with iron oxides or ferromagnesium clay minerals is transported from the river to the ocean in the presence of lots of dissolved organic matter in the Tanshui River estuary.

This rather technical discussion indicates the extent to which nature alters but does not eliminate potentially harmful trace and heavy metals as they flow to the sea. The river's sediment flow is 6.095 million mt. per year (Hou 1988). Much of this material will find its way into the food chain and might be carried considerable distances from the origin. Furthermore, as discussed below, it could have detrimental effects on other economic activities such as the nearby Lin-Kou Power Plant. Clearly, continued monitoring and sampling in this and other estuarine areas is potentially extremely cost effective. The inshore, coastal, and aquacultural fisheries depend heavily on such attention.

THERMAL DIFFUSION AT THE LIN-KOU POWER PLANT

Power Generation in Taiwan

About 88% of Taiwan's electricity is generated by thermal or nuclear power plants (CEPD, 110). By 1986, although the nuclear plants had not been in operation more than a decade, they were generating almost exactly the same amount of power as the thermal. Both types of plant are located on the seashore, and both use seawater for cooling.

Figures 17.9*a* and 17.9*b* show the growth of the two types of power generation. Although thermal generation began to decline after 1980, nuclear power was there to take its place. Total generation continued increasing, rising by a factor of 41.6 in the period from 1952 to 1986 (CEPD, 109). It is reasonable to assume that the usage of ocean water for cooling also increased about 40-fold. This would put rapidly rising pressure on the nearby seawater to absorb and diffuse the heat. It is, therefore, quite appropriate to study the thermal problems of an individual plant.

The Lin-Kou Power Plant

The Lin-Kou Power Plant is located on the northwest corner of the west coast of Taiwan. The Tanshiu and Lin-Kou Rivers are on the east side, while the Nal-Kan River is on the west side. It has a two-unit engine, with total generated

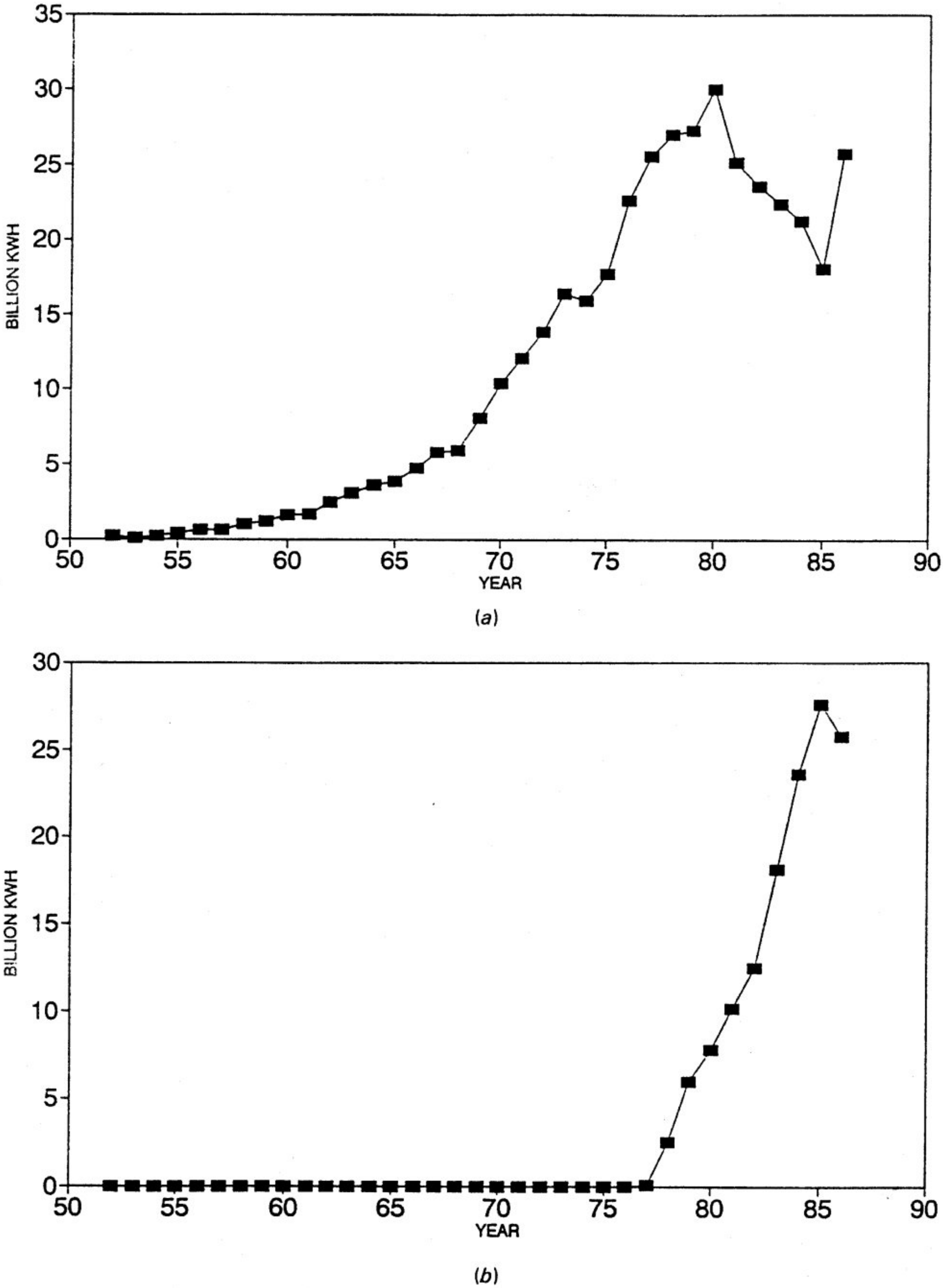


Figure 17.9 (*a*) Thermal power output. (*b*) Nuclear power output.

electric power of 65 mw. During summer, the temperature of sea water is warm. Furthermore, tidal currents along the boundaries of the intake and the outlet structures create the effect of a return current and, therefore, bring the thermal water to the entrance of the intake. Hence, this is a case of self-inflicted thermal pollution.

Oceanographic Data

The monsoon in this area occurs from September to April. The prevailing wind direction is NE-ENE, and the wave direction of the near shore is NNE. The maximum wave height during a strong monsoon is four m. The river sediment discharge that affects the Lin-Kou Power Plant is from the Tanshui River. The sediment transport is toward the south. As mentioned above, the Tanshui River sediment, therefore, may have impact on the economic activity of other sectors.

The temperature distribution around the intake structure is affected by currents along the shore as well as by the tidal current. During ebb tide, the combination of currents brings the thermal water from outlet to inlet, raising average temperatures by about 2 °C. During the summer, the intake of cooling water is affected seriously enough to be inconvenient to the power plant.

Results

Because the distance between the intake and the outlet is not sufficient, the surface temperature from the outlet is easily transported toward the intake. A parallel guide wall that directs the warm water toward the offshore area is the optimal solution. The test results show that, with the wall, the temperature from the outlet has little effect on the intake during all tidal times. The thermal pollution, therefore, has been diffused elsewhere.

As mentioned above, the rapid increase in power generation and use of the sea for cool water may imply that diffusing the thermal pollution elsewhere is not an optimal solution for everyone. In most cases, there is probably little measurable impact, but, as before, continued surveillance and monitoring are highly desirable.

CONCLUSIONS

The major conclusion has already been discussed in detail. Taiwan, as a microcosm of the rest of the world, is highly dependent on a clean and cool ocean environment. Economic activity, so important for the continued support of human welfare, creates waste that must be carefully packaged and disposed of. This waste rarely harms only the agency that creates it, as was the case of the Lin-Kou Power Plant, which is why solutions require tact and bargaining.

Waste is also not always easily detected. The cases we discuss above all involve wastes that, however harmful, may be detected only by experts with elaborate equipment. Hence, the conclusion is that this all-important endeavor requires continued monitoring, continued sampling and testing, and a lot of hard work.

REFERENCES

Buddemeier, R. W. 1974. Environmental controls over annual and lunar monthly cycles in hermatypic coral calcification. In *Proceedings of the Second International Coral Reef Symposium,* vol. 2, 259–267. Brisbane.

Bureau of Environmental Protection of Taiwan. 1986. Pilot project for water quality monitoring in aquaculture breeding areas along west-southern coast of Taiwan. Taipei.

Chen, C. T., K. H. Chang, and L. S. Fang. 1988. Recent changes of trace metals and radionuclides in banded corals in southern Taiwan. Unpublished manuscript presented at the Third Conference on Asia/Pacific Marine Resources and Development, Kaohsiung, 1988.

Chen, J. C. 1975. Heavy elements distribution in shelf sediments adjacent to Taiwan. *Proceedings of the National Science Council* 8:287–304. National Science Council, Taipei, Taiwan.

Chen, K. K. 1985. Carbon and oxygen isotopes and trace elements in corals in Taiwan, M.S. thesis, National Taiwan University.

Chen, Y. C., and T. C. Hung. 1988. The behavior and mobilization of trace metals in the Tanshui River. *Journal of the Environmental Protection Society of the Republic of China* 2:22–31.

Council for Economic Planning and Development (CEPD). 1987. *Taiwan statistical data book.* Taipei.

Dodge, R. E., and J. R. Vaisnys. 1977. Coral populations and growth patterns: Response to sedimentation and turbidity associated with dredging. *Journal of Marine Research* 35:715–730.

Dodge, R. E., and T. R. Gilbert. 1984. Chronology of lead pollution contained in banded coral skeletons. *Marine Biology* 82:9–13.

Gallo, L. J. 1985. Pollutant accumulations in coral skeletons. Oregon State University, unpublished.

Highsmith, R. C. 1979. Coral growth rates and environmental control of density banding. *Journal of Experimental Marine Biology and Ecology* 37:105–125.

Hou, H. S. 1988. Model study of the thermal diffusion effect on the intake of Lin-Kou Power Plant. Unpublished manuscript presented at the Third Conference on Asia/Pacific Marine Resources and Development, Kaohsiung, 1988.

Knutson, D. W., R. W. Buddemeier, and S. V. Smith. 1972. Coral chronometers: Seasonal growth bands in reef corals. *Science* 177:270–272.

Livingston, H. D., and G. Thompson. 1971. Trace element concentrations in some modern corals. *Limnological oceanography* 16:786–796.

Patzold, J. 1984. Growth rhythms recorded in stable isotopes and density bands in the reef coral Porites lobata (Cebu, Philippines). *Coral reefs* 3:87–90.

St. John, B. E. 1974. Heavy metal in the skeletal carbonate of scleractinian corals. *Proc. 2nd. Int. Coral Reef Symp.* vol. 2, 461–469.

Shen, G. T., and E. A. Boyle. 1987. Lead in corals: Reconstruction of historical industrial fluxes to the surface ocean. *Earth. Planet. Science Letter* 82:289–304.

Shen, G. T., and E. A. Boyle. 1988. Determination of lead, cadmium and other trace metals in annually-banded corals. *Chem. Geol.* 67:47–62.

Shen, G. T., E. A. Boyle, and D. W. Lea. 1987. Cadmium in corals as a tracer of historical upwelling and industrial fallout. *Nature* 328:794–796.

Toggweiler, J. R., and S. Trumbore. 1985. Bomb-test Sr-90 in Pacific and Indian Ocean surface water as recorded by banded corals. *Earth and Planet Science Letter* 74:306–314.

Wang, C. H. 1986. Pers. comm.

Wang, Y. P. 1987. Some aspects of heavy metals as an environmental pollutant in Taiwan. *Journal of the Environmental Protection Society of the Republic of China* 10:56–69.