DINOFLAGELLATE BLOOM IN TROPICAL FISH PONDS OF COASTAL WATERS OF THE SOUTH CHINA SEA

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(Received: February 1995; revised: September 1994)

Abstract. Red tide of dinoflagellate was observed in brackish water fish ponds of Terengganu along the coast of the South China Sea during the study period between January 1992 to December 1992. The nearby coastal moat water facing the South China Sea is the source of water for fish pond culture activities of sea bass during the study period. An examination of water quality in fish ponds during the study period indicated that both the organic nutrients were high during the pre-wet monsoon period. The source of the nutrients in coastal water was believed to be derived from the agro-based industrial effluents, fertilizers from paddy fields and untreated animal wastes. This coincided with the peak production of dinoflagellate in the water column in October 1992. The cell count ranges from 8.3 to $60.4 \times 10.4 \times 10^4$ / l during the bloom peak period and the bloom species were compared entirely of non-toxic dinoflagellates with *Protoperidinium quinquecorne* occurring > 90% of the total cell count. However, both cultured and indigenous fish species were seen to suffer from oxygen asphyxiation (suffocation due to lack of oxygen). The bloom lasted for a short period (4–5 days) with a massive cell collapse from subsurface to bottom water on the sixth day. The productivity values ranged from 5–25 C g / l / h with a subsurface maximum value in October 1992. Two species of Ciliophora, *Tintinnopsis* and *Favella*, were observed to graze on these dinoflagellates at the end of the bloom period.

1. Introduction

Microplankton blooms usually occur along the productive coastal waters throughout the world. In temperate countries diatom blooms occur in spring while dinoflagellate blooms occur in summer. Red tide refers to the rusty red colouration of the seawater due to the pigmented perdidinin content of dinoflagellate cells. In contrast to normal phytoplankton bloom, red tides are predictable and occur once or twice yearly with regularity, often markedly monospecific in nature (> 90% of total cell count belong to a single species) (Sweney, 1979). Red tides occur in distinct patches as opposed or ordinary blooms which are more diffuse.

Many of the fish cage and pond culture activities in Malaysia are carried out in coastal aquatic environments, especially river mouths, estuaries, mangroves, back waters or any other types of brackish water bodies. These aquatic environments are common features found all round the coastal regions of peninsular Malaysia. These aquatic environments are regarded as important natural breeding and nursery grounds for marine and brackish water organisms (especially fish), which also could be utilized as potential fish culture areas. Some workers calculated the net aquatic community productivity of these water bodies and found it to be low (Ong *et al.*, 1980; Shamsudin and Salleh, 1982). The low value could be due to various

Environmental Monitoring and Assessment **40:** 303–311, 1996.
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factors, viz. high turbidity of the water and consequent low light penetration and high organic loading, leading to a high biological oxygen demand which will ultimately result in pollution. Furthermore, many of these water bodies have also been reported to be polluted by agro-based industrial effluents, untreated human and animals wastes, and siltation due to erosion from land development (Bishop, 1973; Law and Mohsin, 1980; Shamsudin and Salleh, 1982).

Information on red tides occurrence in peninsular Malaysia is scarce; however, Sabah located on the east coast of Malaysia experienced the first toxic red tide outbreak in early 1976 (Maclean, 1979). The causative red tide dinoflagellate has been the armoured, unicell, motile *Pyrodinium bahamense* var. *compressa* (Steidinger, 1979). A study was undertaken of the primary productivity, chlorophyll biomass, water quality and other related parameters of fish ponds along the coastal water of South China Sea, where an intensive fish culture activity is presently located. The incidence of plankton bloom and information on various water quality parameters were especially noted.

2. Method

The study was carried out in brackish-water fish ponds in Terengganu between January 1993 and December 1993. Fish ponds are presently used as an intensive culture activity, obtaining its water source from a moat water facing the South China Sea. The moat water is a semi-enclosed water body, approximately 15 km in length and 1–2 km in width with a depth of 5–7 m. For most of the year it is a moderately fast-moving brackish water body, under the influence of the tidal current, especially during the wet season. The tidal range in the estuary fluctuates seasonally and ranges from 2.0 m during the dry season to over 3.0 m during the flood period.

Subsurface samples (0.5 m depth) were taken in carboys at all stations and transported immediately to the laboratory for analysis. Photosynthetic measurements were carried out using the modified method of Byran *et al.* (1976). This gives a Winkler titration coefficient variaton of 0.1%. Determination of ammonia was carried out by the Shamsudin (1979) modified method of Solorzano (1969) in order to eliminate the high blank values. It is basically a colorimetric phenolhypochlorite method. This method involved the use of double deionized water instead of using distilled water for the preparation of reagents and rinsing of glassware. Nitrate-nitrogen was determined by the colorimetric cadmium-copper amalgam reduction method (Strickland and Parsons, 1972) while the determination of reactive phosphorus was carried out by the colorimetric ascorbic molybdate method (Strickland and Parsons, 1972). Salinity, conductivity and temperature at the sampling site were measured with an SCT meter (YSI model 33) while the pH was measured with a pH meter (Schott Gerate pH meter cg 817) which provides accurate digital reading over its 0–14 unit range with a resolution of 0.1 pH units, reproducible to 0.05 pH.

Determination of total dissolved phosphorus and particulate phosphorus in natural waters was carried out according to the method of Solorzano and Sharp (1980b) which gives 100% recovery with refractory phosphorus compounds and has a mid range precision of 10%. The method involves drying a sample with magnesium sulphate and baking the residue at a high temperature (500 °C) to decompose organic phosphorus compounds. The residue is then treated with hydrochloric acid to hydrolyse polyhosphates and orthophosphate and this is followed by the molybdate method. Determination of total dissolved nitrogen in natural waters was carried out according to the method of Solorzano and Sharp (1980a), which has a mid-range precision of 2%. This method involves careful attention to various factors, namely pH, alkalinity, the neutralizing buffer, reaction vessels and dilution factors.

3. Results and Discussion

Throughout the study period, there was a large variation in the nutrient contents (both inorganic and organic) present in fish ponds. The source of the nutrient supply to the fish ponds could come from upstream waters as well as from surrounding local areas. Apart from that, there are numerous food (especially fish) processing plants and industries found scattered along the banks of the lagoon which is the source of water for fish ponds. The lagoon is situated in a low-lying area and receives effluents from inflows entering the lagoon as well as from overland runoff. Excess water containing agro-based industrial effluents from nearby paddy fields also makes its way into the lagoon. Inflow water in the form of rainfall or drainage from water-based household effluents also makes its way into the lagoon from surrounding areas.

High reactive phosphorus and nitrate concentrations were present in fish ponds especially in August and October 1992. These ranged from 6.1–8.6 μg at N/l and 5.5–11.2 μg at P/l for nitrate and reactive phosphorus respectively (Table I). These values were high during the dry period (May to October). Conversely, the values for ammonium nitrogen and dissolved organic nitrogen were lower during the dry period. These ranged from 3.9–9.4 μg at $NH^{+}{}_{4}$/l and from 2.4–4.7 μg at N/l for ammonium and dissolved organic nitrogen, respectively. Considerable amounts of particulate organic phosphorus were also present in the water, especially during the wet season (November to April). The salinity of the water body was found to be quite high, ranging from 16.4–31.2 ppt.

High biological oxygen demand values were observed during the wet period and vice-versa during the dry period, indicating a similarity to those of inorganic ammonium nitrogen contents. BOD values ranged from 4.9–10.4 mg/l throughout the study period (Table II). The primary production of fish ponds ranged from 5.2–25.3 μg C/l/h with high subsurface values in October 1992. Ong *et al.* (1980)

TABLE I

Means values of the inorganic and organic nutrient contents at the fish ponds (February 1992 to december 1992) (taken during mid-tide). Values are means if duplicate or triplicate analysed. Standard deviations are omitted for clarity; were normally <5%

Month/year 1992		March	May	August	October	November	December
NH^+_4 μg at N/l	SW	17.4	8.1	4.1	3.9	14.3	14.3
depth (m)	SS	21.4	8.3	6.1	4.2	15.4	14.9
	1.2	20.0	3.7	9.1	4.8	15.3	14.4
	1.8	22.4	9.4	5.7	4.9	6.7	16.1
NO^-_3 μg at N/l	SW	3.1	5.1	6.4	7.4	4.2	2.1
depth (m)	SS	3.2	5.2	6.1	7.1	5.3	4.1
	1.2	3.4	5.4	6.4	7.3	6.4	4.2
	1.8	3.7	6.4	6.5	8.6	8.3	4.4
P μg at P/l	SW	3.7	4.4	5.5	7.2	4.4	2.7
depth (m)	SS	4.1	6.3	6.6	8.3	5.5	3.2
	1.2	4.2	8.2	7.1	9.2	6.6	2.4
	1.8	5.8	9.1	10.4	11.2	10.1	13.7
DON μg at/l	SW	12.1	2.4	2.4	4.3	4.1	9.9
depth (m)	SS	16.7	2.3	2.4	4.4	2.6	5.4
	1.2	16.9	3.2	3.5	4.7	3.2	5.1
POP μg at/l	SW	11.4	3.1	5.1	2.9	5.4	7.7
	SS	10.3	5.1	5.2	3.4	6.5	9.8
	1.2	11.2	8.9	8.7	6.3	9.6	9.3
Secchi disc depth (m)		0.70	1.60	1.50	1.45	1.24	0.80
Max. depth (m)		1.9	1.8	1.5	2.1	2.3	2.4

Tr, trace amount, less than 0.05%; DON, dissolved organic nitrogen; POP, particulate organic phosphorus; DOP, dissolved organic phosphorus; PS, net photosynthetic rate; BOD, biological oxygen demand; DO, disssolved oxygen; SW, surface water; SS, subsurface water, 0.6 m.

reported a very low net aquatic community of some coastal waters due to high turbidity and high organic loading to a high biological oxygen demand. Shamsudin and Shazali (1991) reported that a high organic load in a brackish water lagoon was derived from agro-based industrial effluents, fertilizers from paddy fields as well as untreated human and animal wastes. The pH values in the fish ponds were relatively alkaline (pH ranged from 7.7–8.2) during the study period. The subsurface temperature values ranged from 26–30 °C and the values were usually lower during the wet period.

TABLE II

Mean values of chemico-physical parameters at fish ponds in Terengganu (February 1988 to December 1988) (taken during the mid tide). Values are means of duplicate or triplicate analysed. Standard deviations are ommited for clarity, were normally <5%

Month/Year 1992		March	May	August	October	November	December
PS μg C/l/h	SW	5.2	6.6	6.8	18.2	10.4	5.8
depth (m)		7.4	8.8	9.9	25.3	10.1	9.1
Temp. °C subsurface	SS	27	29	30	28	26	26
pH subsurface	SS	8.0	7.8	8.0	8.2	7.9	7.7
Salinity ppt	SW	16.4	21.7	21.4	27.4	24.1	18.4
depth (m)	SS	17.1	23.4	24.5	28.7	24.4	21.1
	1.2	17.2	26.3	26.1	29.7	26.5	23.7
	1.8	17.9	27.0	28.0	31.2	29.3	23.1
D.O mg/l	SW	3.5	3.7	4.3	4.9	4.3	4.3
depth (m)	SS	3.3	3.4	4.4	4.3	4.3	4.4
	1.2	2.9	3.1	4.3	4.1	4.1	4.5
B.O.D. mg/l	SW	8.1	7.4	5.9	5.1	4.9	6.4
depth (m)	SS	8..2	7.7	6.4	5.3	5.7	7.0
	1.2	8.4	7.8	7.5	5.4	6.4	6.9
	1.8	10.4	8.4	7.8	5.7	6.8	7.8

Tr, trace amounts, less than 0.05%; SW, surface water; SS subsurface.

The fish pond is situated in a low-lying region and it is a convenient depository ground or outlet for water-based effluents (industrial, agricultural, untreated human and animal wastes and siltation due to erosion from land developments). The neighbouring region around the study area is presently undergoing heavy paddy plantation and crop fertilization. The results from Table III show the distribution of microplankton species, expressed as the mean persentage of the total cell count in fish ponds. The most common microplankton species encountered during the study period included those of diatom (Baceillariophyceae), dinoflagellate (Dinophyceae), blue-green algae (Cyanophyceae) and Ciliophora. Plankton bloom occurred in October 1992 during which time its mean cell count had already reached a peak value of 60.4×10^4 cell/l. During the bloom, dinoflagellates were the most predominant algae, comprising species of *Ceratium, Peridinium, Protoperidinium, Gonyaulax, Dinophysis, Ornithocercus* and *Gymnodinium*. The most dominant dinoflagellate in the October bloom comprised the non-toxic species of *Protoperidinium quinquecorne* (> 90% of total cell count) with a smaller proportion

TABLE III

Microplankton distribution, expressed as the mean percentage of the total cell count, in fish ponds in Terengganu (February 1992 to December 1992). Values are means of duplicate or triplacate analysed. Standard deviations are ommited for clarity, were normally <5%

Year 1992	February	March	August	October	November	December
Diatom	36.4	32.1	29.5	0.5	29.4	33.8
Rhizosoleniaceae	18.5	14.1	16.1	Tr	17.4	15.3
Chetoceracaea	13.2	10.7	4.1	0.2	6.2	5.1
Bacteriastraceae	–	–	0.1	4.0	3.4	
Nitzschiaceae	2.2	3.3	6.1	0.2	–	3.5
Coscinodiscaeae	–	4.2	1.0	–	1.8	6.5
Naviculazeae	2.5	–	1.2	–	–	–
Surirellaceae	–	–	1.0	Tr	–	–
Dinoflagellate	22.4	24.4	22.7	91.4	27.2	27.8
Peridinium	7.1	7.1	6.7	90.1	14.1	16.1
Protoperidinium	3.6	6.6	4.6	1.2	Tr	3.0
Gymnodium	4.1	4.2	6.3	0.1	4.2	4.3
Ceratium	4.3	–	4.1	Tr	2.5	–
Gonyaulax	3.3	4.4	1.0	Tr	4.3	2.1
Dinophysis	–	2.1	–	–	2.1	–
Ornithocercus	–	–	–	–	–	2.3
Cyanophyta	28.3	33.5	36.7	0.5	27.1	22.1
Trichodesmium	18.1	22.4	10.3	0.4	10.3	14.1
rhiebautie	10.2	11.1	16.4	0.1	16.8	8.0
T. eryheraum						
Ciliophora	16.4	14.3	12.7	7.0	12.3	12.4
Tintinnopsis	1.4	1.4	3.0	4.9	2.1	3.7
Favella	1.3	1.3	2.1	2.1	2.2	2.0
Codonellopsis	3.7	–	–	–	4.9	3.2
Epiplocylis	3.0	2.1	0.6	–	3.1	3.5
Miscellanous	1.8	1.5	1.3	TR	1.7	1.4
Cell number $\times 10^4 l^{-1}$	8.3	14.4	20.3	60.4	19.4	9.3

Tr, trace amount, less than 0.05%.

of *Protoperidinium brochii* and *Protoperidinium excentricum*. Gires *et al.* (1988) reported that about 98% of the flora in the red of Sabah was comprised of *Pyrodinium bahamense*, and the bloom lasted for 3–4 days. This dinoflagellate species can co-exist together with another dinoflagellate, *Ceratium fulcra*. The presence of

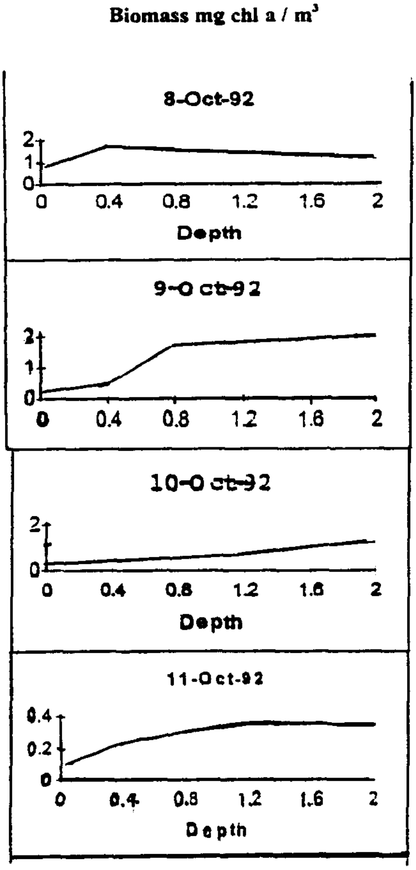

Fig. 1. Microplankton dinoflagellate biomass (expressed as mg chl a/m^3) with depth (m) between 8 October 1992 to 11 October 1992.

this species in high number in the sea can produce volatile substances which can irritate the eye, nose and throat as well as emitting a bluish white fluorescence at night. Toxic red tide species usually produce a lethal poison, saxitoxin, which can accumulate in the tissues of bivalves. Consumption of contaminated bivalves can cause paralytic shellfish poisoning (PSP) to humans.

The occurrence of a high population of toxic dinoflagellates in fish ponds were not detected during the study period. However, both cultured and indigenous fish species in ponds were seen to suffer from oxygen asphyxiation due to the lack of oxygen. The first toxic red tide outbreak of Sabah in the east coast of Malaysia in 1976 was the most extensive and covered nearly the whole west coast of Sabah (Maclean, 1979). The causative dinoflagellate of the red tide was *Pyrodinium bahamense* var *compressa* which was also responsible for the bloom in Papua New Guinea (Maclean, 1979) and Brunei (Gires *et al.*, 1988). This species is armoured, unicell, motile and formed resting cysts similar to its related non-toxic species *P. bahamense* var. *bahamense*. Another interesting microplankton species present in considerable amount during the bloom was Ciliophora which was comprised mainly of *Tintinnopsis* and *Favella.* These two species were observed to graze on these dinoflagellates.

The chrlorophyll a biomass value with depth was determined during the 5 to 6-day bloom period between 8 October 1992 to 11 October 1992 (Figure 1). At day 1, immediately after the bloom outbreak, the maximum chlorophyll a biomass was at subsurface depth (0.4 m) with a maximum value of 1.85 mg chlorophyll a/m^3 and gradually decreased in values with depth. The subsurface cells then sunk to the bottom beginning at day 2 onwards. At day 4, the chlorophyll a biomass started to dwindle and eventually collapsed to values between 0.1 and 0.6 mg chlorophyll a/m^3. Ichimura (1956b) reported that during the initial period of a bloom outbreak, the microplanktonic cell is distributed homogeneously in the water column but the *in situ* photosynthesis biomass at each depth is different, being inhibited at the near surface by light intensities and then decreasing from a subsurface maximum, due to light attenuation. As the cell density increases at the subsurface photosynthetic maximum, the average extinction coefficient of light will increase, and self shading will occur (Aruga, 1966). Furthermore, as nutrient become exhausted in the surface layers, the depth of maximum microplankton biomass deepens. It was suggested that organic substances stimulate growth of microplankton during the early part of the bloom. Humic substances in seawater are reported to stimulate dinoflagellate growth (Prakash and Rashid, 1968).

Acknowledgement

This research was supported by the Malaysian National Research Grant, under project code 50366.

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