PN-ABG-145

Huang, X., Wang, J., Cheng, G., Yang, Z. & Yang, L. (1988). Water quality of the Zhujiang River (Guangzhou River reach) in early 80's. In *Pollution in the Urban Environment—POLMET 88*, Vol. 2 (P. Hills, R. Keen, K. C. Lam, C. T. Leung, M. A. Oswell, M. Stokes & E. Turner, eds), pp. 438–443. Vincent Blue Copy Co. Ltd., Hong Kong.

Hungspreugs, M. & Yuangthong, C. (1983). A history of metal pollution in the Upper Gulf of Thailand. *Mar. Pollut. Bull.* **14**, 465–469.

Hungspreugs, M. & Yuangthong, C. (1984). The present levels of heavy metals in some molluscs of the Upper Gulf of Thailand. *Water, Air Soil Pollut.* **22**, 395–402.

Hungspreugs, M., Utoomprurkporn, W., Dharmvanij, S. & Sompongchaiyakul, P. (1989). The present status of the aquatic environment of Thailand. *Mar. Pollut. Bull.* **20**, 327–332.

Huschenbeth, E. &. Harms, U. (1975). On the accumulation of organochlorine pesticides, PCB and certain heavy metals in fish and shellfish from Thai coastal and inland waters. *Arch. Fisch. Wiss.* **2**, 109–122.

Ip, H. M. H. & Phillips, D. J. H. (1989). Organochlorine chemicals in human breast milk in Hong Kong. *Arch. Environ. Contam. Toxicol.* (in press).

Jensen, A. A. (1983). Chemical contaminants in human milk. *Residue Reviews* **89**, 1–128.

Keen, R. C. & Jhaveri, N. (1988). Quantifying hazardous waste generation in Asia. In *Pollution in the Urban Environment—POLMET 88*, Vol. 2 (P. Hills, R. Keen, K. C. Lam, C. T. Leung, M. A. Oswell, M. Stokes & E. Turner, eds), pp. 164–170. Vincent Blue Copy Co. Ltd., Hong Kong.

Koh, H.-L., Chong, C.-S. & Lim, P.-E. (1988). Impact assessment of sewage disposal in Penang Southern Channel of Malaysia. In *Pollution in the Urban Environment—POLMET 88*, Vol. 2 (P. Hills, R. Keen, K. C. Lam, C. T. Leung, M. A. Oswell, M. Stokes & E. Turner, eds), pp. 171–176. Vincent Blue Copy Co. Ltd., Hong Kong.

Maclean, J. L. (1984). Indo-Pacific red tide occurrences, 1972–1984. In *Toxic Red Tides and Shellfish Toxicity in Southeast Asia* (A. W. White, M. Anraku & K. K. Hooi, eds), pp. 92–98. Southeast Asian Development Fisheries Center, Singapore, and International Development Research Centre, Ottowa.

Maclean, J. L. (1989). Indo-Pacific red tide occurrences, 1985–1988. *Mar. Pollut. Bull.* **20**, 304–310.

Maclean, J. L. & White, A. W. (1985). Toxic dinoflagellate blooms in Asia: a growing concern. In *Toxic Dinoflagellates* (D. M. Anderson, A. W. White & D. G. Baden, eds), pp. 517–520. Elsevier, New York.

Menasveta, P. & Cheevaparanapiwat, V. (1981). Heavy metals, organochlorine pesticides and PCBs in green mussels, mullets and sediments of river mouths in Thailand. *Mar. Pollut. Bull.* **12**, 19–25.

Morton, B. S. (1989). Pollution of the coastal waters of Hong Kong. *Mar. Pollut. Bull.* **20**, 310–318.

Myers, S. D., Cheung, W. H. S. & Phillips, D. J. H. (1985). Effluent reuse in an urban situation. In *Pollution in the Urban Environment—POLMET 85* (M. W. H. Chan, R. W. M. Hoare, P. R. Holmes, R. J. S. Law & S. B. Reed, eds), pp. 641–647. Elsevier Applied Science Publishers, London.

Phillips, D. J. H. (1980a). Toxicity and accumulation of cadmium in marine and estuarine biota. In *Cadmium in the Environment; Part I: Ecological Cycling* (J. O. Nriagu, ed.), pp. 425–569. John Wiley & Sons, New York.

Phillips, D. J. H. (1980b). Proposal for Monitoring Studies on the Contamination of the East Asian Seas by Trace Metals and Organochlorines. Report UNEP/WG. 41/INF. 13. Food and Agriculture Organisation/United Nations Environment Programme, Geneva.

Phillips, D. J. H. (1984). The WESTPAC programme on the use of commercially exploited shellfish as bio-indicators in the Western Pacific region. *Asian Mar. Biol.* **1**, 1–16.

Phillips, D. J. H. (1985). Monitoring and control of coastal water quality. In *Pollution in the Urban Environment—POLMET 85* (M. W. H. Chan R. W. M. Hoare, P. R. Holmes, R. J. S. Law & S. B. Reed, eds), pp. 559–565. Elsevier Applied Science Publishers, London.

Phillips, D. J. H. (1989). Trace metals and organochlorines in the coastal waters of Hong Kong. *Mar. Pollut. Bull.* **20**, 319–327.

Phillips, D. J. H. & Muttarasin, K. (1984). Trace metals in bivalve molluscs from Thailand. *Mar. Environ. Res.* **15**, 215–234.

Polprasert, C. (1982). Heavy metal pollution in the Chao Phraya River estuary, Thailand. *Water Res.* **16**, 775–784.

Sivalingam, P. M. (1984). Ocean disposal and land reclamation problems of Penang, Malaysia. *Conservation & Recycling* **7**, 85–98.

Sivalingam, P. M. & Bhaskaran, B. (1980). Experimental insight of trace metal environmental pollution problems in mussel farming. *Aquaculture* **20**, 291–303.

Suckcharoen, S., Nuorteva, P. & Hasanen, E. (1978). Alarming signs of mercury pollution in a freshwater area of Thailand. *Ambio* **7**, 113–116.

Tanabe, S., Tatsukawa, R., Kawano, M. & Hidaka, H. (1982). Global distribution and atmospheric transport of chlorinated hydrocarbons: HCH (BHC) isomers and DDT compounds in the western Pacific, eastern Indian and Antarctic oceans. *J. Oceanogr. Soc. Japan* **38**, 137–148.

Tanabe, S., Tanaka, H. & Tatsukawa, R. (1984). Polychlorinated biphenyls, ΣDDT, and hexachlorocyclohexane isomers in the western North Pacific ecosystem. *Arch. Environ. Contam. Toxicol.* **13**, 731–738.

Tanabe, S., Yasuhara, Y. & Tatsukawa, R. (1985). Persistent organochlorines in the East China Sea—their distribution, behavior and fate inherent in marginal sea. In *Pollution in the Urban Environment—POLMET 85* (M. W. H. Chan, R. W. M. Hoare, P. R. Holmes, R. J. S. Law & S. B. Reed, eds), pp. 670–678. Elsevier Applied Science Publishers, London.

Tanabe, S., Kannan, N., Fukushima, M., Okamoto, T., Wakimoto, T. & Tatsukawa, R. (1989). Persistent organochlorines in Japanese coastal waters: an introspective summary from a Far East developed nation. *Mar. Pollut. Bull.* **20**, 344–352.

Tay, J. H. (1988). Complete reclamation of wastewater and sludge in a highly urbanised city. In *Pollution in the Urban Environment—POLMET 88*, Vol. 2 (P. Hills, R. Keen, K. C. Lam, C. T. Leung, M. A. Oswell, M. Stokes & E. Turner, eds), pp. 282–288. Vincent Blue Copy Co. Ltd., Hong Kong.

Wang, J., Jiang, Z., Xu, L. & Zhou, L. (1988). A feasibility study on wastewater treatment and water reuse. In *Pollution in the Urban Environment—POLMET 88*, Vol. 2 (P. Hills, R. Keen, K. C. Lam, C. T. Leung, M. A. Oswell, M. Stokes & E. Turner, eds), pp. 629–633. Vincent Blue Copy Co. Ltd., Hong Kong.

Wolfe, D. A., Champ, M. A., Cross, F. A., Kester, D. R., Park, P. K. & Swanson, R. L. (1984). Marine pollution research facilities in the People's Republic of China. *Mar. Pollut. Bull.* **15**, 207–212.

Yamato, Y., Suzuki, M., Shimohara, K. & Akiyama, T. (1980). Behaviour of HCH (1,2,3,4,5,6-hexachlorocyclohexane) residue in the aquatic environment. *Water Res.* **14**, 247–251.

Yanagi, T. (1988). Preserving the Inland Sea. *Mar. Pollut. Bull.* **19**, 51–53.

Yeoh, B. G. (1985). Ponding as a treatment method for organic waste management in Malaysia. In *Pollution in the Urban Environment—POLMET 85* (M. W. H. Chan, R. W M. Hoare, P. R. Holmes, R. J. S. Law & S. B. Reed, eds), pp. 515–520. Elsevier Applied Science Publishers, London.

Yeoh, B. G. (1988). Technological options for small-scale piggery waste management in Malaysia. In *Pollution in the Urban Environment—POLMET 88*, Vol. 2 (P. Hills, R. Keen, K. C. Lam, C. T. Leung, M. A. Oswell, M. Stokes & E. Turner, eds), pp. 326–331. Vincent Blue Copy Co. Ltd., Hong Kong.

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Indo-Pacific Red Tides, 1985–1988

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A summary of recent toxic red tides in the southwestern Pacific region is given, showing that the dinoflagellate *Pyrodinium bahamense* var. *compressa* remains the major causative organism of paralytic shellfish poisoning and is apparently continuing to spread around the region. *Noctiluca scintillans* blooms occur in some countries and have been associated with mass mortality of fish. The raphidophyte *Chattonella* (= *Hornellia*) has been implicated in both fish and shrimp kills. A relationship with El Niño–Southern Oscillation (ENSO) events and some similarities with recent plagues of the crown-of-thorns starfish (*Acanthaster planci*) are discussed.

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The major toxic red tide species in the central part of the Indo-Pacific zone is *Pyrodinium bahamense* var. *compressa* first observed to be toxic in Papua New Guinea (Worth *et al.*, 1975) and subsequently noted elsewhere in the South Pacific and Southeast Asia. An annotated chronology of the red tide events up to 1984 was provided by Maclean (1984). An update was made in 1985 (Maclean & White, 1985). The information in this report summarizes events since these publications. Apart from a few key earlier references, the citations herein constitute a supplement to the previous bibliography for the region discussed (Maclean & Teraprosa, 1984). Figure 1 shows summary data on first and seasonal outbreaks around the region.

Country Accounts

Australia

The northern 'Indo-Pacific' portion of Australian waters appears to have remained free from *Pyrodinium* and red tides other than of the harmless blue-green alga *Trichodesmium*. In fact, the absence of *Pyrodinium* (and synonyms) is based on rather dated work, most recently Wood (1963). No new collections are known, although samples taken by the author in Darwin Harbour on 20 June 1988 were negative for *Pyrodinium* (Y. Fukuyo, pers. comm.). The possibility remains that *Pyrodinium* will be introduced in vessel ballast or transported by currents from nearby Papua New Guinea. Hallegraeff *et al.* (1988a) have found conclusive evidence that toxic dinoflagellate cysts can be transferred through ship ballast water between Japan and Australia.

In the south, the first authenticated incidence of toxic dinoflagellate blooms occurred during January–June 1986, of *Gymnodinium catenatum* near Hobart in Tasmanian waters (Oshima *et al.*, 1987a). Two persons were found with PSP symptoms (Hallegraeff & Sumner, 1986). A close relationship between phytoplankton abundance and shellfish toxicity was found (Hallegraeff *et al.*, 1987). Hallegraeff (pers. comm.) has since discovered PSP problems near two other southern Australian cities, Melbourne and Adelaide, and found two other potentially troublesome species, *Alexandrium* (= *Protogonyaulax*) *catenella* and *A. minutum* (Hallegraeff *et al.*, 1988b).

Noctiluca scintillans blooms are known in southern coastal waters (Hallegraeff, 1987). *Scrippsiella trochoidea* has caused occasional fish kills, while blooms of nontoxic plankton species include those of *Mesodinium rubrum* and *Gonyaulax polygramma* (Hallegraeff, 1987).

Brunei Darussalam

Major toxic blooms of *Pyrodinium* occurred in Brunei Bay in 1976 and 1980, which prompted a monitoring programme of both water and cultured mussels (*Perna viridis*). No blooms or highly toxic mussels were detected between 1980 and 1987. The monitoring programme is continuing (Chua *et al.*, 1987). Toxic planktivorous fish (*Sardinella* sp.) from Sabah waters were discovered in Brunei Darussalam in December 1987 (see section on Malaysia, Sabah). Abnormal numbers of *Pyrodinium* were observed in plankton hauls in January, February, and April–July 1988. PSP toxin levels of up to 5354 μg 100 g^{-1} were found in green mussels (*Perna viridis*) during January–August 1988. The high levels occurred in February and April; toxin levels were generally less than 100 μg 100 g^{-1} in the other months (Matdanan *et al.*, 1988).

India

Single accounts of PSP have been recorded for the east and west coasts of India in 1981 and 1983, respectively (Maclean, 1984). A two-year study followed on the west coast, revealing elevated levels of toxin in oysters and clams during March–April of 1985 and 1986 (Segar *et al.*, 1987). Diarrheic shellfish poison in the shellfish was also detected but did not appear to be seasonal. The only potentially causative organism for

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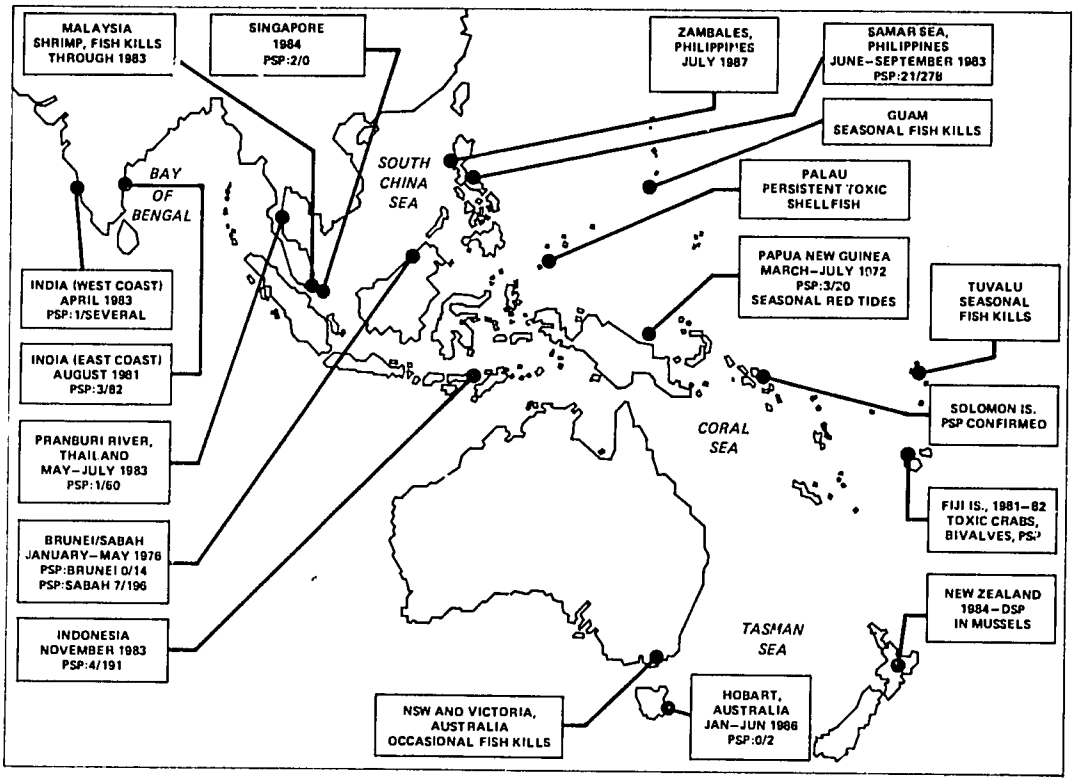

Fig. 1 Sites of central Indo-Pacific red tides, fish kills and paralytic shellfish poisonings. Numbers and dates in boxes refer to number of deaths/illnesses and time of first reported incidents. Harmless red tides omitted. (Updated from Maclean & White, 1985).

PSP in monthly plankton samples was *Prorocentrum* which did not appear to bloom. Other than *Noctiluca*, the raphidophyte *Hornellia* (= *Chattonella*) *marina* blooms and causes seasonal fish kills off the Malabar coast of India (Subrahmanyan, 1954).

Indonesia

The first recorded PSP outbreak in Indonesia was in East Nusa Tenggara, East Flores, from ingestion of planktivorous fish (*Sardinella* spp. and *Selaroides leptolepis*) in November 1983, when four persons died and a further 191 became ill (Adnan, 1984). The dinoflagellate responsible was not determined.

In Jakarta Bay, *Noctiluca scintillans* is the dominant dinoflagellate and has bloomed there occasionally or seasonally since 1976 at least (Adnan, 1984). An instance of mass mortality of fish occurred during the *Noctiluca* bloom there in July 1986 (Adnan, 1987).

Malaysia, Peninsular

Blooms of *Hornellia* (= *Chattonella*) *marina* occurred at different times between March and November 1983 along the Johor Straits and in January and February 1985 (possibly longer) in the same area. Shrimp farms suffered heavy losses during both events (Khoo, 1985). The gills of affected shrimps and other organisms such as crabs and fish were covered by a slime which turned gills brown. Khoo (pers. comm.) and his farm staff ate affected shrimp and fishermen continued selling their catch. No poisonings were reported. It is assumed that suffocation was responsible for the deaths of marine organisms, resulting in 30–50% loss in shrimp ponds where *Hornellia* bloomed (Khoo, pers. comm.). *Noctiluca miliaris* (= *scintillans*) also blooms, harmlessly, in Johor Straits and Penang, triggered by heavy rainfall and reportedly reducing fish catches (Jothy, 1984).

Malaysia, Sabah

Sabah experienced toxic blooms only in 1976 and 1980, but a few PSP deaths have occurred each year since then. A recent newspaper report (Lee, 1988) drew attention to the potential loss of export capital from fish and shrimps—US$28 million in shrimp alone—in the event of a red tide scare. The report stated that officials wish to 'soft-pedal' the problem which is said to affect 'only Philippine refugees', numbering over 100 000, who eat inshore bivalves. In December 1987, toxic planktivorous fish (*Sardinella* sp.) from Sabah were found to be responsible for deaths of cats in nearby Brunei Darussalam. The fish flesh contained 196 $\mu g\ g^{-1}$ of PSP toxin and the intestines of the fish were full of *Pyrodinium* (Matdanan *et al.*, 1988).

In the most recent PSP events, three Filipinos died and 31 others were affected at Gaya Island, 5 km from the State Capital of Kota Kinabalu in January 1988 (Lee, 1988). There were six more PSP deaths in May

1988, at Sipitang, in Brunei Bay adjacent to Brunei Darussalam (R. De Silva, pers. comm.).

In September 1985, the author visited Kuala Penyu, a lagoon in Kimanis Bay, southern Sabah, where oysters (*Crassostrea belcheri*) in an experimental farm had been reported to have consistently high levels of PSP toxin although no red tide had been reported in Sabah since 1980. Phytoplankton samples in the turbid lagoon revealed that over 90% of the community was composed of *Pyrodinium*. Tollervey (1987) subsequently studied the lagoon and found a recurrent bloom, not dense enough to be visible, which was correlated with the toxicity of the experimental shellfish. Dense blooms of *Pyrodinium* in Papua New Guinea were also found to occur at various depths, not visible above water, depending on oceanographic and/or climatic conditions (Maclean, 1977). Harada *et al.* (1982) found *Pyrodinium* was usually only seen by submarine observation as a turbid layer in Palauan waters.

New Caledonia

There are no recent reports of red tides or associated phenomena in New Caledonia. An old account I had previously thought of insufficient interest is instead perhaps worthy of mention. In 1856, in New Caledonia, five men on a French gunboat died from eating poisonous fish; later there were several deaths at Port de France. The account, by Father P. Montrouzier in *La Moniteur de la Nouvelle Caledonie*, 21 October 1860, noted that some fish were poisonous at certain times of the year, including a sardine, a sparid, barracuda, and "generally, the tetrodons". the second part of the account, in the *La Moniteur* edition of 28 October 1860, said that according to the indigines, the poison only occurred after the fish eat a 'monad' which sometimes covered the sea, colouring it green, or at times red, for hundreds of metres. Simple contact with the organisms caused irritation.

Philippines

The first recorded outbreak of paralytic shellfish poisoning (PSP) in the Philippines occurred in June–September 1983 in the Samar Sea (Hermes *et al.*, 1985). The causative organism was *P. bahamense* var. *compressa* and about 20 deaths and (perhaps) nearly 700 illnesses resulted (Loyola, 1987), mostly from eating bivalves, with a few from planktivorous fishes (Hermes & Villoso, 1983; Arafiles & Morales, 1985). Many persons were said to have felt relief from PSP symptoms by drinking coconut milk with brown sugar, a traditional palliative (Gacutan, 1986). Some distance south of the red tide area a case of PSP was reported where there were low *Pyrodinium* counts but very potent mussels (*Perna viridis*) (Gacutan *et al.*, 1985).

A magazine article in June 1987 (Loyola, 1987) contained the first mention of red tide since the 1983 event. Ironically, it recalled the latter, noting that a lesson on dealing with the problem had been learnt. However, on 7 June, and in the same area as before, nine food poisoning cases, one fatal, from *P. viridis* were reported and suspected to be caused by red tide (Anon., 1987a). By 11 June, officials banned shellfish harvesting and sale (Rous, 1987a); 11 deaths had been reported, a figure amended to 3 by the end of the month with about 60 hospitalizations (Anon., 1987b). There were attempts by some mussel farmers to smuggle mussels out of the affected area (Anon., 1987b). A week earlier farmers were preparing to rally against the ban on mussel harvesting (Rous, 1987b). Most of these newspaper reports advised affected persons to drink coconut milk and brown sugar, the traditional poison 'cure', tested after the 1983 outbreak and found to reduce toxin levels in mussels (Gacutan, 1986).

By 18 July, it was reported that infected mussels were rendered nontoxic after 24 h immersion in clean water and that depuration activities were beginning (Anon., 1987c).

The blooms were still present in the Samar Sea in mid-August while a new outbreak was reported (Anon., 1987d) around the end of July in Masinloc, a bay facing the South China Sea in Zambales (Fig. 1), as far north from the Samar area as Sabah is to the south. Sabah is the nearest *Pyrodinium* bloom area to the Philippines. Thus, the Zambales blooms represent a further significant spread of the problem.

Depuration activities apparently did not continue; nor was an all-clear signal ever published. Altogether the 1987 events caused 6 reported deaths and a further 205 PSP-related illnesses, 13% of which were said to be caused by eating planktivorous fish (Gonzales *et al.*, 1987).

Plankton monitoring in the Samar Sea had been undertaken since the 1983 outbreak. Two months before the 1987 blooms, *Pyrodinium* was less than 1% of the phytoplankton (using a 45 μm mesh net), but had reached up to 9.8% in April 1985 (Gonzales *et al.*, 1987). From observations of phytoplankton composition before, during and after red tides of *P. bahamense* var. *compressa* in Papua New Guinea, Maclean (1977) found that proportions of *Pyrodinium* in excess of 2% indicated a recent or approaching bloom. Since blooms can occur in subsurface waters (Maclean, 1977), the possibility of unobserved red tides in the Philippines between 1983 and 1987 as well as in years before cannot be discounted.

In August 1988, *Pyrodinium* red tides began to appear for the first time in Manila Bay, adjacent to the nation's capital, Manila. A total of 61 hospitalizations including four fatalities due to PSP were recorded by the end of September when blooms disappeared. Organisms identified as responsible included not only bivalves, but small shrimp eaten whole, digestive glands of crabs and planktivorous fish eaten with gills intact (Dr. Y. N. Pastor, pers. comm.).

By September 1988, red tides and PSP were being reported in Samar in the same area as in 1983 and 1987. Toxin levels were still high in mussels in December 1988; 37 hospitalizations including one fatality were recorded in Samar up to that time. Gastropod molluscs (*Umbonium* sp.) were found to be toxic there in addition to the toxic organisms found in Manila Bay (Dr. Y. N. Pastor, pers. comm.).

The Manila Bay event aroused intense interest in the problem by the media and pollution was blamed

(Anon., 1988d; Crisostomo, 1988; Mata, 1988). The financial losses of the Manila Bay red tide event have not been officially assessed. The following summary is derived from various newspaper accounts and statistical data (BFAR, 1986). Estimates of the number of affected persons ranged from 30 000 to 50 000. Prices of all seafood dropped to 40% of normal prices and landings fell by up to 80%, while mussels were virtually unsaleable. Japan and Singapore were said to have banned shrimp imports from the Philippines (Anon., 1988c).

If mussel fishermen and growers in Manila Bay lost 3 months of their crop, their economic loss would have been some P20 million (US$1.0 = P21). At the nation's largest fish landing, Navotas in Manila Bay, losses during the height of the 'scare' would have been over P6.0 million per day. Perhaps as much again would have been lost by fish brokers and market vendors. If banned shrimp were not finally exported, losses of P10 million per day were accumulating in that sector. Major losses no doubt occurred in many related industries, even the vinegar industry (because the toxin was found to be enhanced in acid conditions), while fuel oil revenue fell by P3000 for each trip cancelled by a large trawler.

The Philippine Government responded by offering funds to various nongovernmental organizations for production loans to subsistence fishermen (Anon., 1988b). Regular *Red Tide Bulletins* were disseminated to the media and interested parties such as restauranteurs. An interdepartmental group was formed to coordinate future government activities related to red tides and funds have been allocated for a number of research projects.

Singapore

Phytoplankton blooms are said to occur offshore in Singapore waters, of which only one harmless dinoflagellate, *Cochlodinium catenatum* has been reported (Cheong *et al.*, 1984). However, two persons died from PSP in 1984, after eating mussels taken from the Seletar River area (Tan & Lee, 1987). This was the first PSP incidence in Singapore. The organism responsible was not identified.

Solomon Islands

Oshima *et al.* (1987b) showed the presence of PSP toxin in an oyster (*Crassostrea gigas*) from the Solomon Islands. The toxin profile was similar to that of *Pyrodinium*. Previous evidence of PSP poisoning there was anecdotal (Oshima *et al.*, 1984). The author observed a red tide patch, identical to those of *Pyrodinium*, during a low flight near Munda, western Solomon Islands, on 9 July 1988. However, a plankton sample taken by the author near Gizo Island, also in the western Solomon Islands, on 7 July 1988, was negative for *Pyrodinium*.

Thailand

Only one toxic event has been recorded in Thailand, in the inner Gulf, in May 1983 (Tamiyavanich *et al.*, 1985). An intensive study over the following years concluded that the causative organism was probably *Protogonyaulax* (= *Alexandrium*) *tamarensis*, although it has only been found there in very small numbers (Kodama, 1987). However, cultured strains of *P.* (= *Alexandrium*) *tamarensis* were all nontoxic, while strains of *P. cohorticula*, also from the Gulf of Thailand, were toxic, with toxin profiles similar to those of toxic mussels collected during the 1983 PSP event (Fukuyo *et al.*, 1987).

Status of *Pyrodinium*

Initially, *Pyrodinium* in Papua New Guinea was identified as a toxic strain of *P. bahamense* Plate. However, it was subsequently determined to belong to the variety *compressa* and redescribed by Steidinger *et al.* (1980) based on samples from various western Pacific locations. More recently, Balech (1985) compared specimens from the Caribbean and Western Pacific. He noted that *compressa* should be *compressum* as described by the original author (Böhm). Balech concluded that while there were trends in their morphology, there was a range of shapes within each population and that the intraspecific distinction was not warranted. Thus, Balech (1985) proposed that all *Pyrodinium* be reinstated as *Pyrodinium bahamense* Plate.

Current Research

In Brunei Darussalam, a 12 month project is underway which will establish an action plan for monitoring red tide occurrences and for health protection mechanisms. The plan is to include warning systems and legal procedures to control the sale of affected organisms (Chua & Agulto, 1987). Nearby Sabah, Malaysia, began research in 1986 involving various institutions. The Universiti Kebangsaan Malaysia has been investigating taxonomy, distribution and population dynamics of *Pyrodinium*, as well as the mechanism of bloom formation (Gires Usup, pers. comm.).

Recognizing the importance of *Pyrodinium* in the western Pacific, staff of Australia's CSIRO Marine Laboratories are also working on aspects of its biology, as well as on biology and culture of the local *Gymnodinium catenatum* (Hallegraeff & Sumner, 1986).

In the Philippines, a group in the Bureau of Fisheries and Aquatic Resources is undertaking cooperative research on red tides with the laboratory of Fisheries Oceanography, University of Tokyo. The 1988 outbreak in Manila Bay, Philippines, has led to the formulation of a number of research and monitoring projects for 1989 and beyond.

Recent Workshops, Plans

Papers on recent *Pyrodinium* red tides and PSP were presented at the Workshop and International Conference on the Problems of Toxic Dinoflagellate Blooms in Aquaculture, Ireland, 8–13 June 1987 (Dale *et al.*, 1987), at the First Asia-Pacific Congress on Animal, Plant and Microbial Toxins, Singapore, 24–27 June 1987 (Gopalakrishnakone & Tan, 1987), and at the International Symposium on Red Tides, Takamatsu, Japan, 10–14 November 1987.

The Western Pacific group (WESTPAC) of the Intergovernmental Oceanographic Commission (IOC) held a training workshop on dinoflagellate taxonomy in March 1985 in Thailand. WESTPAC also organized short workshops on cysts and toxin analysis during the Takamatsu symposium. Under the auspices of WESTPAC, a three-year Asian regional survey of dinoflagellates is expected to begin in 1989 and the results are to be discussed at a symposium in 1991.

Pyrodinium will also undoubtedly be discussed in the two conferences scheduled for June 1989: on taxonomy and biology of toxic dinoflagellates and other harmful plankton (Sherkin Island Marine Station, Ireland); and the fourth international conference on toxic dinoflagellates (Sweden), respectively.

Finally, an international workshop on *Pyrodinium* is planned for 1989, to bring together researchers from the southwestern Pacific with those from the tropical Atlantic, where *Pyrodinium* is also beginning to cause PSP problems.

Conclusions

Pyrodinium remains by far the most important dinoflagellate in the southwestern Pacific. Since the early 1970s, toxic *Pyrodinium* red tides have apparently spread westward from Papua New Guinea (1972) to Borneo (1976), the central Philippines (1983), and the northern Philippines (1987). There is every possibility of the phenomenon spreading southward to northern Australia. The presence of *Pyrodinium* in a number of Pacific islands is of unknown duration. Evidence has been found that dinoflagellate introductions can be made through cysts in the ballast water of vessels, and indeed this may explain the relatively recent appearance of *Pyrodinium* in the Indo-Pacific region.

Taking the present series of toxic *Pyrodinium* blooms from 1972 as a whole, there is remarkable coincidence with El Niño–Southern Oscillation (ENSO) events. Table 1 summarizes the two sets of events.

Within this general correlation, the significant factors contributing to the toxic blooms in the southwestern Pacific are unknown. In a recent article (Stern & Gutzler, 1988), data are presented on empirical orthogonal functions (EOFs) of zonal wind anomalies between 70°E and 170°E at about 6°N and zonal mean sea surface temperature anomalies (ZMTs) between 137.5°E and 82.5°W along 2.5°S. Moderate to strong positive anomalies were found associated with each ENSO event. These data are shown in Fig. 2.

If abnormal winds or water temperatures or related ENSO phenomena provided the environmental triggering of toxic blooms of *Pyrodinium*, 'seed' populations must have been already present. This seems to have been the case at least in Port Moresby Harbour, Papua New Guinea, site of the first recorded toxic bloom in 1972. A surface sediment sample collected by the author there in 1974 consisted of 90% *Pyrodinium* cysts (G. M. Hallegraeff, pers. comm.).

The situation is more complex, however. Nontoxic red tides in 1973 and 1974 followed the toxic Papua New Guinea blooms of 1972 (Maclean, 1984); later

TABLE 1
Years of El Niño–Southern Oscillation (ENSO) and toxic *Pyrodinium* red tide events from 1972 onwards.

ENSO events	*Pyrodinium* toxic bloom years	Red tide site
1972–1973	1972	Papua New Guinea
1976–1977	1976	Brunei/Sabah
1979–1980	1980	Brunei/Sabah
1982–1983	1983	Philippines
1986–1987	1987	Philippines
	1988	Philippines

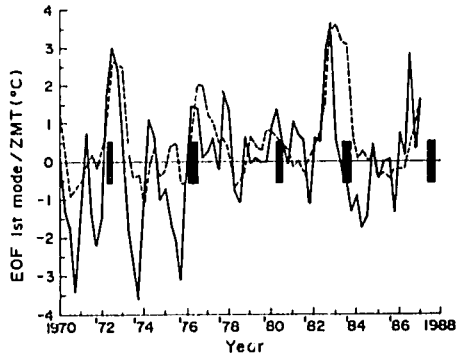

Fig. 2 Time series P[1] of principal components associated with the first EOF mode (solid line), and ZMT (broken line). Graph from Stern & Gutzler (1988), to which bars have been added representing periods of toxic *Pyrodinium* red tides from 1972 onwards.

ENSO events apparently did not cause corresponding toxic blooms in Papua New Guinea, in Sabah sub-bloom concentrations of *Pyrodinium* appear to have caused PSP fatalities almost continuously since 1980.

One interpretation is as follows: ENSO events probably affect different parts of the southwestern Pacific to varying degrees on each occasion; they not only result in abnormal (=toxic) events but also create the conditions to maintain to some extent the 'abnormal' plankton succession that they initiate, over a varying number of years; the environment in years without ENSO events exerts a dampening effect; the ENSO-generated pattern may decline quickly or become at least semi-permanent.

If one substitutes 'pollution' or 'typhoon' or other perturbations for ENSO events, probably most toxic red tides can be covered by this interpretation. The significant point is that *Pyrodinium* seems to be triggered by a natural phenomenon rather than a human-induced one.

I am struck by the similarity of *Pyrodinium* blooms and outbreaks of the crown-of-thorns starfish (*Acanthaster planci*). The latter have occurred in many apparently isolated or undisturbed areas in numerous islands throughout the Indo-Pacific area, as well as in the Great Barrier Reef (GBR) of Australia. Nevertheless, debate about the origin of the starfish plagues has centered on whether or not human activities are in some way responsible. So far the starfish seems to have had no impact, even on tourism (Anon., 1988a), although a great deal of research on the species is underway. *Pyrodinium*, on the other hand, has been responsible for at least 50 deaths in recent years and its potential impact on coastal aquaculture, especially of bivalve molluscs, is

enormous. Yet very little research is presently being carried out.

Core samples from the GBR now show that population explosions of *Acanthaster* have occurred in the past, up to 7700 years ago (Anon., 1988a). Core samples are only recently beginning to be used in *Pyrodinium* research, but could well show previous bloom periods. That would end discussion on the influence of human activities and perhaps pinpoint other geographical areas where *Pyrodinium* outbreaks may occur in the future.

If Australian officials are convinced that the *Acanthaster* plague on the GBR is a cyclic phenomenon, they are unlikely to attempt to control the starfish populations (Anon., 1982a). In the case of *Pyrodinium*, however, such control appears highly desirable. The problem, of course, is to devise a control mechanism.

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Adnan, Q. (1984). Distribution of dinoflagellates at Jakarta Bay, Taman Jaya, Banten and Benoa Bay, Bali: A report of an incident of fish poisoning at Eastern Nusa Tenggara. In *Toxic Red Tides and Shellfish Toxicity in Southeast Asia* (A. W. White, M. Anraku and K. K. Hooi, eds), pp. 25–27. Southeast Asian Fisheries Development Center, Singapore, and International Development Research Centre, Ottawa.

Adnan, Q. (1987). Red tide, *Noctiluca scintillans* (Macartney) EHRENB. (= *miliaris*) and fish poisoning in the Jakarta Bay. In *International Symposium on Red Tides, Biology, Environmental Science and Toxicology*. Takamatsu, Japan, 10–14 November 1987. Abstracts, p. 15.

Anon. (1987a). Red tide in Samar? *Philippine Daily Enquirer*, 7 June 1987, p. 6.

Anon. (1987b). Red tide downs 56: spreading. *The Manila Journal*, 30 June 1987, p. 7.

Anon. (1987c). 'Red tide' now under control. *Manila Standard*, 18 July 1987, p. 11.

Anon. (1987d). Manilans' 'red tide' fears allayed. *Expat* (Manila), 15 August 1987, p. 1.

Anon. (1988a). New evidence on the crown of thorns starfish. *Reeflections* (Great Barrier Reef Marine Park Authority) **21**, 4–5.

Anon. (1988b). Displaced fishermen given assistance. *Manila Bulletin*, 4 October 1988, p. 1.

Anon. (1988c). S'pore, Japan move to stop buying Manila seafood 'hasty'. *Business Times*, 8 October 1988, p. 5.

Anon. (1988d). Red tide peril exposes country's helplessness on environmental pollution. *Ang Peryodiko Dabaw*, 15 October 1988, p. 5.

Arafiles, L. M. & Morales, J. B. T. (1985). Lethal effects of paralytic shellfish poison (PSP) from *Perna viridis*. *Fish. Res. J. Philipp.* **10**, 16–26.

Balech, E. (1985). A revision of *Pyrodinium bahamense* Plate (Dinoflagellata). *Rev. Palaeobot. Palynol.* **45**, 17–34.

BFAR. (1986). Fisheries statistics of the Philippines 1986. Bureau of Fisheries and Aquatic Resources, Manila, Philippines.

Cheong, L., Chuan, L. L. & Chung, C. Y. (1984). Status of shellfish toxicity in Singapore. In *Toxic Red Tides and Shellfish Toxicity in Southeast Asia* (A. W. White, M. Anraku and K. K. Hooi, eds), p. 86. Southeast Asian Fisheries Development Center, Singapore, and International Development Research Centre, Ottawa.

Chua Thia Eng & Agulto, M. A. A. (1987). ASEAN/US Cooperative program on marine sciences: coastal resources management project research, training and information programs and activities 1986–1989. Working Paper 87/13, 86 p. International Center for Living Aquatic Resources Management, Manila, Philippines.

Chua Thia Eng, Chou Loke Ming & Sadorra, M. M. (eds). (1987). The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Tech. Rep. 18. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Crisostomo, M. (1988). Bay extracts vengeance for abuse. *Daily Globe*, 10 October 1988, p. 1.

Dale, B., Baden, D. G., Bary, B. M., Edler, L., Fraga, S., Jenkinson, T. R., Hallegraeff, G. M., Okaichi, T., Tangen, K., Taylor, F. J. R., White, A. W., Yentsch, C. M. & Yentsch, C. S. (1987). The problems of toxic dinoflagellate blooms in aquaculture. Proceedings: International conference and workshop, Ireland, 8–13 June 1987. Sherkin Island Marine Station, Cork, Ireland.

Fukuyo, Y., Yoshida, K., Kodama, M., Pholpunthin, P., Wissesang, S. & Piyakarnchana, T. (1987). Suspected causative dinoflagellates of paralytic shellfish poisoning in the Gulf of Thailand: identification and toxicity of three *Protogonyaulax*. In *International Symposium on Red Tides. Biology, Environmental Science and Toxicology*. Takamatsu, Japan, 10–14 November 1987. Abstracts, p. 19.

Gacutan, R. Q. (1986). Effects of coconut milk and brown sugar on toxins from mussels exposed to *Pyrodinium bahamense* var. *compressa*. In *The First Asian Fisheries Forum* (J. L. Maclean, L. B. Dizon and L. V. Hosillos, eds), pp. 311–313. Asian Fisheries Society, Manila.

Gacutan, R. Q., Tabbu, M. Y., Aujero, S. J. & Icatlo, Jr., F. (1985). Paralytic shellfish poisoning due to *Pyrrodinium bahamense* var. *compressa* in Mati, Davao Oriental, Philippines. *Mar. Biol.* **87**, 223–227.

Gonzales, C. L., Ordoñez, J. A. & Maala, A. M. (1987). Red tide: The Philippine experience. In *International Symposium on Red Tides. Biology, Environmental Science and Toxicology*. Takamatsu, Japan, 10–14 November 1987. Abstracts, p. 14.

Gopalakrishnakone, P. & Tan, C. K. (eds). (1987). *Progress in Venom and Toxin Research*. Singapore Faculty of Medicine, University of Singapore.

Hallegraeff, G. & Sumner, C. (1986). Toxic plankton blooms affect shellfish farms. *Aust. Fish.* **45**(12), 15–18.

Hallegraef, G., Bolch, C., Koerbin, B. & Bryan, J. (1988a). Ballast water a danger to aquaculture. *Aust. Fish.* **47**(7), 32–34.

Hallegraeff, G. M. (1987). Red tides in the Australasian region. CSIRO, Mar. Lab. Rep. No. 187.

Hallegraeff, G. M., Stanley, S. O., Bolch, C. J. & Blackburn, S. I. (1987). *Gymnodinium catenatum* blooms and shellfish toxicity in Southern Tasmania, Australia. In *International Symposium on Red Tides. Biology, Environmental Science and Toxicology*. Takamatsu, Japan, 10–14 November 1987.

Hallegraeff, G. M., Steffensen, D. A. & Wetherbee, R. (1988b). Three estuarine Australian dinoflagellates that can produce paralytic shellfish toxins. *J. Plankton Res.* **10**, 533–541.

Harada, T., Oshima, Y., Kamiya, H. & Yasumoto, T. (1982). Confirmation of paralytic shellfish toxins in the dinoflagellate *Pyrodinium bahamense* var. *compressa* and bivalves in Palau. *Bull. Japan Soc. Sci. Fish.* **48**, 821–825.

Hermes, R. & Villoso, E. P. (1983). A recent bloom of the toxic dinoflagellate *Pyrodinium bahamense* var. *compressa* in Central Philippine waters. *Fish. Res. J. Philipp.* **8**(2), 1–8.

Hermes, R., Jamir, T. V. C. & Villoso, E. P. (1985). Spatial distribution of *Pyrodinium bahamense* var. *compressa* in the Samar Sea and associated oceanographic parameters. *Univ. Philipp. Visayas, Fish. J.* **1**, 1–12.

Jothy, A. A. (1984). Status of shellfish toxicity and related problems in Malaysia. In *Toxic Red Tides and Shellfish Toxicity in Southeast Asia* (A. W. White, M. Anraku and K. K. Hooi, eds), pp. 33–34. Southeast Asian Fisheries Development Center, Singapore, and International Development Research Centre, Ottawa.

Kodama, M. (ed.). (1987). Studies on paralytic shellfish poisoning occurred in the coastal water of Thailand, and its causative dinoflagellate. School of Fisheries Sciences, Kitasato University, Japan.

Khoo Eng Wah. (1985). Occurrences of "red tide" along Johore Straits, Malaysia, resulted in heavy mortality of shrimp. *World Maricult. Soc. Newsl.* **16**(1), 4.

Lee, S. J. (1988). "Red Tide" menace endangers fisheries. *Jakarta Post*, 23 April 1988.

Loyola, V. C. (1987). Remember the "red tide". *Food World*, Vol. 6. June 1987.

Maclean, J. L. (1977). Observation on *Pyrodinium bahamense* Plate, a toxic dinoflagellate, in Papua New Guinea. *Limnol. Oceanogr.* **22**, 234–294.

Maclean, J. L. (1984). Indo-Pacific red tide occurrences, 1972–1984. In *Toxic Red Tides and Shellfish Toxicity in Southeast Asia* (A. W. White, M. Anraku and K. K. Hooi, eds), pp. 92–98. Southeast Asian Fisheries Development Center, Singapore, and International Development Research Centre, Ottawa.

Maclean, J. L. & Temprosa, R. M. (compilers). (1984). A bibliography on toxic red tides and shellfish poisoning related to the Indo-Pacific Region. In *Toxic Red Tides and Shellfish Toxicity in Southeast Asia* (A. W. White, M. Anraku and K. K. Hooi, eds), pp. 99–102. Southeast Asian Fisheries Development Center, Singapore, and International Development Research Centre, Ottawa.

Maclean, J. L. & White, A. W. (1985). Toxic dinoflagellate blooms in Asia: a growing concern. In *Toxic Dinoflagellates* (D. M. Anderson, A. W. White and D. G. Baden, eds), pp. 517–520. Elsevier, New York.

Mata, E. (1988). Has the 'red tide' come to stay? *Daily Globe*, 6 October 1988, p. 1.
Matdanan, Haji Jaafar, De Silva, M. 'V. R. N., Sharifuddin, P. H. Y. & Siti Amin Mahali (1988). A red tide action plan for Brunei Darussalam. Paper presented at the Technical Workshop on Integrated Tropical Area Management, Singapore, 28–31 October 1988. National University of Singapore, Science Council of Singapore, and International Center for Living Aquatic Resources Management, Manila, Philippines.
Oshima, T., Raj, U. & Bagnis, R. (eds). (1984). *Seafood Poisonings in Tropical Regions*. Laboratory of Food Hygiene, Tohoku University, Japan.
Oshima, Y., Hasegawa, M., Yasumoto, Y., Hallegraeff, G. & Blackburn, S. (1987a). Dinoflagellate *Gymnodinium catenatum* as the source of paralytic shellfish toxins in Tasmanian shellfish. *Toxicon* **25**, 1105–1111.
Oshima, Y., Yasumoto, T., Hallegraeff, G. & Blackburn, S. (1987b). Paralytic shellfish toxins and causative organisms in the tropical Pacific and Tasmanian waters. In *Progress in Venom and Toxin Research* (P. Gopalakrishnakone and C. K. Tan, eds), pp. 423–428. Faculty of Medicine, National University of Singapore, Singapore.
Rous, A. (1987a). 11 reported dead as red tide hits Samar anew. *The Manila Journal*, 11 June 1907, p. 7.
Rous, A. (1987b). Samar 'tahong' banned. *The Manila Journal*, 24 June 1987, p. 14.
Segar, K., Karunasagar, I. & Karunasagar, I. (1987). Dinoflagellate toxins in shellfishes along the coast of Karnataka. Paper presented at the First Indian Fisheries Forum, Mangalore, India, December 1987.
Steidinger, K. A., Tester, L. S. & Taylor, F. J. R. (1980). A redescription of *Pyrodinium bahamense* var. *compressa* (Böhm) stat. nov. from Pacific red tides. *Phycologia* **19**, 329–337.
Stern, I. & Gutzler, D. S. (1988). Zonal wind anomalies over the near-equatorial eastern Indian and western Pacific Oceans during the early stages of the 1986–87 ENSO warm event. *Tropical Ocean–Atmosphere Newsletter* **44**, 1–4.
Subrahmanyan, R. (1954). On the life history and ecology of *Hornellia marina* Gen. et. Sp. Nov. (Chloromonadineae), causing green discoloration of the sea, and mortality among marine organisms off the Malabar Coast. *Ind. J. Fish.* **1**, 182–203.
Tamiyavanich, S., Kouama, M. & Fukuyo, Y. (1985). The occurrence of paralytic shellfish poisoning in Thailand. In *Toxic Dinoflagellates* (D. M. Anderson, A. W. White and D. G. Baden, eds), pp. 521–524. Elsevier, New York.
Tan, C. T. T. & Lee, E. J. D. (1987). Paralytic shellfish poisoning in Singapore. In *Progress in Venom and Toxin Research* (P. Gopalakrishnakone and C. K. Tan, eds), pp. 429–432. Faculty of Medicine, National University of Singapore, Singapore.
Tollervey, A. G. (1987). *Pyrodinium bahamense* var. *compressa* blooms in a tropical lagoon. In *International Symposium on Red Tides. Biology, Environmental Science and Toxicology*. Takamatsu, Japan, 10–14 November 1987. Abstracts, p. 36.
Wood, E. J. F. (1963). Dinoflagellates in the Australian region III. Further collections. CSIRO Aust. Div. Fish. Oceanogr. Tech. Pap. No. 17.
Worth, G. K., Maclean, J. L. & Price, M. J. (1975). Paralytic shellfish poisoning in Papua New Guinea, 1972. *Pac. Sci.* **29**, 1–5.

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Pollution of the Coastal Waters of Hong Kong

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This paper reviews the available literature on Hong Kong's marine coastal pollution. The highly urbanized and industrial cities of Victoria and Kowloon pollute Victoria Harbour with untreated domestic sewage and industrial effluents. The development of new cities, Shatin and Tai Po, on the shores of the partially enclosed Tolo Harbour have created Hong Kong's first critical marine environmental problem, secondary sewage treatment schemes having been inadequate to prevent this. Agricultural wastes (notably pig manure) compound the problem in Tolo Harbour, but virtually everywhere in the New Territories lowland water courses are polluted from this source leading to the degradation of most enclosed bays. Sufficient evidence is at hand to understand local long-term trends in environmental degradation. Hong Kong's coastal waters are polluted generally; Tolo Harbour, grossly so. Concern exists regarding the safety of bathing beach water quality, contaminated sea food, and the overall quality of other enclosed bodies of water in Hong Kong.

As with other Asian cities, pollution control measures in Hong Kong are in their infancy and nowhere is this better seen than in the sea, which characteristically receives virtually all of the urban, industrial and agricultural liquid pollution load. The inshore hydrography of Hong Kong is complex and influenced at a number of levels by the sub-tropical climate. The capacity of the sea to adsorb pollution fluctuates accordingly. This complex hydrography has made interpretation of pollution effects difficult—abnormal events being confused by and with natural seasonal changes. A picture is, however, emerging that separates and yet links such natural and unnatural (man-induced) changes, allowing evaluation of pollution levels and effects.

Fears regarding marine pollution were first expressed in the early 1970s and the available information first reviewed by this author (Morton, 1976). In 1988, Tolo Harbour, Hong Kong's most polluted body of water, has reached a critical stage (Morton, 1988). This paper reviews the current pollution status of the coastal waters